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Research Article

An Ant-Hocnet Routing Protocol Based on Optimized Fuzzy Logic for Swarm of UAVs in FANET

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Drones or unmanned aircraft are commonly known as unmanned aerial vehicles (UAVs), and the ad hoc network formed by these UAVs is commonly known as Flying Ad Hoc Network (FANET). UAVs and FANET were initially associated with military surveillance and intelligence gathering; moreover, they are now excessively used in civilian roles including search and rescue, traffic monitoring, firefighting, videography, and smart agriculture. However, due to the distinctive architecture, they pose considerable design and deployment challenges, prominently related to routing protocols, as the traditional routing protocols cannot be used directly in FANET. For instance, due to high mobility and sparse topology, frequent link breakage and route maintenance incur high overhead and latency. In this paper, we employ the bio-inspired Ant Colony Optimization (ACO) algorithm called "Ant-Hocnet" based on optimized fuzzy logic to improve routing in FANET. Fuzzy logic is used to analyze the information about the status of the wireless links, such as available bandwidth, node mobility, and link quality, and calculate the best wireless links without a mathematical model. To evaluate and compare our design, we implemented it in the MATLAB simulator. The results show that our approach offers improvements in throughput and end-to-end delays, hence enhancing the reliability and efficiency of the FANET.

1. Introduction

An unmanned aircraft is stated to as a drone. Drones are also known as unmanned aerial vehicles (UAVs) or unmanned aircraft systems. A drone is a flying robot that can be controlled remotely or flow independently using software-driven flight plans in embedded systems that work in tandem with sensing devices and a global positioning system (GPS). Recently, with the rapid advancement and development in sensors, computation, and networking technologies, many researchers consider the usage of several small-unmanned aerial vehicles or UAVs for a variety of military and civilian applications [1]. UAVs are a collection of independent flying wireless nodes, which communicate with each other and a ground base through wireless links [2]. Mobile Ad hoc Network (MANET) is a self-organizing, infrastructure-less, and on-demand network, which can be adapted in dynamic conditions, but suffers from several limitations in terms of communication range and availability [3]. MANET has a few application territories such as emergency handling, patient monitoring, fault-tolerant mobile sensor grids, environment control, and intelligent transportation systems. However, MANETs do not provide the required level of performance for disaster and war field applications such as flood handling, battlefield, earthquake, search, and rescue operations where MANETs cannot be deployed. For such cases, Flying Ad Hoc network (FANET) is a distinct subgroup of MANET and Vehicular Ad Hoc

Network (VANET) [4], which works in scenarios where communication service is out of reach or simply not accessible. The nodes in FANET play role of communication relay, rapidly deployable and self-managed ad hoc network. FANET is developed as a capable technique in both civilian and military applications, such as border surveillance, search and destroy, search and rescue, road traffic management, airborne photography, disaster management, urban security, remote sensing, and wind estimation, as shown in Figure 1 [5].

FANET can be seen as multi-UAV and single UAV systems. Multi-UAV systems have several advantages over single UAV systems such as scalability, stability, accuracy and precision, and effectiveness [6]. However, multi-UAV systems have several challenges because of their unique characteristics such as high mobility and infrequent deployment. One of the major issues is routing among the UAVs and base stations [7]. Furthermore, there is also the issue of range limitation between UAVs and ground-based station. On the off chance that a UAV is outside the inclusion of the ground base station, it ends up disconnected [8]. In this respect, it is important to build a wireless ad hoc network, in particular, a decentralized network with powerfully evolving topology and high node mobility.

In [9], fuzzy-logic-assisted AODV (FL-AODV) routing algorithm is proposed for MANET. In [10], the authors propose the use of Q-learning-based fuzzy logic for the FANET routing protocol. The authors in [11] use fuzzy logic for a QoS and QoE aware routing protocol for FANET networks. Link Defined OLSR (OLSR-LD) is proposed for MANET in [12]. Link Stability Estimation-based Preemptive Routing (LEPR) protocol for FANET is proposed in [13]. A common issue in the existing ad hoc routing protocols is that they did not consider the important factors (i.e., bandwidth, mobility, and link quality) all together for choosing the best routing path for more effective and robust routing.

In terms of implementation and architecture, FANET presents significant obstacles. Bandwidth, link quality, and determining the optimum routing path for data exchange are all significant problems in routing among the swarm of UAVs. The rationale for this is that these parameters have a significant impact on the network's overall performance. According to research, existing systems in FANETs do not take into account aspects such as bandwidth, mobility, or link quality when picking a routing option ([2] and Mukherjee et al.). Finding a new path in a highly mobile UAV network is inconvenient in typical protocols, resulting in a greater delay. Ant-Hocnet, on the other hand, is less effective in locating a high-quality routing link and so is unsuitable for higher packet loads. In this paper, we focus on how to improve the existing routing protocol for highly mobile UAV networks and how to calculate the best routing path for sending lager packets in FANET. We do further research for routing algorithm and proposed an algorithm based on Ant-Hocnet and fuzzy logic to increase throughput and packet delivery ratio and decrease end-to-end delay and improve overall network communication ability.

The rest of the paper includes the related work being summarized in Section 2. In Section 3, we present the overview of Ant-Hocnet, and Section 4 presents a fuzzy logic system. The detailed explanation of the calculation of bandwidth, mobility, and link quality is presented in Section 5. Section 5.4 presents the simulation results and comparison FAnt-Hocnet (FAHR) and existing Ant-Hocnet algorithm. Finally, the conclusion and future direction are given in Section 6.

2. Related Works

In this section, we review state-of-the-art existing routing protocols for MANETs, FANETs, and VANETs and analyze their strengths and weaknesses. The reason for reviewing related work to MANET and VANET is that they provide the basic foundation to from FANETs. Furthermore, most of the early work on FANET trace back to the use of MANET and VANET protocol usage for FANET.

Zheng et al. [14] proposed a novel hybrid protocol for routing based on location prediction directional MAC protocol (PPMAC) and a self-learning and reinforcement learning routing protocol called RLSRP. PPMAC merges the location prediction and directional antennas in the MAC layer to solve the directional deafness issue. The RLSRP empowers updating the local routing strategies with the location information of drones and an advantage task defined based on the global network efficacy; however, this protocol cannot support multichannel structure. Zheng et al. [15] proposed Stable Ant-based Routing Protocol (SARP). In SARP, a HELLO message is broadcasted occasionally to get the neighbor information. However, SARP route selection considers only the shortest path, which is not enough for routing in FANET with high mobility nodes and hence result in possibly weak links. In [16], Fatemidokht and Kuchaki Rafsanjani propose an optimize routing scheme called F-Ant for VANET; this scheme comprises of ACO algorithm and fuzzy logic. The scheme design is based on bandwidth, received signal strength metric (RSSM), and congestion metric (CM) for computing link's validity. In [17], the authors present a Fuzzy control Q-learning Ad Hoc On Demand Distance Vector (FQLAODV) approach for VANET. Fuzzy logic estimates a wireless link whether it is good or bad by determining metrics of signal limitation, bandwidth, and mobility, whereas Q-learning selects a route which can offer multihop consistency and effectiveness. The biggest downside of this method is its computational overhead. In [18], the authors proposed Ant-Hocnet based on the ACO routing algorithm for MANET. It uses both reactive and proactive approaches; proactive approach maintains and improves path before reactive path setup phase. Ant-Hocnet is enlivened by the stigmergy-driven which emerges from the behavior of ant colonies and the ACO system. The authors compared Ant-Hocnet with Ad Hoc On Demand Distance Vector (AODV), and the results show that Ant-Hocnet outperforms AODV. However, Ant-Hocnet is not efficient in terms of routing overhead.

The utmost challenge of FANET is to make sure the ubiquitous communication in a needy situation, where real-time transmission of data is prerequisite. Routing in FANET is much difficult than MANET and VANET due

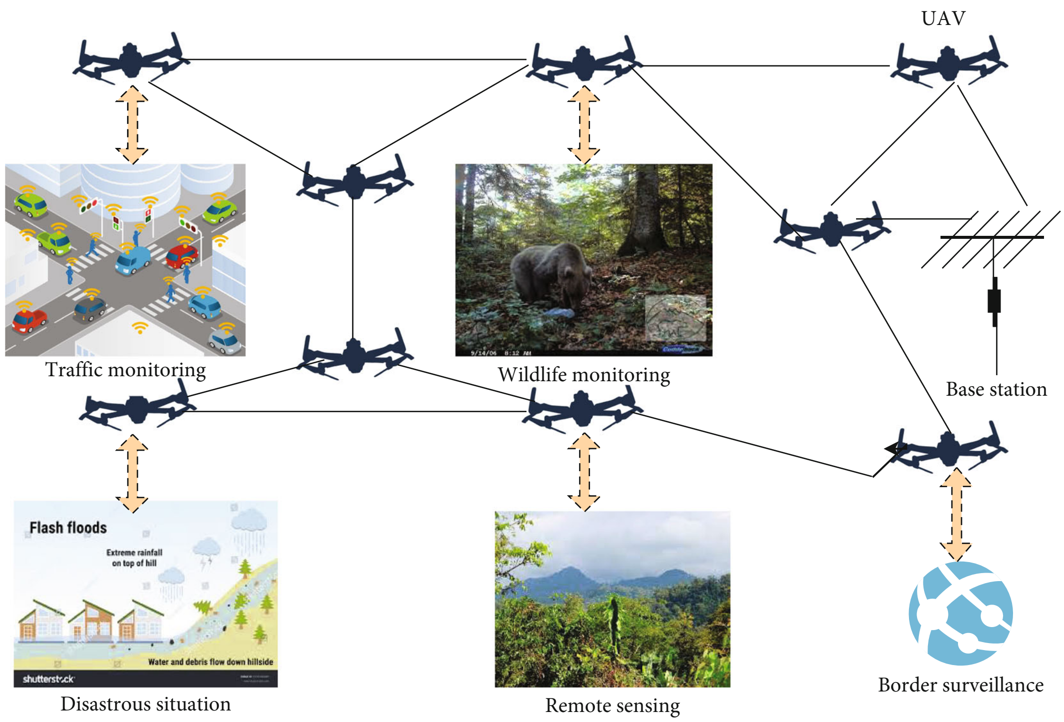


Figure 1: Multiple scenarios of Flying Ad Hoc Networks.

to its complex characteristics. A routing link may be weak, or a link may be broken in the network due to the high mobility and rapidly changing topology, sending a segmented packet produces high overhead resulting in higher latency and congestion, and these issues occur with most of the existing routing protocols. A vital problem arising in FANET is to choose the finest route among the UAV nodes. From literature review, it is concluded that a common issue in the existing ad hoc routing protocols is that they did not consider the important factors (i.e., bandwidth, mobility, and link quality) all together for choosing the best routing path for more effective and robust routing and requires a suitable technique to solve the issue.

In summary, the following are the limitations of the existing related work:

(i) The proposed scheme is not effective in decreasing the link failure as well as ensuring successful packet retransmission [12]

(ii) E-Ant-DSR leads to more delay as topology changes occur more frequently in FANET [19]

(iii) The RLSRP empowers updating the local routing strategies with the location information of drones and an advantage task defined based on the global network efficacy; however, this protocol cannot support multichannel structure [14]

(iv) SARP route selection considers only the shortest path, which is not enough for routing in FANET with high mobility nodes and hence result in possibly weak links [15]

(v) LEPR has not shown considerable results in both the finding frequency of route and the routing overhead [13]

There are various approaches to solve routing issues in FANET, the bio-inspired ACO-based algorithm is broadly used for routing issues in ad hoc networks. We use ACO-based Ant-Hocnet algorithm along with fuzzy logic to improve routing in FANET. Fuzzy logic is used to analyze the wireless link status info (i.e., available bandwidth, node mobility, and link quality) and calculate the best wireless links without a mathematical model.

3. The Proposed Scheme

In this research work, we exploit the bio-inspired Ant Colony Optimization (ACO) algorithm called "Ant-Hocnet" along with fuzzy logic to improve routing in FANET. Fuzzy logic considers the communication wireless link status info (i.e., available bandwidth, node mobility, and link quality) and calculates the best wireless links without a mathematical model in the swarm of UAVs. Fuzzy logic-based Ant-Hocnet selects the best routing path for sending larger packet loads more reliably with less delay.

3.1. System Design. Our proposed scheme is constructed on the ACO family algorithm for Ant-Hocnet routing. We consider Ant-Hocnet routing as it is a widely recognized routing protocol. The proposed scheme objective is to discover the best multihop routing path from the source node to the destination node. The effectiveness of a multihop routing path relies on the direct wireless links (one-hop links) that establish the routing path. Every node broadcasts a hello packet periodically. Every hello packet contains the accessible bandwidth and all neighbors' addresses of the sender node. Through using a hello packet, every node preserves its two-hop neighbor information. The mobility factor (MoF) in our proposed scheme is estimated by using location information or one-hop and two-hop neighbor data. Therefore, our proposed scheme can still work even if the information on the position is not available. The reception ratio of the hello packet is estimated by every node to assume the quality of a wireless link to a neighbor. On the hello packet reception, every node computes the link status value of the wireless link to the hello message of a source node. The bandwidth, UAV mobility, and link quality estimate the link status value. Fuzzy logic is used to measure these three metrics jointly while choosing the best routing path shown in Figure 2.

To address the issue of improving routing protocol for reliable communication in FANET with the best available route among the UAV swarm as mentioned above, we consider the existing bio-inspired approaches used in ad hoc networks, which help us to classify the issues and challenges in FANETs. In FANET for the analysis of routing issues, the bio-inspired algorithms have been effectively implemented. Moreover, bio-inspired algorithms enable us to improve the intelligence in wireless ad hoc networks. Thus, in proposed method, the same algorithm has been adopted to achieve our intended results.

The models of fuzzy set theory are the description of inaccurate and incomplete sensory information as imagine by human brain. Consequently, it characterizes and mathematically works with such linguistic data in a natural method via the membership functions and the set of fuzzy rules. We tend to use fuzzy logic to resolve this issue without obtaining the mathematical model and to assess a link-based method to choose a route that might offer a multihop reliability and efficiency and examine available bandwidth, node mobility, and link quality in the selection of route. Fuzzy rules are efficiently stated to obtain the last fuzzy value. The fuzzy membership functions and the accompany fuzzy rules can be adapted to assure a specific situation. Moreover, by defuzzification, the resultant fuzzy values are changed to a numerical value.

3.2. Ant Colony Optimization (ACO). We exploit the bio-inspired Ant Colony Optimization (ACO) algorithm called "Ant-Hocnet" along with fuzzy logic to improve routing in FANET. Fuzzy logic considers the communication wireless links status info (i.e., available bandwidth, node mobility, and link quality) and calculates the best wireless links without a mathematical model in the swarm of UAVs. Fuzzy logic-based Ant-Hocnet selects the best routing path for sending larger packet loads more reliably with less delay.

For the proposed scheme, we exploit the Ant-Hocnet routing protocol which is constructed on Ant Colony Optimization (ACO) family algorithm. We consider Ant-Hocnet routing since it is a widely recognized routing protocol. ACO is a bio-inspired algorithm like Bee Colony Optimization (BCO), birds flock, etc.; mainly, it represents

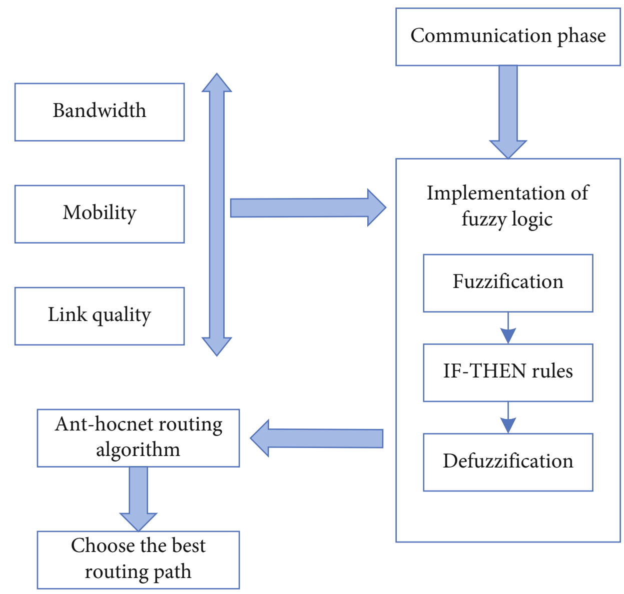


Figure 2: Block diagram of fuzzy logic-based Ant-Hocnet.

and uses the actions of ants and their liveliness. Ant-Hocnet has lots of similarity with reactive protocols such as AODV and Dynamic Source Routing (DSR) and as well as proactive protocol behavior similarities such as Destination-Sequenced Distance Vector (DSDV) and Optimized Link State Routing (OLSR). The proposed scheme objective is to discover the best multihop routing path to the destination node from the source node. The effectiveness of a multihop routing path relies on entirely the direct wireless links (one-hop links) that establish the routing path. Every node broadcasts a hello packet periodically. Every hello packet contains the accessible bandwidth and all neighbors' addresses of the sender node. By using the hello packet, every node preserves its two-hop neighbor info. The mobility factor (MoF) in our proposed scheme is estimated by using location info or one-hop and two-hop neighbor data. Therefore, our proposed scheme can still work even if the information of the position is not available. The reception ratio of the hello packet is estimated by every node to assume the quality of a wireless link to a neighbor. On the hello packet reception, every node computes the wireless link status to the hello packet of a source node. The bandwidth, UAV mobility, and link quality estimate the link status value. Fuzzy logic is used to measure these three metrics jointly as shown in Figure 2. The estimation of the considered factors are as follows.

3.2.1. Estimation of Each Link. Due to high mobility in FANET, wireless link quality changes more frequently. A good routing link in FANET is dependent on the bandwidth, mobility, and link quality of the network. Hence, in the estimation of a routing link, these matrices are considered together as shown in Figure 2. Mathematical model for choosing the routing path is complicated to derive, and a solution created on it would not be flexible. Meanwhile, a fuzzy logic system can manage uncertain and vague information. The use of fuzzy logic system is to resolve this issue by not using the mathematical model. The range of the fuzzy logic numerical values is characterized by the fuzzy membership functions. The following is the process for estimating a direct wireless link.

3.2.2. Estimation of Bandwidth Factor (BwF). It is dependent on the channel idle time ratio (CITR), so first we derived CITR as follows:

$$\omega = \frac{\tau_i}{\tau_o}. \tag{1}$$

In equation (1), CITR is represented by ω, τ_i denotes the idle time interval, and τ_o is the observation time interval, where the observation time can be adjusted relative to the execution complication and essential accuracy (by default 50 ms). It is never a good idea to reach 100% bandwidth utilization. A typical rule is that average utilization should not exceed 70 percent, because beyond this limit, the collision rate allegedly becomes excessive. The average to avoid this may be as low as 30%, although 50% would be more common.

The idle time calculation as shown by [17] (same for all equations) is given as follows:

$$\text{idle time} = \begin{cases} T_{\text{ob}} - \sum_{k=1}^{n} \frac{S_k}{\text{Rate}_{\text{avg}}}, & \sum_{k=1}^{n} \frac{S_k}{\text{Rate}_{\text{avg}}} < T_{\text{ob}}, \\ 0, \text{otherwise}. \end{cases} \tag{2}$$

In equation (2), n denotes the number of packets managed in the observation period T_{ob}, and S_k describes the kth packet size. The Rate_{avg} denotes the average channel data rate which is deliberate by the variation scheme. The channel usage specifies by the application programming interface (API), some of the wireless cards can offer the API. In that situation, the CITR is estimated in our proposed scheme with the help of MAC layer data. CITR is updated from every observation time with the help of a moving weighted exponential average as follows:

$$\omega \longleftarrow (1-\psi) \times \omega_{j-1} + \psi \times \omega_j, \tag{3}$$

where ω_j represents the current CITR value and ω_{j-1} represents the previous CITR value. The constant ψ is set default to 0.7, which is the finest value in our simulation results for various cases. Each node affixes its personal CITR to hello packets and reactive forward ant (ReFANT) packets. Every node senses the channel and estimates a BwF as follows:

$$\text{BwF} = \min\left(\omega(s), \omega(d)\right), \tag{4}$$

where $\omega(s)$ represents the CITR at the source node s and $\omega(d)$ represents the CITR at destination node d. For estimation of mobility factor (MoF), in our proposed scheme, the GPS accessibility is not adopted, and the MoF is estimated from the neighbor data. Additional coverage of the node d is used to signify the set of nodes that are one hope neighbors of the node d; nonetheless, one hop neighbors are not of the recent node s. Explicitly, $\lambda(s, d)$ is described as follows:

$$\lambda(s, d) = \bar{N(s)} \cap N(d). \tag{5}$$

In equation (5), $N(d)$ represents the one hop neighbor of node d, and $N(s)$ denotes the one hop neighbor of the s node. Here, we observe that node d is associated to $N(s)$. On the hello packet reception, a node estimates a MoF for the hello source node. The MoF at time j for a node d is calculated as follows:

$$\text{MoF}_j(s, d) = \begin{cases} \sqrt{\frac{\left|\lambda_j(s, d) \cap \lambda_{j-1}(s, d)\right|}{\left|\lambda_j(s, d) \cup \lambda_{j-1}(s, d)\right|}}, & \left|\lambda_j(s, d) \cup \lambda_{j-1}(s, d)\right| \neq \psi, \\ 0, \text{otherwise}. \end{cases} \tag{6}$$

In equation (6), $\lambda_{j-1}(s, d)$ denotes the previous value, and $\lambda_j(s, d)$ denotes the current value, respectively. For removing some errors, we use a moveable exponential average to compute the MoF as follows:

$$\text{MoF}(s, d) \longleftarrow (1-\psi)\text{MoF}_{j-1}(d) + \psi \text{MoF}_j(d), \tag{7}$$

where ψ is a constant value set to 0.7 and MoF is adjusted to 0. In equation (6), the alteration in the additional coverage is used to calculate the neighbor node comparative mobility. With the movement of a neighbor UAV at the similar speed as the current UAV, the distinction of the additional coverage is minimum because of the comparatively static neighbor set. As earlier discussed, the proposed scheme can compute the MoF from neighbor data. Consequently, the proposed scheme performs when location data is not available. Nevertheless, when the location is easy to obtain, the protocol estimated the MoF by using data of the location. The MoF is estimated as follows:

$$\text{MoF}_j(s, d) = \begin{cases} 1 - \sqrt{\frac{\left|x_j(s, d) - x_{j-1}(s, d)\right|}{R}}, & \left|x_j(s, d) - x_{j-1}(s, d)\right| < R, \\ 0. \end{cases} \tag{8}$$

In equation (8), $x_j(s, d)$ is the distances among the current node s and node d at the time j, and R is the average transmission range. Distances $x_j(s, d)$ and $x_{j-1}(s, d)$ can be calculated by every sender node attaching its location information to the hello messages. For estimating link quality factor (LqF), we consider link quality metric for reliable forwarding and minimize packet retransmissions and delay. The LqF is estimated from neighbor's data. A source node keeps a counter of every neighbor within a sliding window size to estimate the number of received hello packet. Meanwhile, the hello packets are sent with a defined time interval, the hello packet reception ratio can be computed by each node, and also, there is a probability of collision of hello packets. To address this issue, the hello reception ratio (φ) is updated for each hello interval depends on the amount of hello packet reception within the last 10 s as follows:

$$\varphi_j(s,d) = \begin{cases} \dfrac{\eta_r(s,d)}{\eta_s(d)}, & \eta_s(d) \geq 10, \\ \dfrac{\eta_r(s,d)}{\eta_s(d)}, \left(1 - \left(\dfrac{1}{2}\right)^{\eta_s(d)}\right). \end{cases} \quad (9)$$

In equation (9), $\varphi_j(s,d)$ denotes the hello reception ratio, $\eta_r(s,d)$ is the amount of received hello packets at s from d, and $\eta_s(d)$ is the amount of hello packets transmitted from d. In the above equation, we define that the nodes that are only neighbors are discounted for less than 10 s (when $\eta_s(d) < 10$). The LqF was estimated as follows:

$$\mathrm{LqF}(s,d) \longleftarrow (1-\psi)\mathrm{LqF}_{j-1}(s,d) + \psi \times \varphi_j(s,d). \quad (10)$$

When $\mathrm{LqF}_{j-1}(d)$ is adjusted to 0, estimation of the LqF, $\mathrm{LqF}_{j-1}(s,d)$ is given as follows:

$$\mathrm{LqF}_{j-1}(s,d) = \begin{cases} 0, & \eta_s(d) < 10, \\ \mathrm{LqF}(s,d). \end{cases} \quad (11)$$

4. Fuzzy Logic

Models of fuzzy set theory [20, 21] are used to investigate imprecision and fractional data. Fuzzy set theory models, in particular, behave in a similar fashion to the human brain, in that they have a goal and make decisions in an uncertain environment. Nevertheless, for communication in FANETs, a specific model is not existing, because of high mobility, unreliable links, and limited resources. Hence, the control decision system has been executed by fuzzy logic theory whichever to manage the issue. The inputs to the fuzzy logic to be considered for routing are (1) bandwidth, (2) mobility, and (3) link quality. These metrics make the pheromone to reproduce the network rank and the node's capability to reliably send packets over the network.

4.1. Fuzzification of Inputs/Outputs. In the inference system, fuzzification is the process of converting multiple types of input data into a single output. The bandwidth factor (BwF), mobility factor (MoF), and link quality factor (LqF), all three-input metrics, need to be fuzzified. We have provided three kinds of labels for different factor in this work, but for more accurate results, the different factors can be labeled with more possible labels. We intend to add more possible labels for our future works. On the base of current information of FANET, the labels "small," "medium," and "large" are used to define the bandwidth factor, and to define the mobility factor, the labels "slow," "medium," and "fast" are used, and "good," "medium," and "bad" are labels for the representation of link quality factor. The membership functions are demonstrated in Figure 3.

4.2. Inference Engine and Knowledge Base System. The fuzzy inference system is a set of instructions developed with the help of experts. Fuzzy set theory models are the description of incorrect and incomplete information, as imagined by human mind. Furthermore, it illustrates linguistic information in ordinary simple method via membership functions and fuzzy rules. The fuzzy rules are well defined for getting the final fuzzy value. The IF-THEN pattern of the fuzzy set rules is used to infer output fuzzy values. The IF component is used to create conditions using predicates and logical linkages, whereas the THEN element is used to determine the degree of membership. Fuzzy membership functions and fuzzy rules are applied effectively to ensure an explicit situation. Furthermore, by defuzzification process, the final fuzzy value is changed to a numerical value.

Figure 3 shows the fuzzy inference system rules for the bandwidth factor, mobility, and link quality factors respectfully in a fuzzy logic system, while Figure 4 shows the graphical interface of these factors. The linguistic variables describe the ranks, i.e., "Perfect, Good, Acceptable, Unpreferable, Bad, Very Bad" are shown in Figure 5. The fuzzy rules are generated by using MATLAB app in the fuzzy logic toolbox, based on the proposed FAnt-Hocnet composes of 27 rules, as shown in Table 1.

4.3. Defuzzification. The procedure of translation of fuzzy output into a single value is called the defuzzification, and the defuzzification technique used in our proposed approach is the center of gravity (CoG). The fuzzy sets are used as an input for the defuzzification procedure. The fuzzy inference system includes the set of output values, which must be defuzzified in directive to determine a single yield value from the fuzzy inference system as presented in Figure 6.

5. Implementation and Analysis

This section gives a detailed interpretation of the simulation environment and the output results that are obtained using the proposed scheme, i.e., FAnt-Hocnet and the existing Ant-Hocnet algorithm. The simulation scenario is shown in Figure 7. We show the results for three different scenarios in which we consider different packet sizes. The performance of throughput, end-to-end delay, and packet delivery ratio is evaluated with the existing method.

To evaluate and implement the proposed solution, simulation is widely used for this purpose. There are various simulation tools available for the evaluation. However, we use MATLAB for our evaluation because of it suitability [22]. The proposed method is compared with one of the most important protocol called Ant-Hocnet protocol. We assume that 100 nodes are randomly located in an area of 500×500 m, and the nodes move as per the mobility model.

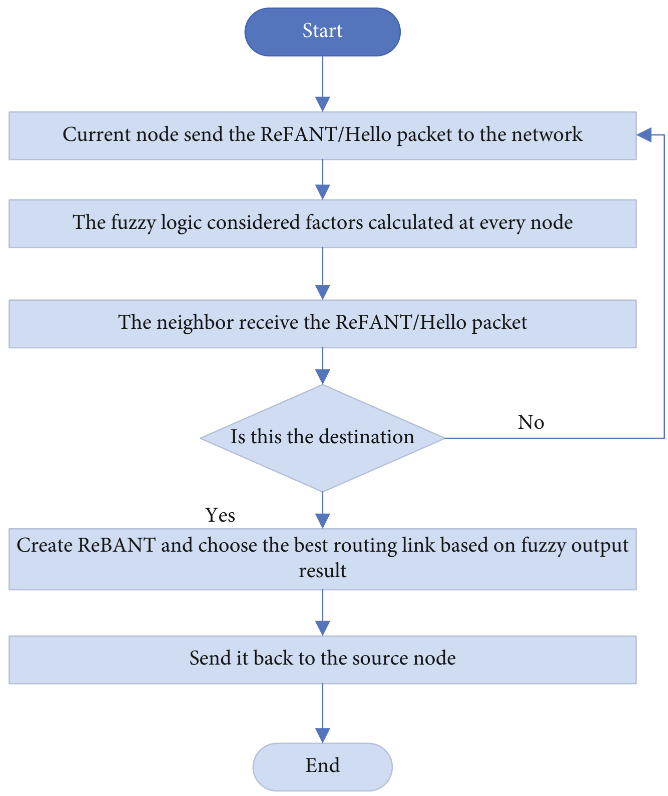


Figure 3: Flow chart of fuzzy logic-based Ant-Hocnet.

We have kept the simulation area 500×500 meters square to allow the swarm of UAVs to communicate with each other using the IEEE 802.11 (WLAN) standard, which has a maximum range of 100 meters in the 2.4 GHz ISM band. If the flying area is increased, the number of UAVs needs to be increased; consequently, the number of hop-count to the sink node will increase, and hence, delay will increase. We use the Gauss–Markov (GM) mobility model. The maximum speed is 100 m/s. Each node randomly chooses a destination point for communicating. Data traffic is generated by 10 constant bit rate (CBR) stream, and the packet size is 512 bytes as shown in Table 2. The results are generated for different data rates, i.e., 4, 6, 8, 10, 12, and 14 packets/s. At the MAC layer, the popular 802.11 protocol has been used as it is commonly used in ad hoc routing. Hence, we assume the MAC layer of IEEE 802.11 so the transmission range is that of IEEE 802.11 MAC. Moreover, we consider an Ideal FreeSpace propagation model with clear line of sight between transmitter and receiver.

In our simulation, we consider three different experiments for varying packet sizes (i.e., 64 bytes, 512 bytes, and 1024 bytes).

(i) First case: in this case, the packet size is 64 bytes

(ii) Second case: in this case, the packet size is 512 bytes

(iii) Third case: in this case, a larger packet size is assumed, i.e., 1024 bytes

Assumptions: designed and development for the FAnt-Hocnet and its working procedure, the following various assumption are established:

(i) We assume a swarm of UAVs moving freely in area of $500 * 500\,\mathrm{m}^2$

(ii) We assume a collision free atmosphere

(iii) The range among the UAVs is 15 meters

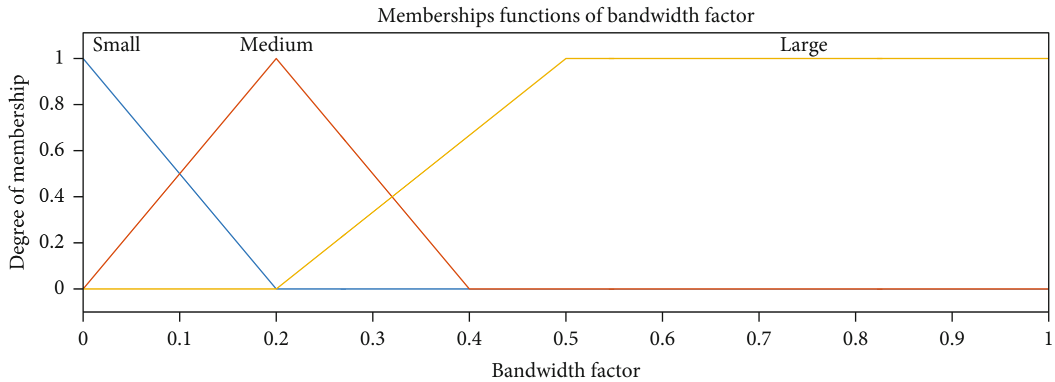
(iv) We assume that no UAV node die due to power drainage

(v) We assume Ant-Hocnet reactive behavior

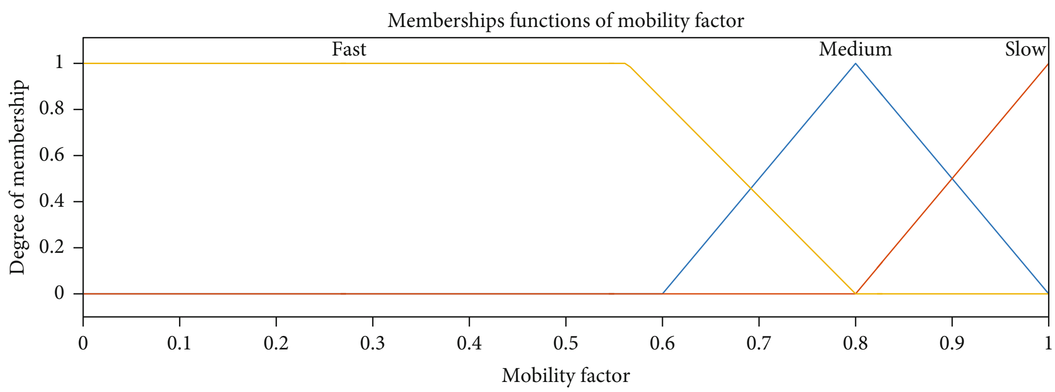
(vi) In our proposed scheme, we consider no queueing delay

Performance metrics: to validate the efficiency of the FAnt-Hocnet routing, we simulate the FANET scenario of Ant-Hocnet and FAnt-Hocnet. There are numerous measurable parameters which are exploited to estimate and examine the results, to estimate different scenarios of the network and routing performance. The following are the measurable parameters which are analyzed in this work.

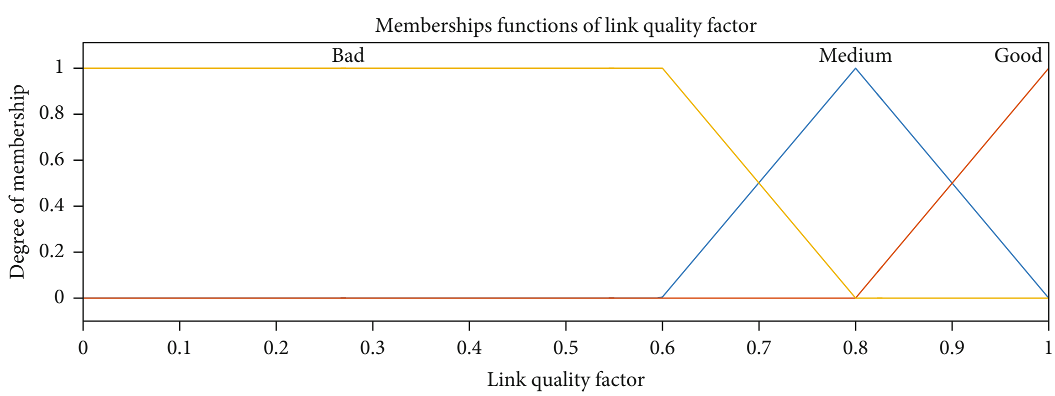
5.1. Throughput. The throughput is defined as the average total amount of data that can be profitably transferred by a sender over a communication medium in a unit



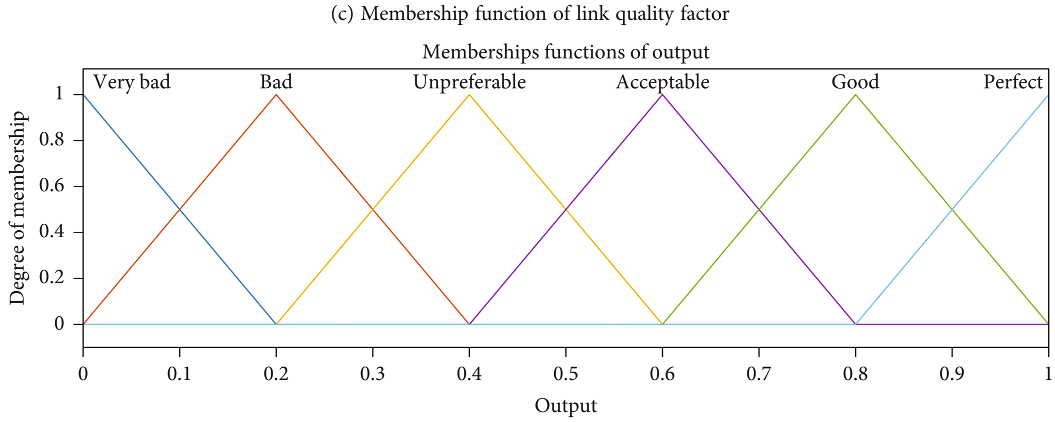
(a) Membership function of bandwidth factor



(b) Membership function of mobility factor



(c) Membership function of link quality factor



(d) Membership function of output

Figure 4: Membership functions.

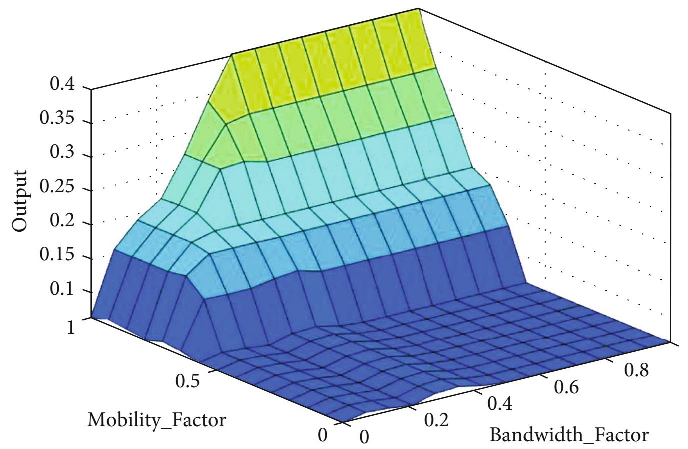


Figure 5: Surface view of membership function.

Table 1: Fuzzy logic rules.

	Bandwidth	Mobility	Link quality	Rank
Rule 1	Large	Slow	Good	Perfect
Rule 2	Large	Slow	Medium	Good
Rule 3	Large	Slow	Bad	Unpreferable
Rule 4	Large	Medium	Good	Good
Rule 5	Large	Medium	Medium	Acceptable
Rule 6	Large	Medium	Bad	Bad
Rule 7	Large	Fast	Good	Unpreferable
Rule 8	Large	Fast	Medium	Bad
Rule 9	Large	Fast	Bad	Very bad
Rule 10	Medium	Slow	Good	Good
Rule 11	Medium	Slow	Medium	Acceptable
Rule 12	Medium	Slow	Bad	Bad
Rule 13	Medium	Medium	Good	Acceptable
Rule 14	Medium	Medium	Medium	Unpreferable
Rule 15	Medium	Medium	Bad	Bad
Rule 16	Medium	Fast	Good	Bad
Rule 17	Medium	Fast	Medium	Bad
Rule 18	Medium	Fast	Bad	Very bad
Rule 19	Small	Slow	Good	Unpreferable
Rule 20	Small	Slow	Medium	Bad
Rule 21	Small	Slow	Bad	Very bad
Rule 22	Small	Medium	Good	Bad
Rule 23	Small	Medium	Medium	Bad
Rule 24	Small	Medium	Bad	Very bad
Rule 25	Small	Fast	Good	Bad
Rule 26	Small	Fast	Medium	Very bad
Rule 27	Small	Fast	Bad	Very bad

time. In fact, it is an associated metric to packet delivery ratio. However, the throughput is measured in bits not in the number of data packets. Characteristically, it is calculated in kbps, Mbps, and Gbps. The throughput can be calculated as by [23] as follows:

$$P_t = \left(\frac{\sum_{i=1}^{n} R_{ij}}{\sum_{i=1}^{n} S_{ij}} \right) * 100, \tag{12}$$

where P_t denotes the throughput (in packets), R_{ij} denotes the packets collected by node j sent from node i, and S_{ij} denotes the packets sent by the node i to node j.

5.2. End-to-End Delay. End-to-end delay denotes the time taken by a data packet transmitted by a source node to reach the destination. End-to-end delay is the sum of all probable delays created by buffering through route-finding latency, queuing at the interface queue, retransmission delays in MAC layer, propagation, and transmission times. In this work, we do not consider the queuing delay. In the situation, no link breaking prediction algorithm and multipath routing protocol are existing; then, this delay will be high since the time consumed in discovering a route is involved in the end-to-end delay. Mathematically, average end-to-end delay can be defined as follows:

$$\text{End-To-End Delay} = \frac{1}{n} \sum_{i=1}^{n=1} \left(p_i(T_r) - p_i(T_s) \right), \tag{13}$$

where p_i represents the ith packet, $p_i(T_r)$ represents the receiving packet time, $p_i(T_s)$represents the sending packet time, and n is the total number of successfully delivered packets.

5.3. Packet Delivery Ratio. This parameter is computed among the amount of data packets successfully sent from the sources and the number of data packets received by the destinations. In this work, we consider the average packet delivery ratio, which is the average value of the packet delivery ratios of the whole traffic inside network. The fewer data loss at the receiver side of all the destinations shows that the

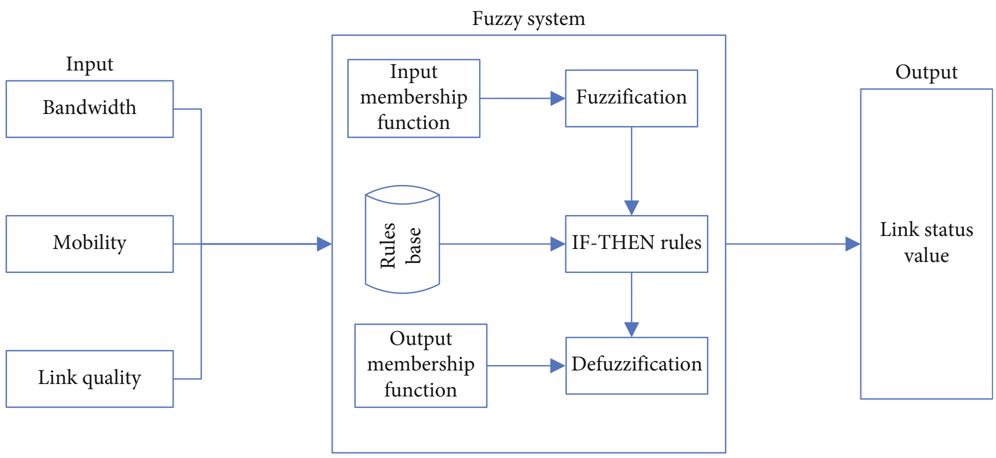


Figure 6: Fuzzy inference system.

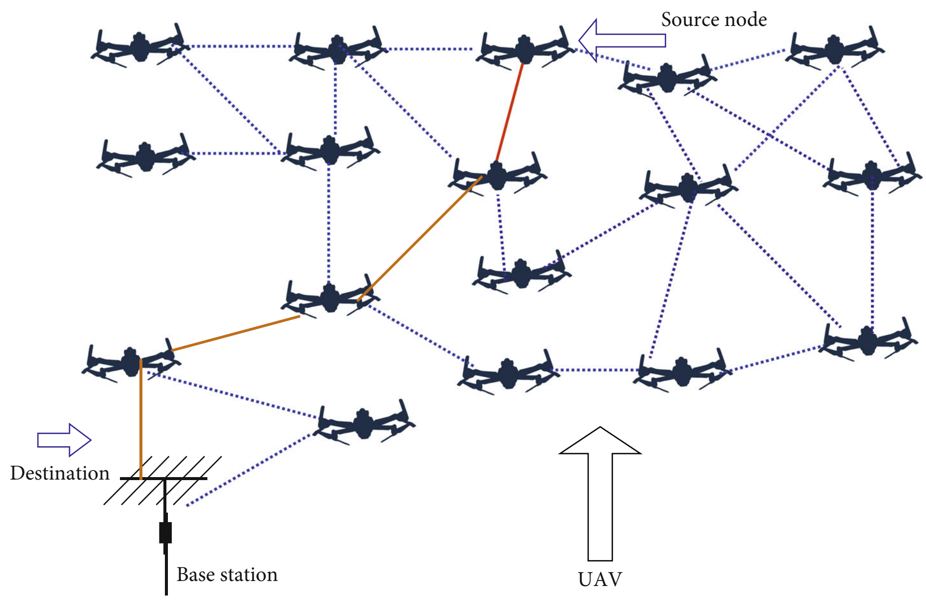


Figure 7: Simulation scenario.

Table 2: Simulation parameters.

Parameter	Values
Simulation tool	MATLAB 2013b
Simulation area	500 m * 500
Number of UAVs	100
UAV speed	100 m/s
Data rate	4, 6, 8, 10, 12, and 14 packets/s
Traffic type	CBR
CBR packets per second	10
Packet size	512 bytes
MAC layer	802.11
Protocol	Ant-Hocnet
Mobility model	Gauss-Markov

packet delivery ratio is significantly higher and the improved network performance. The formula is given as follows:

$$\mathrm{PDR} = \frac{\sum \mathrm{RP}_d}{\sum \mathrm{SP}_s} \times 100, \tag{14}$$

where RP_d is the receiving packets at destination and SP_s is the sending packets from source.

5.4. Comparison of Results and Discussion. We show the result for throughput in Figure 8. Here, FAnt-Hocnet exceptionally outperforms the Ant-Hocnet routing protocol. Ant-Hocnet shows lower throughput than FAnt-Hocnet; this is due to the fact that Ant-Hocnet does not consider UAV's bandwidth, mobility, and link quality in the routing path selection and, therefore, result in the throughput degradation. For larger packets, the FAnt-Hocnet algorithm shows higher throughput than Ant-Hocnet from the start because

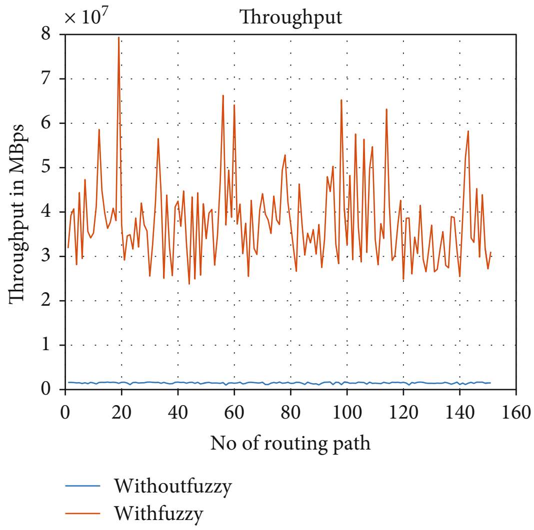


Figure 8: Throughput vs. number of routing path.

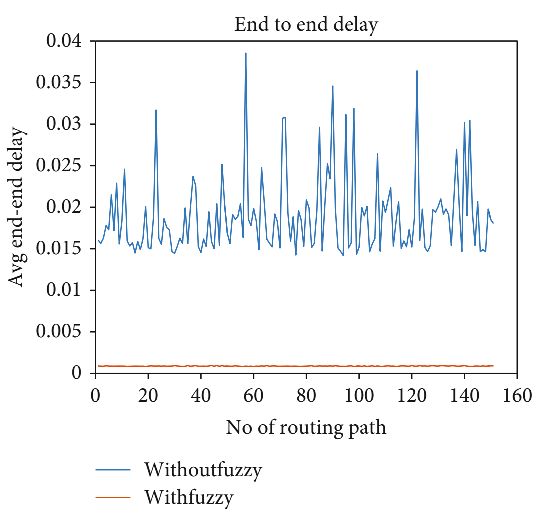


Figure 9: Avg. end-to-end delay vs. number of routing path.

FAnt-Hocnet chooses the best routing path for routing by using the fuzzy logic [24], while retransmission of larger packets due to poor-quality channel selection in the case of Ant-Hocnet degrades its throughput.

Figure 9 shows the end-to-end delay for both the schemes; the FAnt-Hocnet considers the bandwidth, mobility, and link quality which decreases the number of weak links and hence result in less end-to-end delay than Ant-Hocnet. The frequent changes in topology, route discoveries, and retransmission of larger packet result in higher end-to-end delay for Ant-Hocnet. FAnt-Hocnet decrease the end-to-end delay by choosing the fuzzy logic-based best routing path for reliable communication.

Figure 10 shows the PDR of the proposed scheme vs. the Ant-Hocnet algorithm. The FAnt-Hocnet algorithm shows higher PDR as compared to the Ant-Hocnet algorithm. For larger packet, the FAnt-Hocnet algorithm shows higher

Figure 10: PDR in % vs. number of routing path.

PDR than Ant-Hocnet from the start, because FAnt-Hocnet choose the best routing path for routing by using the fuzzy logic.

6. Conclusions

In this paper, we employ the bio-inspired Ant Colony Optimization (ACO) algorithm called "Ant-Hocnet" and propose FAnt-Hocnet routing protocol based on optimized fuzzy logic to improve routing in FANET. Fuzzy logic is used to analyze the information about the status of the wireless links, such as available bandwidth, node mobility, and link quality, and calculate the best wireless links without a mathematical model. FAnt-Hocnet being a multipath routing protocol achieves the highest throughput and low end-to-end delay especially in high network loads and high mobility as it chooses the best routing path for packet transmission. The results show that by applying the intelligence of fuzzy logic systems provides the best routing path from source to destination in a network. Thus, it provides effective and robust communication channel for packets.

In future, we intend to expand the proposed work and to measure the packet drop probability and priority-based packet reliable communication. Moreover, the security consideration will also be address in the future to prevent the malicious nodes. To reduce the congestion in FANETs, a novel smart solution will be proposed.

Data Availability

Data is available in the paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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