Fuzzy-ZRP: An Adaptive MANET Radius Zone Routing Protocol

Nassir Harrag
Mechatronics Laboratory, Ferhat Abbas University, Algeria
nassir.harrag@gmail.com
(corresponding author)

Abdelghani Harrag
Mechatronics Laboratory, Ferhat Abbas University, Algeria
abdelghani.harrag@gmail.com

Received: 25 January 2023 | Revised: 24 February 2023 and 3 March 2023 | Accepted: 6 March 2023

ABSTRACT

A Mobile Ad-hoc Network (MANET) is a group of active mobile nodes wirelessly connected in a self-configuring and self-healing network without a preexisting centralized infrastructure. Several studies have been conducted to improve the stability and lifetime of routes for communicating between source and destination nodes, integrating new techniques with existing protocols. This paper presents a fuzzy-based approach to improve the performance of the standard Zone Routing Protocol (ZRP) by selecting the optimal value of the zone radius. Each node has a fuzzy inference system that is periodically fed with parameters, such as the remaining energy and mobility of the node, to calculate the optimal value of the zone routing radius, which makes the node autonomous and intelligent. The simulation results obtained using the NS-2 simulator showed that the proposed fuzzy radius approach outperformed the standard ZRP, OVBAZRP, and PSOZRP routing protocols in all measures considered: PDR, NRL, and E2ED.

Keywords-ad hoc; MANET; hybrid routing protocol; ZRP; fuzzy logic; radius

I. INTRODUCTION

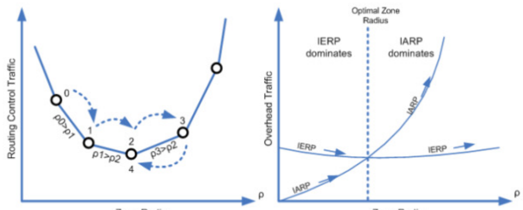
Mobile Ad-hoc Networks (MANETs) are becoming a significant technology in telecommunication networks and have attracted considerable attention over the past decades. Most MANET applications are suitable in a wide range of fields that require rapid deployment, such as military battlefields, emergency searches, rescue sites, classrooms, and conferences where participants dynamically share information using their mobile devices [1-2]. A MANET is a set of active mobile nodes that organize and configure themselves dynamically to form a wireless network without an administrator. Each node can communicate with others directly, if within transmission range, or indirectly, by relaying by intermediate mobile nodes. MANET nodes can move at any speed and in any direction independently. Moreover, they can join or leave the network arbitrarily. Due to the main characteristics of MANETs, such as high mobility, low bandwidth, and low power, developing an efficient routing protocol is a critical task [3-4]. The three main types of routing protocols in MANETs are proactive, reactive, and hybrid [5-6]. Proactive routing saves the network topology by keeping the route to each node in a particular routing table and updating it continuously [7], which speeds up sending packets from the source to the target. On the other hand, reactive routing protocols send control messages only upon request, providing a route to send a packet from a source to a specific target [8], reducing network overload. Finally, hybrid-routing protocols combine the advantages of proactive to deliver packets to nodes within the network while using reactive techniques to forward packets to nodes outside the network [9-10].

Among the MANET protocols that handle the above problems [11-12], ZRP [13] has an advanced position. ZRP is a hybrid wireless routing protocol that offers the advantage of adapting to various network conditions. Typically, ZRP is designed to speed up delivery and reduce processing costs by applying a proactive paradigm inside a zone and a reactive paradigm outside it. In the proactive scheme, the ZRP collects neighborhood information in a local region of the network called the routing area. In contrast, reactive routing operates globally, where an on-demand routing protocol does not require neighborhood information [14-15]. To optimize the network's performance, ZRP uses an essential factor, the zone radius (by default 2), which plays a critical role between the network's overload and the delay in transferring packets by dividing the network into zones. Therefore, decreasing the radius value reduces proactive routing and increases the area of reactive routing, thus reducing network load and increasing delay in the message routing process, and vice versa [1].

The node's mobility significantly impacts the network's performance and depends mainly on speed and pause factors.

For example, for a high-mobility network with fast nodes and low pause time, the topology will constantly change, increasing the network's routing load and energy consumption because of the significant loss of communication between nodes due to the departure of the node. On the contrary, for a stable network with low-speed nodes and high pause times, the network topology will become more stable and the chances of communication between the nodes will increase. Therefore, reducing the network's routing load reduces energy consumption.

The Independent Zone Routing Protocol (IZRP) depends on the local network conditions that vary considerably due to the movement of the nodes [1-5]. Using this protocol, each node in the network can fine-tune its optimal area radius, making it independent and adaptable. IZRP is based on a hybrid scheme that combines minimum search and adaptive traffic estimation schemes [1]. This hybrid scheme aims to create a minimal amount of extra overhead by dynamically adjusting and reconfiguring the optimal zone radius of each node in a distributed manner, which allows network nodes to adapt quickly to any changes in the network's characteristics. The minimum search scheme iteratively estimates the radius of the routing area of a node by incrementing or decrementing it by one hop. At first, the amount of routing traffic passing through the node in the current estimation interval is measured and compared to the previous interval. If it is smaller, the radius of the area is incremented/decremented in the same direction. If not, the direction of the zone radius change is reversed. This process continues until a minimum is detected. The adaptive traffic estimation scheme relies on $\Gamma(\rho)$, represented by the ratio of reactive to proactive traffic of the zone radius during a specific estimation interval, by comparing it with a predetermined threshold Γ_{thres}. If $\Gamma(\rho) > \Gamma_{thres}$, an increment or decrement of the radius ρ will be triggered to decrease the routing of reactive/proactive traffic respectively, as shown in Figure 1.



(a) (b)

Fig. 1. (a) Min searching algorithm, (b) ZRP zone routing radius optimization.

The Enhanced Zone Routing Protocol (EZRP) is more efficient than ZRP [16], as it avoids network congestion by reducing the number of IERP packets using a fixed value for the area radius, mobility, and packet size. Velocity-Based Adaptive ZRP (VBAZRP) is an enhancement of ZRP in ad hoc networks [17], which allows nodes to select the radius of the area based on their respective mobility and reduces the discovery delay resulting from the incorporation of an asymmetric request and response mechanism to maintain the routing area. The speed-optimized adaptive ZRP (OVBAZRP) performed better than ZRP in increasing network traffic loads by allowing the zone radius to be selected according to the mobility speed of the node [18]. Particle Swarm Optimization Intelligence-independent ZRP (PSO-IZRP) dynamically determines the zone radius based on the velocity and location of the nodes by tracking the optimum in the space of solutions that satisfies the constraints of the objective function to calculate the radius at each interval [19]. Another improvement of ZRP was proposed in [20], by a novel technique named Zone-based Energy-aware Hybrid Multicast Routing Protocol (ZEHMRP), which selects stable routes for multicast packet delivery based on the residual energy of nodes in areas along the route to reduce control overhead and delay in packet delivery. The energy-efficient zone routing algorithm [21], improves the clustering mechanism by using the energy loss rate of the nodes in the zone and considering the nodes with the highest residual energy as cluster heads in each iteration. In ZRP fuzzy-based scheduling and load balance [22], the service cycles of the border nodes are adaptively adjusted according to the state of the queue, the expected residual energy, and the distance to the border nodes. In [23], a logic-based control (FLC) method was proposed to improve QoS for MANETs. As in ZRP, the mobility of the network nodes was used to establish probabilistic QoS.

This paper proposes a zone radius determination algorithm based on a fuzzy inference system, named Fuzzy-ZRP, that improves the routing performance of the standard ZRP in wireless ad-hoc networks. Furthermore, simulations showed that Fuzzy-ZRP outperformed the standard ZRP. Fuzzy-ZRP tunes the radius value of each zone by estimating it based on the node's residual energy and speed, leading to increased network lifetime and reduced overload regardless of network conditions. This study aims to achieve the following objectives:

- An adaptive algorithm where each node can rapidly adapt to network conditions.
- A multi-constraint fuzzy logic controller that makes the algorithm autonomous in the sense that it can automatically estimate the optimal value of the radius zone based on the node's residual energy and speed.
- Different realistic scenarios with different mobility models were considered to study the performance of Fuzzy ZRP in terms of packet delivery rate, routing overhead, and end-to-end delay.

II. MATERIALS AND METHODS

This section describes the modification of the classical ZRP to improve the radius selection scheme and enhance network performance by using a fuzzy logic inference system.

A. *Standard ZRP*

The standard ZRP is based on the division of the network in zones. Each zone consists of nodes within the maximum hop distance *r*. The radius is defined as a circle around the node with the value *r* (default=2). It should be noted that the zone is defined in hops, not as physical distance [13]. ZRP uses the proactive paradigm within the zone by applying the intra-zone routing protocol (IARP) [15]. In contrast, the reactive paradigm is provided by the interarea routing protocol (IERP). A route to a destination in the local area can be established from the source routing table proactively cached by the IARP; therefore, if the source and the destination are in the same area, the packet can be delivered immediately.

The hybrid zone routing protocol can adapt to a wide variety of network scenarios by proactively adjusting the range of nodes and maintaining routing zones. Large routing areas are preferable when the demand for routes is high and/or the network is composed of many slow-moving nodes. In the extreme case of a fixed topology, the ideal routing area radius would be infinitely large. On the other hand, smaller routing areas are appropriate in situations where route demand is low and/or the network consists of a small number of nodes that move quickly relatively to each other. In the worst case, a one-hop radius routing area is the best, and ZRP defaults to a traditional reactive flooding protocol [13]. For a particular network scenario and proper configuration, ZRP performs at least as well (and often better than) its purely proactive and reactive constituent protocols. In situations where network behavior varies across different regions, ZRP's performance can be fine-tuned by individual adjustment of each node's routing zone [24].

B. Proposed Fuzzy-ZRP

In traditional ZRP, the value used for each area radius is a constant *p*, manually initialized by an expert (the default is 2). It is not enough to obtain the best performance of the protocol for a given scenario either the state of the network is stable or unstable. In the proposed Fuzzy-ZRP, important node metrics, such as node residual energy and mobility, are considered to automatically estimate the radius zone's value. Furthermore, a faster speed means that a node has to reduce its radius to guarantee the stability of the network connection, while a slower speed increases it. This is accomplished by iteratively fine-tuning the value of radius *p* after calculating residual energy and speed. The decision to start the process is made during a fixed period by a fuzzy logic system [25].

1) Energy and Speed Calculation

At the initial stage, each network node starts to calculate the information needed to feed the system inference, which is represented by:

- Energy (EN)*:* represents the remaining energy in the battery of the node in question, valued as a percentage (%).

$$Energy(EN) = \frac{RE(t)}{IE} \quad (1)$$

where *RE*(*t*) is the remaining energy of the node at time *t*, and IE is the initial energy of the node at time t_0.

- Speed (SP): represents the speed at time *t* valued in m/s.

2) Radius Zone Selection Using Fuzzy Logic

Fuzzy logic is suitable for problems that require a decision [26]. A fuzzy system describes the relationship between fuzzy input and output variables using *if-then*-based rules [27]. As shown in Figure 2, the system consists of fuzzification, defuzzification, and a fuzzy inference engine. Fuzzification represents the decisive input variables in fuzzy set membership functions. In contrast, defuzzification converts the fuzzy output into decisive values using a mathematical formula. At the same time, the inference engine calculates the fuzzy output according to the rules listed in Table 1.

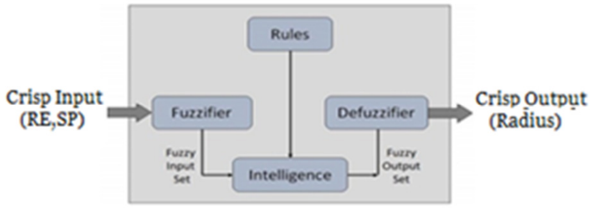


Fig. 2. Fuzzy system architecture.

To work with a fuzzy inference system, the input and output variables must be defined as membership functions. Then fuzzy rules are proposed to relate input to output memberships [28]. The membership functions should be represented by a graphical interpretation of the input and output linguistic variables. In this case, the inputs are the node's residual energy and speed, and the output is the node's radius value. Equations (2) and (3) illustrate triangular and trapezoid membership functions that describe the input and output membership degrees of the input and output variables for fuzzy inference. The residual energy of the nodes is treated as a critical input value, which directly impacts the network's lifetime and communication through the transmission and reception of packets and internal computational processes [29]. The node speed input parameter also significantly affects the stability of the network, as nodes with higher speeds increase the probability of route failure and control overhead.

$$\mu_{A_1}(x) = \begin{cases} 0 & x \le a_1 \\ \frac{x-a_1}{b_1-a_1} & a_1 \le x \le b_1 \\ \frac{c_1-x}{c_1-b_1} & b_1 \le x \le c_1 \\ 0 & x \ge c_1 \end{cases} \quad (2)$$

$$\mu_{A_2}(x) = \begin{cases} 0 & x \le a_2 \\ \frac{x-a_2}{b_1-a_2} & a_2 \le x \le b_2 \\ 1 & b_2 \le x \le c_2 \\ \frac{c_2-x}{c_2-b_2} & c_2 \le x \le d_2 \\ 0 & x \ge d_2 \end{cases} \quad (3)$$

The fuzzy inference engine relies on a knowledge base of rules that define the input and output membership functions. As shown in Table I, the proposed system consists of nine rules calculated by multiplying the number of membership functions characterized by each input variable. These memberships are associated using a particular fuzzy operator represented by the AND. For example, selecting the ninth rule, which supposes that the node's residual energy and speed are high, the node radius value should be very low. If the node's residual energy is low and the speed is high, the output of the inference is very high. Defuzzification is a weighted average mathematical approach to extract a net output value from the aggregation of the fuzzy output representation. Several approaches have been proposed to find crisp output, and this method used the centroid defuzzification method that has the following mathematical expression:

$$COG = \int \frac{u_A(x).x\, d_x}{u_A(x).d_x} \quad (4)$$

where $u_A(x)$ is the weight of the output membership function defined in (2) and (3), x denotes the centroid of each output membership function, and *COG* (Center Of Gravity) indicates the crisp value of the defuzzified output[26-30].

TABLE I. FUZZY BASE RULE SET

RULES	SPEED	ENERGY	RADIUS
1	LOW	HIGH	VERY HIGH
2	LOW	MEDIUM	HIGH
3	LOW	LOW	MEDIUM
4	MEDIUM	HIGH	HIGH
5	MEDIUM	MEDIUM	MEDIUM
6	MEDIUM	LOW	LOW
7	HIGH	HIGH	VERY LOW
8	HIGH	MEDIUM	LOW
9	HIGH	LOW	MEDIUM

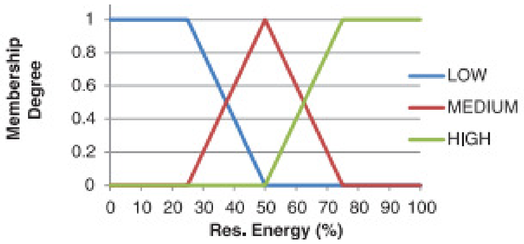


Fig. 3. Membership function of the residual energy input.

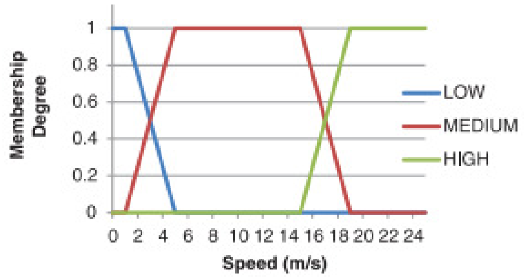


Fig. 4. Membership function of the node speed input.

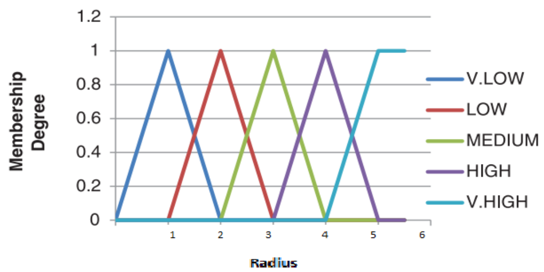


Fig. 5. Output membership function of the node radius.

C. Description of the Proposed Fuzzy Logic Algorithm

The description of the proposed algorithm can be summarized in four basic steps: fuzzification, *if-then* rule evaluation, output aggregation, and defuzzification to calculate the crisp value. These steps can be described as:

- Step 1: The fuzzification of the crisp input parameter values represented by the residual energy and the node velocity is defined by their membership functions, as shown in Figures 3-5. Each input's membership degree is found by mapping the input value with the membership function.
- Step 2: The membership degrees found in the first step will be evaluated from the rules to determine the fuzzy output set. The AND operator selects the minimum membership values from the input membership values.
- Step 3: The system collects all output from the previous step in union form and constructs a new aggregate fuzzy set by selecting the maximum evaluating values using the OR operator.
- Step 4: The defuzzification process is performed using the centroid method (center of gravity) with the new aggregate function obtained in step 3 to calculate the node radius value using (4).

III. PERFORMANCE METRICS

The performance of the proposed algorithm was compared with the standard ZRP, the OVBAZRP, and the Practical Swarm-Optimized ZRP (PSOZRP) considering the Packet Delivery Ratio (PDR), the End-to-End Delay (E2ED), and the Network Routing Load (NRL).

TABLE II. PERFORMANCE OF ZRP AND PROPOSED ALGORITHM

Parameters	ZRP algorithm	Proposed algorithm
PDR	AVG	HIGH
NRL	HIGH	LOW
E2ED	HIGH	LOW

- PDR is the fraction of the data packets successfully delivered to the destination [31]:

$$PDR = \frac{\sum packets\ received\ by\ destination}{\sum packets\ sents\ by\ the\ source}\ x\ 100 \quad (5)$$

- NRL is the ratio of routing packets transmitted to data packets delivered [32]:

$$NRL = \frac{\sum transmitted\ routing\ packets}{\sum packets\ received\ by\ the\ destination} \quad (6)$$

- E2ED is the average end-to-end delay, calculated by summing the times taken by all received packets divided by their total numbers[32]:

$$E2ED = \frac{\sum(packets\ received\ time - packets\ send\ time)}{\sum \hat{a}ckets\ received\ by\ the\ destination} \quad (7)$$

IV. SIMULATION ENVIRONMENT

A. Simulation Parameters:

The simulation study considered a network area of $1000\times1000m^2$ and 50 wireless mobile nodes randomly distributed throughout the simulation area with a maximum speed of 50m/s. Tables III and IV show the speed scenarios and simulation parameters.

TABLE III. SPEED SCENARIOS

Case 1	Case 2	Case 3	Case 4	Case 5
5m/s	10m/s	30m/s	40m/s	50m/s

TABLE IV. PARAMETERS OF SIMULATION SCENARIO

Parameters	Value
Simulation time	300s
Simulation area	1000×1000m^2
Node speed	0-50m/s
Propagation model	Two Ray Ground
Mobility model	Random waypoint
Radio frequency	2.47GHz
Channel bandwidth	2 Mbps
Mac protocol	IEEE 802.11
Type dataflow	CBR
Number of nodes	50
Assigned energy	20J
Transmit power	0.8W
Receive power	0.5W

B. *Simulation Metrics:*

The performance of MANET routing protocols can be evaluated using many quantitative metrics. This study used Packet Delivery Ratio (PDR), End-to-End Delay (E2ED), and Normalized Routing Load (NRL) to evaluate the performance of the proposed routing protocol simulation, as shown in (5)-(7).

V. RESULTS AND DISCUSSION

The NS-2 simulator [33] was used to simulate and compare the performance of the proposed Fuzzy-ZRP with ZRP, OVBAZRP, and PSOZRP, based on different speed scenarios.

A. *Packet Delivery Ratio*

Figure 6 shows the packet delivery ratio for the compared protocols with variable speeds of the nodes. It is clear that the proposed Fuzzy-ZRP protocol outperformed the other protocols and achieved a higher PDR. However, the PDR of all protocols decreased with increasing speed, due to the increasing number of broken links in the network which increased by the mobility rate. The proposed Fuzzy-ZRP algorithm achieved the highest PDR mainly due to the dynamic area radius determination adopted, which balances the IARP and IERP routing overhead. Thus, channels and bandwidth are available for data traffic, improving the PDR. The PSOZRP dynamically determines the radius of the zone based on the speed and location of the nodes. It searches the entire space for the best optimum that satisfies the constraints of the objective function to calculate the radius at each point in time, generating additional traffic that decreases the bandwidth needed for the actual data transfer. For the OVBAZRP, the determination of the radius is based only on the speed of the node and completely ignores local parameters such as the remaining energy, which is an important factor in determining the stability of the route. The ZRP uses a static radius value for all nodes as a mechanism without taking into account local network parameters. This radius value setting causes an imbalance between IARP and IERP, leading to a reduction in packet transfer rates. Figure 7 clearly shows the PDR gain for the proposed Fuzzy-ZRP compared to the others for all speed scenarios. The PDR ranged from 6.02 to 13.15% for Fuzzy-ZRP and conventional ZRP, the gain of Fuzzy-ZRP over OVBAZRP was between 4.30 and 10.40%, the gain of Fuzzy-ZRP with PSOZRP was between 1.80% and 6.20%.

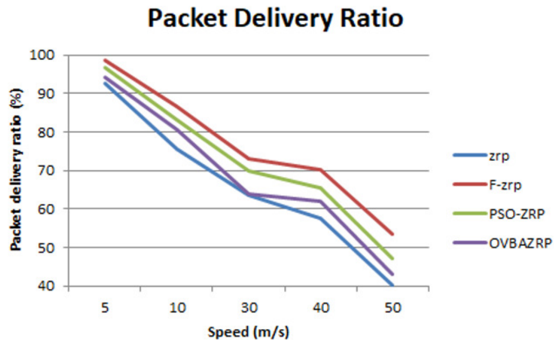


Fig. 6. Packet delivery ratio vs speed.

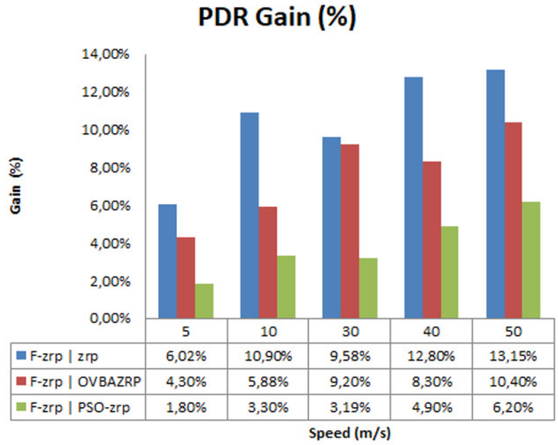


Fig. 7. Packet delivery ratio gain.

B. *Average End-To-End Delay*

As shown in Figures 8-9, Fuzzy-ZRP had a lower average delay than ZRP, OVBAZRP, and PSOZRP in all speed scenarios. This is because ZRP uses a static zone radius regardless of the network state. However, for a stable network, the proposed Fuzzy-ZRP algorithm increased the area radius, forcing a larger area to be covered by the IARP protocol. Therefore, the IERP protocol only controls a smaller area to reduce the latency incurred by the route discovery process. On the other hand, by increasing mobility, a smaller area radius forces the IERP to take care of a larger area to minimize the IARP overhead involved in updating and maintaining the routing table.

For PSOZRP, the transfer time is influenced by the time taken to search for the best value of the zone radius at each timestamp. Additionally, OVBAZRP suffers from the inability to determine an unstable route in a short time. As shown in Figure 9, the gain obtained by incorporating the proposed Fuzzy-ZRP in the zone radius estimation over ZRP varied between 2 and 53%, over OVBAZRP varied between 1.80 to 30%, and over Fuzzy-ZRP and PSOZRP varied from 0.8% to 20%.

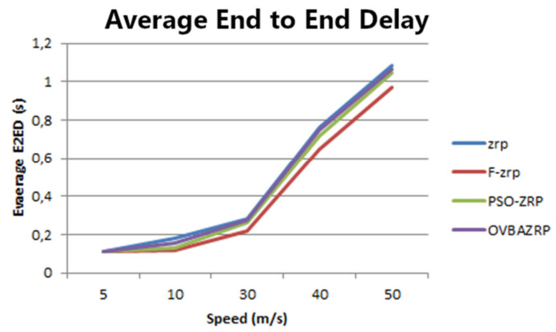


Fig. 8. End-to-end delay vs speed.

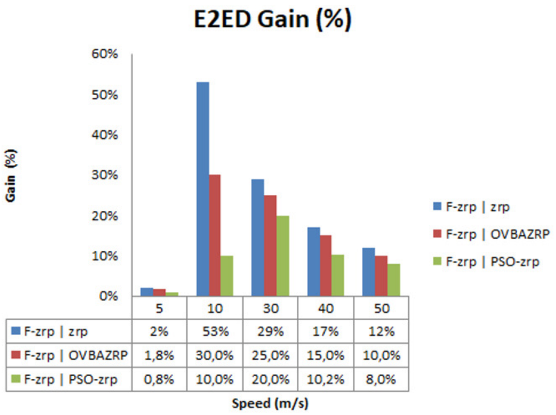


Fig. 9. End-to-end delay gain.

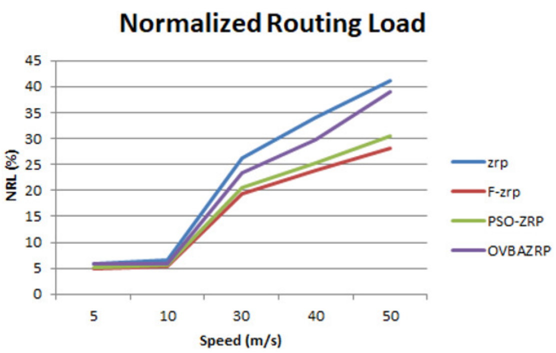


Fig. 10. Normalized routing load vs speed.

C. Normalized Routing Load

Figure 10 shows the effects of node mobility on routing control packets in the two routing scenarios used in this study. As can be seen, the overhead of routing packets increases with the speed of the nodes. Although Fuzzy-ZRP minimizes the number of control packets transmitted to the network, it maintains a different zone radius for each node depending on mobility speed and energy. The nodes in different zones have different views of the current network topology. Thus, nodes can establish more stable and reliable routes by minimizing the zone radius. PSOZRP iteratively performs the process of finding the optimal value of the zone radius, generating additional control packets to determine information on the speed and location of each node. As shown in Figure 10, the gain obtained by applying the Fuzzy-ZRP protocol compared to ZRP varied between 21% and 46%, the difference between Fuzzy-ZRP and OVBAZRP was 12-38%, and for Fuzzy-ZRP compared to PSOZRP was 4-8%.

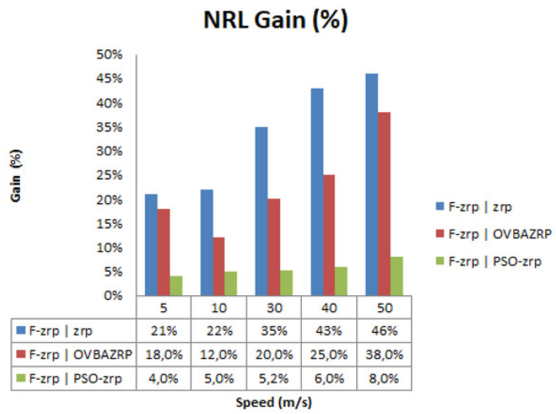


Fig. 11. Normalized routing load gain.

VI. CONCLUSION

This study investigated the problem of adjusting the radius of the ZRP by proposing a fuzzy-based approach that provides an auto-tuning method to automatically adjust the radius. The simulation results showed that, compared to other approaches such as PSOZRP, OVBAZRP, and classical ZRP, the proposed fuzzy-based ZRP method effectively improved the overhead of control traffic without sacrificing other performance metrics, such as packet delivery ratio and average end-to-end delay, and without requiring manual configuration. Compared to classical ZRP, the proposed approach improved PDR by 6.02-13.15%, NRL by 21-46%, and E2ED by 2-53%. The proposed protocol achieved a significant gain compared to OVBAZRP in PDR by 4.30-10.40%, NRL by 12-38%, and E2ED by 1.8-30%. Finally, the proposed Fuzzy-ZRP outperformed PSOZRP with gains of 1.80-6.20% in PDR, 4-8% in NRL, and 0.8-20% in E2ED.

REFERENCES

[1] P. Samar, M. R. Pearlman, and Z. J. Haas, "Independent zone routing: an adaptive hybrid routing framework for ad hoc wireless networks," *IEEE/ACM Transactions on Networking*, vol. 12, no. 4, pp. 595–608, Dec. 2004, https://doi.org/10.1109/TNET.2004.833153.

[2] M. R. Pearlman and Z. J. Haas, "Determining the optimal configuration for the zone routing protocol," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 8, pp. 1395–1414, Dec. 1999, https://doi.org/10.1109/49.779922.

[3] B. Patel and S. Srivastava, "Performance analysis of zone routing protocols in Mobile Ad Hoc Networks," in *2010 National Conference On Communications (NCC)*, Chennai, India, Jan. 2010, pp. 1–5, https://doi.org/10.1109/NCC.2010.5430164.

[4] R. M. A. Qasem and S. M. Massadeh, "Solving Cell Placement Problem Using Harmony Search Algorithms," *Engineering, Technology & Applied Science Research*, vol. 8, no. 4, pp. 3172–3176, Aug. 2018, https://doi.org/10.48084/etasr.2113.

[5] Y. Bai, Y. Mai, and N. Wang, "Performance comparison and evaluation of the proactive and reactive routing protocols for MANETs," in *2017 Wireless Telecommunications Symposium (WTS)*, Chicago, IL, USA, Apr. 2017, pp. 1–5, https://doi.org/10.1109/WTS.2017.7943538.

[6] H. M. Haglan *et al.*, "Analyzing the impact of the number of nodes on the performance of the routing protocols in manet environment," *Bulletin*

of Electrical Engineering and Informatics, vol. 10, no. 1, pp. 434–440, Feb. 2021, https://doi.org/10.11591/beei.v10i1.2516.

[7] S. Shruthi, "Proactive routing protocols for a MANET — A review," in *2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*, Palladam, India, Oct. 2017, pp. 821–827, https://doi.org/10.1109/I-SMAC.2017.8058294.

[8] M. P. Manohar, "Performance Analysis of Reactive Routing Protocols AODV, DYMO, DSR, LAR in MANETs," *International Journal on Future Revolution in Computer Science & Communication Engineering*, vol. 4, no. 3, pp. 01–07, Mar. 2018.

[9] M. H. Hassan and R. C. Muniyandi, "An Improved Hybrid Technique for Energy and Delay Routing in Mobile Ad-Hoc Networks," *International Journal of Applied Engineering Research*, vol. 12, no. 1, pp. 134–139, 2017.

[10] K. W. Al-Ani, S. Yussof, H. M. Haglan, and H. Shaker, "Review on Routing Protocols for Mobile Ad-Hoc Network," *European Journal of Scientific Research*, vol. 117, no. 4, pp. 568–584, Jan. 2014.

[11] A. Rajab, "Genetic Algorithm-Based Multi-Hop Routing to Improve the Lifetime of Wireless Sensor Networks," *Engineering, Technology & Applied Science Research*, vol. 11, no. 6, pp. 7770–7775, Dec. 2021, https://doi.org/10.48084/etasr.4484.

[12] M. A. Mahdi, T. C. Wan, A. Mahdi, M. a. G. Hazber, and B. A. Mohammed, "A Multipath Cluster-Based Routing Protocol For Mobile Ad Hoc Networks," *Engineering, Technology & Applied Science Research*, vol. 11, no. 5, pp. 7635–7640, Oct. 2021, https://doi.org/10.48084/etasr.4259.

[13] N. Beijar, "Zone Routing Protocol (ZRP)," University of Technology, Helsini, Finland.

[14] Z. Haas and M. Pearlman, "The zone routing protocol (zrp) for ad hoc networks"," IETF, Internet Draft, Aug. 2002.

[15] Z. J. Haas, M. R. Pearlman, and P. Samar, "The Intrazone Routing Protocol (IARP) for Ad Hoc Networks," IETF, Internet Draft, Jun. 2001.

[16] H. Osanai, A. Koyama, and L. Barolli, "An Implementation and Evaluation of Zone-Based Routing Protocol for Mobile Ad-Hoc Networks," in *2011 14th International Conference on Network-Based Information Systems*, Tirana, Albania, Sep. 2011, pp. 517–522, https://doi.org/10.1109/NBiS.2011.85.

[17] J. Zhou, Y. Cheng, and J. Lu, "Velocity based adaptive zone routing protocol," in *2007 International Symposium on Intelligent Signal Processing and Communication Systems*, Xiamen, China, Aug. 2007, pp. 337–340, https://doi.org/10.1109/ISPACS.2007.4445892.

[18] A. K. Jaiswal and P. Singh, "Optimizing Velocity Based Adaptive Zone Routing Protocol," in *2010 International Conference on Computer and Communication Technology (ICCCT)*, Allahabad, India, Sep. 2010, pp. 149–152, https://doi.org/10.1109/ICCCT.2010.5640413.

[19] N. Harrag, A. Refoufi, and A. Harrag, "PSO-IZRP: New enhanced zone routing protocol based on PSO independent zone radius estimation," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol. 32, no. 1, 2019, Art. no. e2461, https://doi.org/10.1002/jnm.2461.

[20] G. A. Walikar and R. C. Biradar, "Energy aware hybrid multicast routing in mobile ad hoc networks: zone-based approach," *International Journal of Mobile Network Design and Innovation*, vol. 8, no. 2, pp. 80–100, Jan. 2018, https://doi.org/10.1504/IJMNDI.2018.092344.

[21] P. Tamil Selvi and C. Suresh GhanaDhas, "A Novel Algorithm for Enhancement of Energy Efficient Zone Based Routing Protocol for MANET," *Mobile Networks and Applications*, vol. 24, no. 2, pp. 307–317, Apr. 2019, https://doi.org/10.1007/s11036-018-1043-x.

[22] "Fuzzy Based Scheduling and Load Balancing for Zone Routing Protocol (ZRP) in Mobile Ad Hoc Networks," *Journal of critical reviews*, vol. 7, no. 04, pp. 600–604, Feb. 2020, https://doi.org/10.31838/jcr.07.04.109.

[23] M. Vargheese, S. Vanithamani, D. David, and G. Rama, "Design of Fuzzy Logic Control Framework for QoS Routing in MANET," *Intelligent Automation & Soft Computing*, vol. 35, no. 3, pp. 3479–3499, 2022, https://doi.org/10.32604/iasc.2023.030948.

[24] Khalid W. Al-Ani, Salman Yussof, Hussein M. Haglan, Hothefa Shaker, and Linda Mahdi Alani, "Determining an optimum zone radius for zone routing protocol (ZRP) based on node mobility," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 2, pp. 1230–1237, Feb. 2021.

[25] M. B. A. Fadhillah and R. Anggoro, "Time Optimization for Radius Updates in Zone Dynamics of Zone Routing Protocol," *Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control*, pp. 147–154, May 2020, https://doi.org/10.22219/kinetik.v5i2.1064.

[26] G. W. Nurcahyo, S. M. Shamsuddin, R. A. Alias, and M. Noor Md Sap, "Selection of defuzzification method to obtain crisp value for representing uncertain data in a modified sweep algorithm," *Journal of Computer Science & Technology*, vol. 3, no. 2, pp. 22–28, Oct. 2003.

[27] F. Dernoncourt, "Introduction to fuzzy logic," Massachusetts Institute of Technology, Jan. 2013.

[28] W. El-Hajj, D. Kountanis, A. Al-Fuqaha, and M. Guizani, "A Fuzzy-Based Hierarchical Energy Efficient Routing Protocol for Large Scale Mobile Ad Hoc Networks (FEER)," in *2006 IEEE International Conference on Communications*, Istanbul, Turkey, Jun. 2006, vol. 8, pp. 3585–3590, https://doi.org/10.1109/ICC.2006.255628.

[29] M. Youssef, M. Ibrahim, M. Abdelatif, L. Chen, and A. V. Vasilakos, "Routing Metrics of Cognitive Radio Networks: A Survey," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 1, pp. 92–109, 2014, https://doi.org/10.1109/SURV.2013.082713.00184.

[30] G. Kalpana and D. M. Punithavalli, "Fuzzy Logic Technique for Gossip Based Reliable Broadcasting in Mobile Ad Hoc Networks," *Journal of Theoretical and Applied Information Technology*, vol. 51, no. 3, pp. 498–505, May 2005.

[31] R. R. Chandan, B. S. Kushwaha, and P. K. Mishra, "International Journal of Computer Network and Information Security(IJCNIS)," *International Journal of Computer Network and Information Security(IJCNIS)*, vol. 10, no. 7, pp. 59–65.

[32] H. M. Haglan, S. Yussof, K. W. Al-Ani, H. S. Jassim, and D. A. Jasm, "The effect of network size and density to the choice of zone radius in ZRP," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 1, pp. 206–213, Oct. 2020.

[33] P. Whigham, "The Vint Project, the Network Simulator - ns-2," University of Sourthern California, 2003. [Online]. Available: https://www.isi.edu/nsnam/ns/.