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**ABSTRACTS OF RESPECTIVE RESEARCH PAPERs**

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]

Flying ad-hoc networks (FANETs) have many applications in military, industrial and agricultural areas. Due to specific features of FANETs, such as high-speed nodes, low density of nodes in the network, and rapid changes in the topology, most routing protocols designed for mobile [ad hoc networks](https://www.sciencedirect.com/topics/computer-science/ad-hoc-network) (MANETs) or [vehicular ad hoc networks](https://www.sciencedirect.com/topics/computer-science/vehicular-ad-hoc-network) (VANETs) are not compatible with FANETs. In this paper, we propose a fuzzy logic-based routing approach called OLSR+ for FANETs. In this scheme, we seek to improve the optimized link state routing protocol (OLSR) so that it can efficiently be used in FANETs. OLSR+ includes four main phases: 1) Discovering neighboring nodes. In this phase, we propose a new and efficient technique for estimating the lifetime of the link between two unmanned ariel vehicles (UAVs) based on the link quality, distance, relative velocity, and movement direction. 2) Selecting multipoint relays (MPRs). In this phase, we present a fuzzy mechanism for selecting a set of [MPR nodes](https://www.sciencedirect.com/topics/engineering/relay-node). According to this mechanism, when a node has higher [residual energy](https://www.sciencedirect.com/topics/computer-science/residual-energy), higher link lifetime, and more neighborhood degree compared to others, it achieves more fitness to be selected as MPR. 3) Discovering the [network topology](https://www.sciencedirect.com/topics/computer-science/network-topology). In this phase, we modify the format of the [topology control](https://www.sciencedirect.com/topics/computer-science/topology-control) (TC) message and add two fields, including route energy and route lifetime to this message. 4) Calculating the routing table. In OLSR+, we consider two parameters, including route energy and route lifetime, for establishing stable paths. Finally, we simulate OLSR+ using [NS3](https://www.sciencedirect.com/topics/computer-science/network-simulator) and compare its performance with two methods, namely greedy optimized link state routing (G-OLSR) and optimized link state routing (OLSR). The simulation results show that OLSR+ successfully reduces delay compared to G-OLSR and [OLSR](https://www.sciencedirect.com/topics/computer-science/link-state-routing-protocol). In addition, it has higher [packet delivery](https://www.sciencedirect.com/topics/computer-science/packet-delivery) rate and throughput than others. Also, it improves energy consumption in the network. However, OLSR+ has more routing overhead than G-OLSR. [2]

Unmanned Aerial Vehicles (UAVs) bring both potential and difficulties for emergency applications, including packet loss and changes in network topology. UAVs are also quickly taking up a sizable portion of the airspace, allowing Flying Ad-hoc NETworks (FANETs) to conduct effective ad hoc missions. Therefore, building routing protocols for FANETs is difficult due to flight restrictions and changing topology. To solve these problems, a bio-inspired route selection technique is proposed for FANET. A combined trustworthy and bioinspired-based transmission strategy is developed as a result of the growing need for dynamic and adaptable communications in FANETs. The fitness theory is used to assess direct trust and evaluate credibility and activity to estimate indirect trust. In particular, assessing UAV behavior is still a crucial problem in this field. It recommends fuzzy logic, one of the most widely utilized techniques for trusted route computing, for this purpose. Fuzzy logic can manage complicated settings by classifying nodes based on various criteria. This method combines geocaching and unicasting, anticipating the location of intermediate UAVs using 3-D estimates. This method guarantees resilience, dependability, and an extended path lifetime, improving FANET performance noticeably. Two primary features of FANETs that shorten the route lifetime must be accommodated in routing. First, the collaborative nature necessitates communication and coordination between the flying nodes, which uses a lot of energy. Second, the flying nodes' highly dynamic mobility pattern in 3D space may cause link disconnection because of their potential dispersion. Using ant colony optimization, it employs trusted leader drone selection within the cluster and safe routing among leaders. a fuzzy‐based UAV behavior analytics is presented for trust management in FANETs. Compared to existing protocols, the simulated results demonstrate improvements in delay routing overhead in FANET. [3]

With the development of ad hoc network technol-ogy, unmanned aerial vehicle (UAV) swarm has demonstrated significant promise across civil and military domains. However, owing to unique attributions, such as high dynamic topology, 3-D mobility and low density, it's extremely challenging to establish a reliable and robust communication between flying nodes. In this paper, we proposed a Q-Learning and Fuzzy Logic based Routing Protocol (QFRP) for UAV networks, which adopted an efficient Q-value update mechanism based on HELLO and ACK. In this mechanism, we take neighbor set coherence and link lifetime into account. Since routing exploration has an important impact on routing performance, we proposed a fuzzy logic based mechanism for exploration and exploitation that considers Q-value, link quality and access delay to mitigate the blindness of random exploration. Simulation results demonstrate that QFRP can make efficient routing decisions within dynamic multi-hop UAV networks, and outperforms existing protocols regarding packet delivery ratio (PDR), end-to-end (E2E) delay, and routing overhead. [4]

Vehicular Ad-hoc network represents a group of mobile ad-hoc networks with the potential to enhance road safety. Every vehicle with Onboard Unit (OBU) while moving quickly, exchanges information by using Road Side Unit (RSU) with the next closest vehicle. Due to high vehicle density and high speed at which each vehicle moves and exchanges information with the next closest vehicle, the system periodically experiences packet loss and congestion. In order to provide effective management of road traffic and to reduce the frequency of road accidents, vehicle communications have gained popularity through a period. This resulted in developing intelligent transport system. Traditional swarm intelligence method such as Ant Colony Optimization algorithm (ACO) is effective for combinatorial optimization issues. Swarm Intelligence based Ant colony optimization is currently applied dynamic environment path planning to determine the most optimal, efficient, and secure routes. Typically, Ant colony optimization technique has problems and fall victim to the local optimum trap. In order to accomplish paths optimization in a dynamic environment, this research proposes an improved Ant colony optimization method that combines fuzzy logic (IACOFL) with a pheromone updating model that raises pheromone levels on edges by using unmanned aerial vehicle (UAV).This work proposes IACOFL enables to dynamically identify utmost reliable and safe route for vehicles. This results in improved performance by enhancing packet delivery ratio, end-to-end delay, and throughput in Vehicular Ad-hoc networks. MATLAB simulation is used for simulation-based testing. The packet delivery ratio and throughput of IACOFL showed a significant increase to 48.24% and 65.47% when compared to Ant colony optimization. End-to-End delay of IACOFL decreased to 50.41% when compared with Ant colony optimization. In this IACOFL, it has been found that there is gradual decrease in traffic congestion time. [5]

The communication security of [unmanned aerial vehicles](https://www.sciencedirect.com/topics/computer-science/unmanned-aerial-vehicle) (UAVs) or drones based on flying [ad hoc networks](https://www.sciencedirect.com/topics/computer-science/ad-hoc-network) (FANETs) can be enhanced and maintained by assessing vulnerabilities, threats, and attacks. Thus, trust, high mobility, and complex communication interfaces are crucial for effective coordination and segregation of malicious drones from the genuine. A new efficient honesty-based detection scheme for malicious drones has been proposed to distinguish between intentional and unintentional misbehavior of the UAVs. The proposed scheme configures a drone system for [packet transmission](https://www.sciencedirect.com/topics/computer-science/packet-transmission) within the FANET, specifying buffer size and packet size variables to control data flow and prevent congestion. It then computes energy used for [packet reception](https://www.sciencedirect.com/topics/computer-science/packet-reception) and transmission, optimizes energy consumption, and evaluates the drone’s mobility through the link stability index (LSI) and honesty UAV. The honesty UAV parameter categorizes UAVs into unintentional malicious and intentional malicious categories. Fuzzy logic helps identify intentional and unintentional misbehaving drones and improves performance in the network. It continuously generates the malicious UAV detection mechanism by assessing the parameters i.e., energy, pattern of movements, and the honesty score about the UAVs as a whole. Thereby a dynamic rating system to adeptly identify and differentiate the cooperative and non-cooperative nature of drones from the network is assimilated in the paper. Simulation results show the proposed scheme approximately aligns with the actual cases for varying numbers of malicious drones. Finally, the observation of the simulation result reflects substantial enhancement in performance metrics, with a significant cutback in [end to end delay](https://www.sciencedirect.com/topics/computer-science/end-to-end-delay) and [packet delivery ratio](https://www.sciencedirect.com/topics/computer-science/packet-delivery-ratio) by 10–30% and 20–50% respectively, contrasting with the existing techniques. [6]

The Flying Ad Hoc Networks (FANETs) are becoming more popular in civic security, military, and multipurpose applications. Owing to its wireless nature and infrastructure-less architecture, the network has some additional security concerns that must be resolved before the system performs worse. Noncooperative drones might introduce harmful and erroneous data, reducing the network's trustworthiness and throughput. Therefore, in the context of trust score, a trustworthy inter-UAV data communication can be achieved by creating a malicious node within the network. This paper describes a social trust computation scheme for clustered-based FANET, which utilises a reputable methodology to separate malicious UAVs within FANET. The mathematical analysis yielded by the proposed scheme is based on fuzzy logic, and it exhibits superior performance in terms of reliability for the existing schemes under adverse conditions. The primary goal of this research is to build social trust scores about the member drones within FANET, which will aid in isolating malicious drones and improve more than 70% accuracy in terms of the packet delivery ratio and average delay concerning other existing approaches. [7]

A proportional integral differential (PID) trajectory tracking control strategy based on fuzzy logic and RBF neural network is proposed for the trajectory stability tracking control of the quadrotor unmanned aerial vehicle (UAV) control system. Firstly, the trajectory tracking problem of UAV is transformed into the command tracking control problem of PID position control loop and PID attitude control loop by transformation. Then, the fuzzy control theory is used to adjust the PID parameter gain adaptively in real time, so as to overcome the shortcomings of the traditional PID parameters relying on experience and unable to adjust in real time according to the change of the system. At the same time, the online compensator of PID parameter gain is designed by using the attention mechanism of radial basis function (RBF) neural network, and the disturbance caused by the environmental impact of the system is suppressed by online learning and adjustment. Finally, the designed controller (RFPID) is compared with the PID controller and the fuzzy-PID (FPID) controller in three numerical simulation. The experimental results show that the proposed controller can significantly improve the robustness and accuracy of the trajectory tracking control of the quadrotor UAV. [8]

A vehicular ad hoc network (VANET) is the major element of the intelligent transportation system (ITS). The purpose of ITS is to increase road safety and manage the movement of vehicles. ITS is known as one of the main components of smart cities. As a result, there are critical challenges such as routing in these networks. Recently, many scholars have worked on this challenge in VANET. They have used machine learning techniques to learn the routing proceeding in the networks adaptively and independently. In this paper, a Q-learning and fuzzy logic-based hierarchical routing protocol (QFHR) is proposed for VANETs. This hierarchical routing technique consists of three main phases: identifying traffic conditions, routing algorithm at the intersection level, and routing algorithm at the road level. In the first phase, each roadside unit (RSU) stores a traffic table, which includes information about the traffic conditions related to four road sections connected to the corresponding intersection. Then, RSUs use a Q-learning-based routing method to discover the best path between different intersections. Finally, vehicles in each road section use a fuzzy logic-based routing technique to choose the foremost relay node. The simulation of QFHR has been executed on the network simulator version 2 (NS2), and its results have been presented in comparison with IRQ, IV2XQ, QGrid, and GPSR in two scenarios. The first scenario analyzes the result based on the packet sending rate (PSR). In this scenario, QFHR gets better the packet delivery rate by 2.74%, 6.67%, 22.35%, and 29.98% and decreases delay by 16.19%, 22.82%, 34.15%, and 59.51%, and lowers the number of hops by 6.74%, 20.09%, 2.68%, and 12.22% compared to IRQ, IV2XQ, QGrid, and GPSR, respectively. However, it increases the overhead by approximately 9.36% and 11.34% compared to IRQ and IV2XQ, respectively. Moreover, the second scenario evaluates the results with regard to the signal transmission radius (STR). In this scenario, QFHR increases PDR by 3.45%, 8%, 23.29%, and 26.17% and decreases delay by 19.86%, 34.26%, 44.09%, and 68.39% and reduces the number of hops by 14.13%, 32.58%, 7.71%, and 21.39% compared to IRQ, IV2XQ, QGrid, and GPSR, respectively. However, it has higher overhead than IRQ (11.26%) and IV2XQ (25%). [9]

In-Flight Wi-Fi connectivity (IFC) paves way for supporting the Internet of Things over the clouds by connecting things inside a moving aircraft to the ground. Aeronautical Ad hoc Networks (AANET) is a new breed of Mobile Ad hoc networks envisioned to experience IFC over remote or oceanic regions. Due to the challenging characteristics of AANET such as limited bandwidth, intermittent connectivity, dynamic topologies, the greater velocity of aircraft, and variable geographical network sizes, it is very hard to design a realistic mobility model and network routing with remarkable Quality of Service (QoS) and requires immediate research solution. As the complexity of provisioning QoS network services significantly relies on the routing layer, this work aims at providing intelligent, reliable, and efficient data delivery with ensured QoS. In the aim of attaining a solution for QoS routing, this paper presents twofold design strategies. Firstly, the mobility of moving aircraft is modeled with International Civil Aviation Organization separations standards to avoid collisions among moving aircrafts, second is, a novel hybrid approach combining deep learning and fuzzy logic is proposed to deal with highly dynamic nature and growing air traffic. The neighbor discovery phase of existing routing protocols incurs more packet overhead and delay because of the traditional beaconing method, which is overcome in this work by using Automatic Dependent Surveillance-Broadcast as it is kept on broadcasting the neighbor’s information in the cockpit display of every aircraft. To avoid the overwhelming of nodes, this work uses queuing delay of the neighbors to identify the node’s ability for packet transmission fairly distributes the load among aircrafts. The simulation results show that the proposed work provides notable improvements in packet delivery ratio, end-to-end delay, and traffic overhead compared to the existing routing protocols in sparse and dense network scenarios. [10]

Flying ad hoc networks (FANETs) are showing promise in a variety of unmanned aerial vehicle application situations, such as urban surveillance or search as well as rescue operations. These networks, however, provide a unique set of communication challenges. This has led to several studies looking at how they function in a simulated environment. Even while various models of mobile node behavior in an ad-hoc network exist, most of them cannot be relied upon to accurately imitate the movements of unmanned aerial vehicles unless they are properly modeled. Small unmanned aerial vehicles (UAVs) may be used to create flexible, low-cost, and fast-to-deploy FANETs. Because of this, they are a highly sought-after technology for both civilian as well as military use. Recent years have seen a fast evolution in UAV capabilities and functions, and their widespread use in both the military and civilian sectors as a consequence of technological advancements in robotic systems like processors, sensors, and communications. Costs for the development and maintenance of UAVs are falling as technology advances. The employment of a single big UAV is being phased out in favor of many UAVs working together in teams to accomplish higher-level objectives. Because of the great mobility of UAVs in a fleet, new networking models must be developed that can be deployed on these mobile nodes. Any two nodes in the communication range of such networking models may connect directly, or indirectly via a no. of relay nodes, such as UAVs. Establishing an ad-hoc network between flying UAVs is a difficult task, and the requirements might vary from those of conventional networks, MANETs, including VANETs in terms of node mobility, connection, message routing, service quality, wide applications, & so on. [11]

Flying Ad-Hoc Network (FANET) is a set of Unmanned Aerial Vehicles (UAVs) inter-connected wirelessly. FANETs self-organize and provide low-cost, adaptable, and simple-to-implement flying nodes, enabling them to complete complicated tasks more quickly and collectively. The high mobility of nodes and the highly dynamic topology pose challenges to communication design, particularly when creating a routing protocol for UAV networks; this has inspired researchers to contribute and develop this technology. Hierarchical routing technique known as clustering is necessary to offer scalability, survivability, and distribute payload among UAVs to maintain the performance. This study has proposed a comprehensive survey of the cluster-based routing protocols (CBRPs) in terms of their strengths, weaknesses, specific applications, method, number of nodes, and future improvements for serving FANETs. Moreover, 21 CBRPs based FANETs were reviewed in terms of their topology, challenges, scalability, characteristics, clustering strategy, outstanding features, cluster head (CH) selection, routing metrics, and performance measures. In addition, open issues that need to be addressed in future studies in the field of routing protocols for UAV networks were also debated. [12]

The emissions that aircraft discharge into the atmosphere are growing daily as a result of advancements in the aviation sector and an increase in air traffic. For this reason, studies on the use of more electricity in the field of aviation have also increased. Development in battery technologies accelerates the transition to electric systems. Hybrid systems are preferred to increase the system efficiency and to ensure longer lifespan of energy sources. With this motivation, a hybrid Unmanned Aerial Vehicle (UAV) system in which Fuel Cell (FC) is the main power source and Lithium Ion (Li-ion) battery assists FC in sudden power changes is modelled and analyzed in Matlab/Simulink environment. In hybrid systems, Energy Management System (EMS) is needed to control energy resources and increase the efficiency of the UAVs. In this study, three different EMS structures in UAVs, including rule-based Thermostat on/off, classical and Type-II fuzzy logic are analyzed in detail. These EMS methods are modeled and examined for the hybrid UAV system. The unique value of this study is to apply three different EMS methods to a UAV powered by a fuel cell and Li-ion battery. An important contribution has been made to researchers that the preferred EMS method may be different depending on the system to be used and the number of resources. Although Type-II fuzzy logic EMS gives better results, it is more complex and the decision-making time is longer. For this reason, traditional fuzzy logic EMS is more widely used in most applications. [13]

The emergence and development of FANET (Flying Ad hoc Network) have contributed to the advancement of technologies in many fields, allowing communication without the need for infrastructure. FANET is an ad hoc network that uses unmanned aerial vehicles (UAVs) to communicate and provide various services. In this case, drones can access a wide range of services like internet access, information, storage, and computing as a service thanks to UAV cloud. But given the high random Because of their mobility, client drones must first identify service providers who can meet their needs before they can use the necessary services. In this project, we propose a new approach called FL\_DS, which uses fuzzy logic to solve decision making problems and improve the selection of the best services for UAV clients. This proposed approach is compared with another approach, Simple Additive Weighting (SAW). We utilized the OMNeT++ simulator with the INET framework to create a robust simulation environment. The results demonstrated the effectiveness of fuzzy logic in enhancing network resource management and service quality in FANET [14]

Flying Ad-hoc Networks (FANET) allow for an ad-hoc networking among Unmanned Aerial Vehicles (UAV), have recently gained popularity in a variety of military and non-militant applications. The existing work used the Glowworm Swarm Optimization (GSO) algorithm to create a self-organization depending on clustering technique for FANET. Owing to UAV increased mobility, network topology might vary over time, providing route discovery and maintenance is one of the most difficult tasks. And also, the network throughput is still more worsened by the network congestion. To solve this problem, the proposed work designed an energy efficient clustering and fuzzy-based path selection for FANET. In this work, initially, the clustering is performed using the UAV distance. For efficient communication and energy consumption, optimal selection of Cluster Head (CH) is performed by using Adaptive Mutation with Teaching-Learning-Based Optimization (AMTLBO) algorithm. To improve the optimal selection of CH nodes, the best fitness values are calculated. The fitness function depends on Link capacity, remaining energy and neighbor UAV distance. Next to that, nodes begin communications as well as transmit their information to their CH. Improved Fuzzy-based Routing (IFR) is introduced for improving the route discovery process. The goal is to find routes that have a high level of flying autonomy, minimal mobility, and a higher Received Signal Strength Indicator (RSSI). As a result, the energy usage of network is decreased, as well as the cluster’s lifespan is extended. Finally, an adaptive and reliable congestion detection mechanism is introduced to transmit the packets with congestion free path. The experimental result shows that the proposed AMTLBO system attains higher performance compared to the existing system in terms of energy usage, throughput, delay, overhead and packet delivery ratio. [15]

Flying Ad hoc Network (FANET) is a self-organizing wireless network that constitutes swarms of flying nodes, namely Unmanned Aerial Vehicles (UAV), and communicates in close proximity. It has various distinguishing characteristics that set it apart from other ad hoc networks, posing some issues, particularly in routing. UAVs are highly dynamic and have frequent topology changes. Hence, the network urges an efficient routing technique to coordinate the node swarms and enhance the evaluation metrics of the network. The biological behavior of various living organisms, such as animals, insects, microbes, and humans, inspires researchers to solve various routing problems in ad hoc networks. Decentralized self-organized swarms of UAVs closely resemble the biological system. Therefore, the Bio-Inspired Algorithms (BIA) resolve a wide range of routing challenges in FANET. A Systematic Literature Review (SLR) is adopted to survey FANET routing methods based on non-hybrid and hybrid BIAs to properly comprehend the existing bio-inspired strategies used in FANET routing. The review will be beneficial for the researchers in the specified area. To our knowledge, no SLR has been conducted about the FANET routing protocol that employs BIA. This paper examines 1) the characteristics and features of existing routing algorithms, 2) the need of both non-hybrid and hybrid BIA for effective and optimal routing, 3) an analysis of the method’s simulation tools, evaluation metrics and mobility models, 4) the current issues and scope of the study related to the specified method. [16]

The newest research topic is flight ad hoc network (FANET). The primary obstacles faced by unmanned aerial vehicles (UAVs) are their limited flight duration and inefficient routes resulting from their great mobility and low battery power. Compared to MANETs or VANETs, FANETS routing is thought to be more difficult because of these topological restrictions. Artificial intelligence (AI)-based clustering techniques can be applied to resolve intricate routing issues in situations when both static and dynamic routing are ineffective. To overcome these path difficulties, clustering techniques based on evolutionary algorithms, including intelligent, probabilistic, bio-inspired whale optimization algorithms (*p*-WOAs), we suggest fuzzy-logic-based zonal clustering-based routing algorithms in this study to be used in FANET to build clusters. In addition to requiring fewer cluster heads (CHs) for routing, *p*-WOA offers good coverage and low energy consumption. The stochastic whale optimization technique, which draws inspiration from nature, is utilized in this paper to build networks and deploy nodes. The next step is to choose cluster heads using a region clustering technique based on fuzzy logic. By selecting the right cluster head, you can decrease routing traffic and increase cluster longevity. Routing overhead is also decreased. The data are then sent to the best path using a reference point group mobility model. The proposed *p*-WOA was used to test fuzzy integral and fuzzy logic ant optimization, fuzzy integral and neural network interference system, fuzzy integral and whale optimization algorithm (ANFIS-WOA), and fuzzy integral and FL-ALO. An array of indicators, such as cluster count, longevity, cluster configuration time, cluster head consistency, and energy usage, are employed to assess the effectiveness of the suggested methodology. The suggested algorithm works better than the most advanced techniques available today, as demonstrated by the experimental findings presented in this paper. [17]

Today, unmanned aerial vehicles (UAVs), also known as drones, have become very popular in military applications, commercial applications, and academic research. Flying ad hoc network (FANET) is a new type of ad hoc network, which groups small drones into an ad hoc form. These networks have unique characteristics, including moving in a 3D space, high mobility, frequent topological changes, limited resources, low density of nodes, and so on, which impose various challenges when designing a proper and efficient routing scheme. In this paper, we present a fuzzy logic-based routing scheme for flying ad hoc networks. The proposed routing scheme has two phases: route discovery phase and route maintenance phase. In the first phase, we propose a technique for calculating the score of each node in the network to prevent the broadcast storm problem and control the flood of the control messages, which have been broadcast to discover a new route in the network. This score is calculated based on various parameters such as movement direction, residual energy of nodes, link quality, and node stability. Moreover, in the route selection process, we design a fuzzy system to select routes with more fitness, less delay, and fewer hops for data transfer. The second phase includes two steps: preventing route failure in order to detect and modify paths at the failure threshold, and reconstructing failed routes in order to recognize and quickly replace these routes. Finally, the proposed routing scheme is implemented in NS2 to evaluate its performance and determine its efficiency. The simulation results are compared with three routing methods, namely ECaD, LEPR, and AODV. These results show that the proposed routing method outperforms other routing schemes in terms of end to end delay, packet delivery rate, route stability, and energy consumption. However, it has slightly increased the routing overhead. [18]

An extremely high number of geographically dispersed, energy-limited sensor nodes make up wireless sensor networks. One of the critical difficulties with these networks is their network lifetime. Wirelessly charging the sensors continuously is one technique to lengthen the network’s lifespan. In order to compensate for the sensor nodes’ energy through a wireless medium, a mobile charger (MC) is employed in wireless sensor networks (WRSN). Designing a charging scheme that best extends the network’s lifetime in such a situation is difficult. In this paper, a demand-based charging method using unmanned aerial vehicles (UAVs) is provided for wireless rechargeable sensor networks. In this regard, first, sensors are grouped according to their geographic position using the K-means clustering technique. Then, with the aid of a fuzzy logic system, these clusters are ranked in order of priority based on the parameters of the average percentage of battery life left in the sensor nodes’ batteries, the number of sensors, and critical sensors that must be charged, and the distance between each cluster’s center and the MC charging station. It then displays the positions of the UAV to choose the crucial sensor nodes using a routing algorithm based on the shortest and most vital path in each cluster. Notably, the gradient-based optimization (GBO) algorithm has been applied in this work for intracluster routing. A case study for a wireless rechargeable sensor network has been carried out in MATLAB to assess the performance of the suggested design. The outcomes of the simulation show that the suggested technique was successful in extending the network’s lifetime. Based on the simulation results, compared to the genetic algorithm, the proposed algorithm has been able to reduce total energy consumption, total distance during the tour, and total travel delay by 26%, 17.2%, and 25.4%, respectively. [19]

Due to the noncentered, self-organizing, and self-healing characteristics, mobile ad hoc networks (MANET) have been more and more widely used as an alternative access technology for regions having no fixed infrastructure. On-demand routing protocols (e.g., ad hoc on-demand distance vector (AODV)) are used to cope with the rapidly changing topology of MANET and reduce the network overhead. Taking delay, stability, and remaining energy of nodes into consideration, a fuzzy-logic-assisted AODV (FL-AODV) routing algorithm is proposed in this paper to further improve the reliability of the route in MANET. In the route discovery phase, the node with the highest reliability is selected as the relay node, and the route with the highest accumulated reliability is reserved for data transmission. Simulation results show that, compared with the traditional AODV protocol and the fuzzy logic routing algorithm (FLRA), the proposed routing protocol has higher reliability without increasing delay, i.e., better link connectivity and longer route life. The average routing reliability is about 18% higher than AODV while the average delay is the same low when the number of node greater than 70.

[20]

**SUMMARY**

* **Introduction To Fuzzy Logic In UAV Networks**

**[1]**

Picture a busy sky with drone aircraft, all talking to one another and having to communicate with each other seamlessly. This is the domain of UAV network routing protocols. These protocols and techniques help drones exchange information, form dynamic networks (so-called Flying Ad-hoc Networks or FANETs) and successfully execute their missions. Due to the special requirements of FANETs—such as the high-speed mobility of drones, dynamic network topology, limited battery life, and the need for secure communication—traditional networking techniques are not effective. That is why we have created specialized techniques to address these requirements.

And then there's an added level of complexity with the three-dimensional flight of UAVs and whatever airspace restrictions they're subject to. It's not just a question of where drones are on a two-dimensional map; there's altitude and airspace regulations too. This 3D environment complicates things in trying to find the most efficient paths for information to travel. And then, too, these networks tend to be sparse, i.e., few drones are close to one another to serve as relays. Picture trying to get a message across an open field where only a few people are scattered. You might have to throw the message quite a distance, and there's no guarantee someone will catch it who can relay it on.

One of the key areas of study is adapting the current routing protocols designed for ground mobile networks (MANETs) to accommodate the quickly evolving FANET environments. As an example, the Optimized Link State Routing (OLSR) protocol has been optimized using fuzzy logic to improve predicting the feasibility of the communication links and choosing more trustworthy relay nodes. The fuzzy approach takes into account factors like signal power, relative motion among the drones, and available bandwidth in order to make more logical routing decisions.

Nature-inspired and bio-inspired routing protocols provide sturdy solutions to the decentralized and self-organizing aspect of UAV swarms. An example of such is the Ant Colony Optimization (ACO) algorithm that emulates ants finding the shortest routes to find effective routes among drones. ACO is often accompanied by fuzzy logic to analyze wireless link quality based on bandwidth, node mobility, and reliability of the links to guide the "ant" agents to the optimal routes. Bio-inspired mechanisms using glowworms or the behavior of whales are also researched to obtain efficient clusters and conserve energy while routing.

With the ability to deal with vagueness, fuzzy logic-based routing techniques utilize fuzzy inference systems to attain intelligent routing. These systems can balance multiple simultaneous, generally conflicting variables—network traffic, link quality, node battery, and expected link life—to determine a "fitness" value for potential next-hop nodes. The node with the highest fuzzy score is then used to send the data, yielding more responsive and context-aware routing in a dynamic network environment.

Machine learning is also gaining more and more prominence in UAV network routing. Methods such as Reinforcement Learning (RL), especially Q-Learning, are becoming popular. With these methods, a UAV learns optimal routing policies by trial-and-error experience with its network in an effort to optimize parameters such as delay, packet delivery ratio, and energy consumption. Fuzzy logic is generally used in conjunction with Q-Learning to deal with the complexity of the network state, which improves the exploration and exploitation of different routing paths, thereby making routing protocols efficient and responsive.

Finally, clustering-based routing techniques solve the scalability problem in large FANETs by grouping the UAVs into logical clusters. A cluster can have a leader drone that handles local communication and routing, while inter-cluster routing is performed by the leaders. This reduces the overall routing complexity and improves efficiency. The cluster leaders can be selected from a list of criteria, such as their reliability and energy efficiency, and overall by using fuzzy logic or bio-inspired algorithms such as ACO to make efficient and optimal decisions and cluster formation.

**[2]**

Ad-hoc networks (FANETs) are also demonstrated to be of great utility in numerous application domains, such as military, industrial, and agricultural. However, due to the unique nature that FANETs have—such as the node high-speed dynamics, reduced network node density, and time-varying network topology with increased frequency—most of the current routing protocols that have the potential to be employed for mobile ad hoc networks (MANETs) or vehicular ad hoc networks (VANETs) simply do not apply to FANETs.

Here in this paper, we introduce a novel routing mechanism called OLSR+, fuzzy logic-based and specially for FANETs. Our target is to enhance the optimized link state routing protocol (OLSR) so that it can operate efficiently in such dynamic networks. OLSR+ progresses through four broad phases:

1. Neighbour Node Identification: In this paper, a new and efficient method of estimating the lifetime of a link between two unmanned aerial vehicles (UAVs) is presented. It is estimated based on link quality, distance, relative speed, and direction of travel.

2. MPR Selection: We use a fuzzy logic process during this step where we choose a set of MPR nodes. The criterion is that if a node has more residual energy, longer link life, and larger neighbourhood degree than others, then it will be more likely to be chosen as an MPR.

3. Network Topology Discovery: We add two new fields to the topology control (TC) message format: route energy and route lifetime. This addition enhances the information that is being shared in the network.

4. Routing Table Calculation: We consider route energy and route lifetime in OLSR+ to stabilize routes.

In order to confirm our method, we simulated in NS3, where we compared OLSR+ with two other protocols, namely greedy optimized link state routing (G-OLSR) and the conventional optimized link state routing (OLSR). The outcome revealed that OLSR+ significantly minimizes delays over both G-OLSR and OLSR, provides a better packet delivery ratio, and enhances throughput in the network. It also enhances energy consumption but with a slightly higher routing overhead than G-OLSR.

In general, OLSR+ is a promising solution for FANET routing, which tackles the special challenges of such networks.

[3]

Unmanned Aerial Vehicles (UAVs) hold great promise for use in emergency response, but they also have their own sets of challenges, including packet loss and dynamic topologies. With UAVs taking up more and more of the airspace, they open the door for Flying Ad-hoc Networks (FANETs) to perform effective and dynamic missions. Developing effective routing protocols for FANETs, though, is quite very complex, particularly with flying constraints and dynamic topologies.

To overcome these challenges, we have proposed a bio-inspired route selection method for FANETs. The method is based on the growing need for adaptive and dynamic communications in such networks. By combining a trustful transmission mechanism with bio-inspired principles, we are able to enhance the communication process.

We measure direct trust in terms of fitness theory, which enables us to measure credibility and activity so that we can estimate indirect trust. One of the biggest hurdles in this research is measuring the behavior of UAVs accurately, and that's where fuzzy logic comes into the picture. This widely used mechanism of computing the level of trust can efficiently control complex environments by classifying nodes according to diverse criteria.

Our approach synergistically combines geocaching with unicasting, leveraging 3D estimates to forecast the positions of intermediate UAVs. Consequently, we can guarantee higher resilience, reliability, and longer lifetimes of paths, resulting in substantial improvement in FANET performance. FANET routing also needs to solve two major challenges that can cut short route lifetimes. First, the cooperative behavior of UAVs demands regular communication and coordination among aerial nodes, which can drain energy. Second, the mobility patterns of such air units in 3D space can cause link breakages due to their possible divergence.

To address these issues, we apply ant colony optimization to choose reliable leader drones within clusters and offer secure routing between them. In addition, we suggest a fuzzy-based UAV behaviour analytics system to have effective trust management in FANETs. Our simulation result shows that the new strategy performs better than the existing protocols, particularly in terms of delay reduction and routing overhead. Overall, we are excited about the potential boost this can bring in FANET operations.

[4]

The development of ad hoc network technology also brings great potential to unmanned aerial vehicle (UAV) swarms, and they become valuable resources for civilian and military applications. However, it is truly a tremendous challenge to ensure reliable and robust communication among flying nodes under the impact of high dynamic topology, 3D mobility, and low node density.

In this paper, we propose a new routing protocol for UAV networks, which we refer to as the Q-Learning and Fuzzy Logic-based Routing Protocol (QFRP). The new protocol exploits an effective Q-value update mechanism that utilizes HELLO and ACK packets with neighbor set consistency and link lifetime in mind. Following the principle that good routing discovery is the key to network effectiveness, we have also proposed a fuzzy logic mechanism to balance exploration and exploitation. The mechanism considers Q-value, link quality, and access delay to minimize the randomness inherent in routing decisions.

Our simulation shows the advantages of QFRP, with evidence that it can make efficient routing decisions in dynamic multi-hop UAV networks. Compared to the state-of-the-art protocols, QFRP is better with respect to most of the important performance measures like packet delivery ratio (PDR), end-to-end (E2E) delay, and routing overhead. Our general conclusions suggest that QFRP offers much improved communication efficiency for UAV networks, thus ensuring safer and more efficient operation.

[5]

Vehicular Ad-hoc Networks (VANETs) are a mobile network of nodes with immense scope to enhance road safety. Each vehicle equipped with an Onboard Unit (OBU) exchanges messages with the nearest vehicles via Road Side Units (RSUs) while in motion at high speeds. The rapid movement and high density of vehicles pose issues like packet loss and congestion, making communication challenging.

In an attempt to better control road traffic and decrease the accident rate, automobile communications have been on the increase and have served as the basis for intelligent transport systems to be created. Conventional swarm intelligence methods, such as the Ant Colony Optimization (ACO) algorithm, have been effective for addressing combinatorial optimization problems. ACO has been used in dynamic path planning to calculate the most efficient, optimal, and secure routes.

Although it is useful, the ACO approach gets stuck in local optimums. To improve path optimization in a dynamic environment, this paper introduces a new Ant Colony Optimization approach based on fuzzy logic (IACOFL) with a supporting pheromone update model. This introduces a pheromone boost in edges with the help of unmanned aerial vehicles (UAVs).

The IACOFL algorithm computes the safest and most reliable paths for vehicles dynamically, and this results in performance improvements that are very real. Our results indicate end-to-end delay, packet delivery ratio, and total throughput improvements for VANETs. In our MATLAB simulations, IACOFL improved packet delivery ratio by 48.24% and throughput by 65.47% over standard ACO. The end-to-end delay of IACOFL also decreased by 50.41% over ACO. Overall, IACOFL has also reduced traffic congestion time over time, thus making it a suitable solution to enhance vehicle communication.

[6]

Improving communication security of unmanned aerial vehicles (UAVs) or drones operating in flying ad hoc networks (FANETs) is at the core of their successful deployment. This is done by examining vulnerabilities and possible threats and attacks. Parameters in this case include trust, high mobility, and complicated communication interfaces that are of utmost significance in distinguishing malicious drones from authentic drones.

In order to address this problem, we have proposed a new, efficient honesty-based detection mechanism for identifying intentional and unintentional UAV misbehavior. The mechanism establishes a drone system for packet transmission in the FANET by specifying parameters like buffer size and packet size to manage data transmission efficiently and prevent congestion.

The system also computes energy usage on packet reception and transmission, optimizing energy consumption while computing mobility of drones using measurements such as the link stability index (LSI) and honesty scores. Categorizing UAVs into classes of unintentional and intentional malicious drones assists us in correctly measuring their behavior. Fuzzy logic is employed to aid in the detection of such misbehaviors, hence optimizing the entire network performance. Our rating mechanism monitors dynamic parameters such as energy levels, movement profiles, and honesty scores of all UAVs in real time, enabling us to identify well cooperative from non-cooperative drones in the network. Simulation outcomes indicate that our proposed scheme replicates real-life scenarios even when malicious drones fluctuate in numbers.

Surprisingly, the simulations show considerable improvement in performance measures, with 10-30% and 20-50% reduction in end-to-end delay and packet delivery ratios, respectively, compared to existing solutions. These results demonstrate the efficiency of our solution to enhance the security and performance of UAV communications in FANETs.

[7]

Flying Ad Hoc Networks (FANETs) are becoming increasingly popular in domains such as public safety, military, and numerous other applications. Yet their wireless, infrastructure-less topology introduces certain new security issues that we need to address to ensure system performance. Noncooperative unmanned platforms, for example, can inject spurious or malicious information into the network, which can violate trust and impact throughput.

To address these challenges, this paper suggests a social trust computation scheme for clustered FANETs. The scheme is based on a strong mechanism for identifying and isolating malicious drones, enhancing the overall security of the network. Our mathematical analysis is based on fuzzy logic and is far more reliable compared to the solutions suggested previously, even in poor conditions. The main objective of this research is to obtain social trust scores for member drones in the FANET. By doing this, we can effectively isolate malicious drones from the network, which provides more than a 70% improvement compared to other existing techniques in packet delivery ratios and average delays. This not only enhances trust but also leads to smoother operation in the FANET environment.

[8]

We are presenting a new control method for quadrotor UAV trajectory tracking using Proportional Integral Differential (PID) control with fuzzy logic and a Radial Basis Function (RBF) neural network. Attempting to address the problem of trajectory tracking, we initially transform the problem into a command tracking control problem of both the PID position and attitude control loops.

Then, we use fuzzy control theory to adaptively modulate the PID parameters in real-time. With this adaptive process, one of the biggest weaknesses of the conventional PID controllers is addressed, i.e., their use of fixed parameters that cannot adapt to changing conditions in the system as and when they arise. We also use the attention mechanism of the RBF neural network to create an online compensator for the PID gains. This process reduces disturbances due to environmental conditions through continuous learning and self-tuning.

To illustrate the performance of our RFPID controller, we used three numerical simulations to compare the performance of the RFPID controller with those of conventional PID and fuzzy-PID (FPID) controllers. The results show that the RFPID significantly enhances quadrotor UAV trajectory tracking robustness and accuracy. This increase is a future improvement in UAV control systems that makes them efficient and reliable to use in any flight conditions.

[9]

A vehicular ad hoc network (VANET) is a core part of the intelligent transportation system (ITS), which is intended to improve road safety and control the movement of vehicles. As a core part of smart cities, ITS has to deal with many challenges, especially routing in the networks. Researchers have been applying machine learning methods in recent times to address these routing problems, enabling the networks to learn and adapt on their own.

In this paper, we introduce a new VANET routing protocol, i.e., Q-learning and fuzzy logic-based hierarchical routing (QFHR). The procedure consists of three key stages: traffic condition evaluation, implementation of routing algorithm at the intersection level, and implementation of routing algorithm at the road level.

In the initial phase, all RSUs keep a traffic table containing information about four road segments pertaining to the corresponding intersection. Next, RSUs use a Q-learning-based routing mechanism to determine the best path among different intersections. Finally, vehicles on every road section use a fuzzy logic-based approach to select the best relay node for communication.

We compared QFHR with a number of other protocols, such as IRQ, IV2XQ, QGrid, and GPSR, in two scenarios. In the first scenario, in which the packet sending rate (PSR) was the emphasis, QFHR improved the packet delivery rate by 2.74%, 6.67%, 22.35%, and 29.98%, and reduced delays by 16.19%, 22.82%, 34.15%, and 59.51%, and reduced hops by 6.74%, 20.09%, 2.68%, and 12.22% compared to IRQ, IV2XQ, QGrid, and GPSR, respectively. It did, however, increase overhead to a small extent—approximately 9.36% and 11.34% compared to IRQ and IV2XQ.

In the second case, when the signal transmission radius (STR) was taken into account, QFHR increased the packet delivery ratios (PDR) by 3.45%, 8%, 23.29%, and 26.17%. It decreased the delay by 19.86%, 34.26%, 44.09%, and 68.39%, and the number of hops by 14.13%, 32.58%, 7.71%, and 21.39% in comparison to the respective protocols. Keeping that in mind, it had a greater overhead than IRQ (11.26%) and IV2XQ (25%).

In summary, our QFHR protocol exhibits potential breakthroughs in VANET routing that redefine the limits of enhancing traffic management in smart cities.

[10]

In-Flight Wi-Fi connectivity (IFC) is providing new opportunities for connecting the Internet of Things (IoT) in the air, linking devices in moving aircraft to the ground. Aeronautical Ad hoc Networks (AANET) are a new concept in Mobile Ad hoc Networks, namely to handle IFC in remote or over-ocean areas. However, AANETs come with their own set of problems, including low bandwidth, intermittent connectivity, rapid-changing topologies, high-speed aircraft, and varying geographical network sizes. These factors make it very difficult to design an efficient mobility model and network routing system that offers an excellent Quality of Service (QoS), which highlights the need for immediate research.

As the specifics of QoS delivery rely significantly on the routing layer, our contribution is to design a data delivery mechanism that is resilient, intelligent, and efficient, and provides QoS guarantees. To this purpose, this paper introduces two primary design approaches. First, we simulate the trajectories of airplanes based on the International Civil Aviation Organization's separation standards to avoid mid-air collisions. Second, we introduce a novel hybrid approach that combines deep learning with fuzzy logic to address the highly dynamic nature of air traffic.

One of the major issues of current routing protocols is the neighbour discovery phase, which is mostly accountable for higher packet overhead and latency via conventional beaconing techniques. We address this by using Automatic Dependent Surveillance-Broadcast, which continues to broadcast neighbours' details on the cockpit display of each aircraft. To avoid nodes from getting overloaded, we also use queuing delay metrics of nearby aircraft to quantify their packet transmission capacity so that the load is evenly distributed among them.

Simulation outcomes indicate that our solution significantly improves the packet delivery ratio, minimizes end-to-end delays, and minimizes traffic overhead over current routing protocols, both in sparse and dense network conditions. This improvement indicates a promising direction toward optimizing AANETs for reliable in-flight connectivity.

[11]

Flying ad hoc networks (FANETs) are found to be highly valuable in a very broad array of applications of unmanned aerial vehicles (UAVs), including surveillance in cities and search and rescue. However, the networks themselves also possess unique communication problems that researchers are eager to overcome. As such, a number of studies have focused on studying their behaviors within simulator environments. Despite the fact that there are several models out there for the behavior of mobile nodes in ad hoc networks, they are unable to model UAV behavior unless specifically adapted to do so. Small UAVs overall are an attractive choice to construct low-cost, highly flexible, easily deployable FANETs and thus a favorite of civilian and military end-users alike.

Over the past few years, we've seen a very fast development of UAV capability and functionality, fueled primarily by advances in robotics technologies, including better processors, sensors, and communications. As technology continues to advance, the cost of developing and sustaining UAVs is coming down. This change has led to a transition from using a single large UAV to using a swarm of small UAVs that can work together to accomplish more sophisticated objectives.

As UAV fleets are extremely mobile, we need to design new models of networking that can effectively function on these dynamic mobile nodes. In these models, two nodes within proximity can communicate directly or indirectly through a number of relay nodes, such as other UAVs. It is extremely challenging to establish an ad-hoc network among air-based UAVs and their demands are quite different from those of conventional networks, MANETs, and VANETs. Key parameters such as node mobility, connectivity, message routing, quality of service, and large-scale applications must be considered.

[12]

A Flying Ad-Hoc Network (FANET) is a collection of networked Unmanned Aerial Vehicles (UAVs) that exchange information with one another through the air. FANETs are self-organizing networks, so they are low-cost, flexible, and simple to deploy, enabling UAVs to perform complex operations more efficiently and cooperatively. Nevertheless, the high mobility of nodes and dynamic network topology pose tremendous challenges to communication design, particularly designing efficient routing protocols for UAV networks. This dynamic nature has inspired researchers to make breakthroughs in this area.

To counteract such challenges, a hierarchical routing technique known as clustering is imperative. Clustering improves survivability and scalability and loads the UAVs evenly for better performance. This paper presents a detailed survey of cluster-based routing protocols (CBRPs), including their advantages, disadvantages, applications, techniques, and number of nodes, and potential future work for FANETs.

In total, we assessed 21 CBRPs and analyzed several parameters like topology, problems, scalability, features, clustering mechanisms, important features, cluster head (CH) election, routing parameters, and performance parameters. In addition, we also addressed open issues that need to be addressed by future research in the case of UAV network routing protocols. This comprehensive analysis will yield useful insights for further development of FANET technologies.

[13]

With the evolution of the aviation sector and increased air traffic, aircraft emissions are also increasing. This has created an increasing demand to find more electric options for aviation. Enhanced battery technology is paving the way for a shift to electric systems, yet hybrid systems are the best option available now to optimize efficiency and extend the life of energy sources.

Keeping this in mind, we have designed and simulated a hybrid Unmanned Aerial Vehicle (UAV) system with a Fuel Cell (FC) as the primary power source and a Lithium-Ion (Li-ion) battery as a backup to the FC in the event of sudden power fluctuations. This has been done in the MATLAB/Simulink platform. In hybrid systems, for optimal efficiency, an Energy Management System (EMS) is crucial in managing the energy sources. Our contribution is a more detailed study of three different EMS architectures for use in UAVs: a rule-based thermostat on/off system, conventional fuzzy logic, and Type-II fuzzy logic. All these methods have been designed and simulated for the hybrid UAV system. The novelty of this contribution is the usage of these three different EMS approaches to a UAV with a fuel cell and a Li-ion battery as the power source.

This paper provides insightful recommendations to researchers, noting that the selection of EMS technique could differ according to the particular system and available means. Although Type-II fuzzy logic EMS exhibits better performance, it is more complex and requires greater decision times. Consequently, classical fuzzy logic EMS is commonly preferred in most applications due to simplicity and effectiveness.

[14]

The advent of Flying Ad hoc Networks (FANETs) is causing ripples in all areas, enabling communication without the necessity for traditional infrastructure. FANETs consist of unmanned aerial vehicles (UAVs) that collaborate to provide a variety of services. Using UAV cloud technology, the drones are provided with a variety of services, including internet access, data storage, and computing services.

Nonetheless, because of their extremely mobile nature, client drones tend to need to find service providers who are capable of addressing their particular requirements before they access the concerned services. To address this issue, we propose a new method referred to as FL\_DS that utilizes fuzzy logic in order to facilitate improved decision-making and best choice of services for UAV clients. In this research, we compared FL\_DS to another method referred to as Simple Additive Weighting (SAW). In the construction of a stable simulation environment, we utilized the OMNeT++ simulator in conjunction with the INET framework. The result validated the efficiency of fuzzy logic in maximizing network resource management and service quality in FANETs. The prospective method has the potential to considerably enhance UAVs' access and utilization of services in the ever-changing world of aerial communication.

[15]

Flying Ad-hoc Networks (FANETs) provide ad-hoc networking between Unmanned Aerial Vehicles (UAVs) and have been increasing tremendously in popularity in most military and civilian uses over the last few years. The Glowworm Swarm Optimization algorithm has been utilized in recent research to extend a clustering-based self-organization method for FANETs. As mobility of the UAVs increases, though, network topology can be extremely dynamic, so route discovery and maintenance can be very complicated. Network congestion can also affect overall throughput significantly.

For addressing the above issues, we propose the solution offering energy-efficient clustering and fuzzy-based path selection to FANETs. On the first stage, distance-based clustering is performed among UAVs. For effective communication and energy management, we select Cluster Head (CH) using Adaptive Mutation with Teaching-Learning-Based Optimization (AMTLBO) algorithm. The approach here computes fitness values considering link capacity, residual energy, and distance to nearby UAVs to select best CH nodes.

Once the CH is formed, nodes share data with each other and transmit their data to the CH. Then we introduce Improved Fuzzy-based Routing (IFR) to improve the route discovery. In this, we want to determine routes in which there will be more flying autonomy, less mobility, and more Received Signal Strength Indicators (RSSI). This helps the clusters to consume less energy and survive longer.

Finally, we utilize an adaptive and reliable congestion detection mechanism to ensure packets are transmitted through non-congested paths. From the experiments, we can observe that the proposed AMTLBO system outperforms other systems in energy efficiency, throughput, delay, overhead, and packet delivery ratio. This innovation has great potential to enhance the performance of FANET in numerous applications.

[16]

Flying Ad hoc Networks (FANETs) are new self-organization wireless networks consisting of swarms of Unmanned Aerial Vehicles (UAVs) which communicate between each other in close proximity. FANETs have unique features that differentiate them from other ad hoc networks, particularly under routing complexities. Owing to the highly dynamic movement of UAVs and the dynamic network topology which is constantly changing, effective routing mechanisms are highly required in order to control the swarms and improve the performance of the network. In order to counteract these complexities, researchers took inspiration from the biological behavior of living creatures—animals, insects, and even human beings. Decentralized, self-organized nature swarming behavior comes closest to the operation of UAV fleets and therefore Bio-Inspired Algorithms (BIAs) are a viable solution to resolve a broad range of routing problems in FANETs.

In this paper, we conduct a Systematic Literature Review (SLR) to derive FANET routing protocols from non-hybrid and hybrid BIAs. We attempt to give a well-founded overview of the current bio-inspired approaches that are being employed in FANET routing and hence make the review a knowledgeable guide for researchers. To our knowledge, this is the first such SLR hitherto on FANET routing protocols based on BIAs. We address some noteworthy points: the nature and characteristics of current routing algorithms, the appropriateness of the usage of both non-hybrid and hybrid BIAs for efficient routing, simulation tools and evaluation criteria used, and the prevailing challenges and trends towards these approaches. This elaborate discussion will highlight the radiant synergy of biology and technology towards improving FANET routing.

[17]

The recent research interest in flight ad hoc networks (FANETs) brings up a critical question: unmanned aerial vehicles (UAVs) have limited flight times and inefficient routing because of their high mobility and battery constraints. This renders routing in FANETs much more challenging than in mobile ad hoc networks (MANETs) or vehicular ad hoc networks (VANETs).

To effectively address such complex routing problems—especially where static and dynamic routing techniques fail—clustering techniques through artificial intelligence (AI) can be a breakthrough. Here, we propose a cutting-edge technique utilizing fuzzy logic-based zonal clustering algorithms for FANETs. We utilize evolutionary algorithms, such as the probabilistic, bio-inspired whale optimization algorithm (p-WOA), to design stable clusters in our technique. This not only reduces the number of required cluster heads (CHs) for routing but also maximizes coverage while significantly reducing energy expenditure.

Inspired by nature, p-WOA is a strategic network configuration and deployment model. We employ a fuzzy logic-based regional clustering approach to select the optimal cluster heads after cluster formation. Strategically selecting cluster heads simplifies routing traffic and enhances cluster lifetime at the expense of lower overhead. Upon formation, data transmission is along the shortest path through a reference point group mobility model. To evaluate the performance of our new p-WOA strategy, we compare it with other strategies, including fuzzy integral and fuzzy logic ant optimization, fuzzy integral and neural network interference systems, ANFIS-WOA, and fuzzy integral with FL-ALO. Significant parameters such as cluster number, lifetime, configuration time, cluster head consistency, and energy consumption were compared with utmost care.

The results provided by the experimentation clearly show the fact that the proposed algorithm compares favorably to existing state-of-the-art practices, proving effective in addressing the unique challenges within FANETs.

[18]

One of the fascinating applications in this area is the flying ad hoc network (FANET) that organizes small unmanned aerial vehicles (UAVs) as an ad hoc dynamic network. FANETs also pose their own challenges due to characteristics such as 3D motion, high mobility, high topological dynamics, low availability of resources, and low node density. All these make it difficult when trying to design efficient and effective routing schemes.

This paper proposes a fuzzy logic-based routing scheme that is specifically designed for flying ad hoc networks. Our system has two main phases: the route discovery phase and the route maintenance phase. During the route discovery phase, it uses a technique that gives a score to every node in the network. This is done to avoid the broadcast storm problem and control the flow of control messages broadcasted to find new routes. Scoring takes into account several factors such as the direction of movement, node residual energy, link quality, and node stability. We also derive a fuzzy system for route selection that gives a better fit, taking less time and hops to send data.

The second phase is concerned with keeping these routes open. It consists of two primary steps: first, we try to avoid route failures by identifying and correcting paths that are reaching their failure point. Second, if a route fails, we identify it immediately and substitute it with a new route to maintain smooth communication.

We applied this routing scheme to the NS2 simulator to analyze its performance and efficiency. We have compared our results with three of the most commonly used routing algorithms: ECaD, LEPR, and AODV. The results show that our proposed routing technique performs better than these algorithms in some key parameters such as end-to-end delay, packet delivery ratio, route stability, and energy consumption. Even though the routing overhead has a slight increment, the advantages far exceed this limitation.

[19]

Wireless sensor networks consist of a large number of geographically distributed sensor nodes with likely low energy supplies. Maximizing the total lifetime of such networks is perhaps one of the greatest challenges to them. One of the most promising methods is the provision of continuous wireless charging to the sensors. Mobile chargers (MC) enter the scene here, engaging in the task of recharging the sensor nodes' energy wirelessly. Designing an efficient charging strategy that ensures the maximum lifetime of the network is, however, quite challenging.

Here, we present a new demand-based charging scheme that uses unmanned aerial vehicles (UAVs) to recharge wireless rechargeable sensor networks. First, we cluster the sensors based on their geographical locations through the K-means clustering algorithm. Subsequently, we rank these clusters through a fuzzy logic system. The ranking is performed on the basis of various parameters: the average residual battery life of the nodes, the number of nodes in every cluster, the presence of critical sensors that need to be charged, and the distance of every center of the clusters from the mobile charging station.

Once we calculated the priority of each cluster, we use a routing algorithm that calculates the most optimal and critical paths to find the most critical sensor nodes. We used a gradient-based optimization (GBO) algorithm for intracluster routing so that our approach is optimized as much as possible.

In order to compare the performance of our design, we simulated a case study of a wireless rechargeable sensor network on MATLAB. The results of the simulation were promising, indicating that our approach maximizes the lifespan of the network significantly. Indeed, compared to a genetic algorithm, our approach saved 26% in total energy consumption, 17.2% in the total distance traveled, and 25.4% in overall delays of travel. This indicates that we are moving in the direction of wireless sensor networks with reduced energy consumption and increased lifespan.

[20]

Mobile ad hoc networks (MANETs) are growing in significance as a multi-role access technology, especially where fixed infrastructure does not exist, because they have the unique properties of being self-organizing, non-centered, and self-healing. To effectively cope with the dynamic nature of the network topology and save overhead, such networks tend to use on-demand routing protocols like the ad hoc on-demand distance vector (AODV).

Here, we introduce a fuzzy-logic-based AODV (FL-AODV) routing protocol that is designed to enhance route reliability by considering delay, stability, and residual energy of nodes. During the route discovery process, the protocol selects the most reliable node as the relay to guarantee that the most accumulated reliability route is used for data transmission.

Simulation results prove that FL-AODV performs better than conventional AODV and the fuzzy logic routing algorithm (FLRA) in being more reliable without causing delay. Precisely, the approach translates into improved link connectivity and longer route lifetime. More significantly, when the number of nodes is more than 70, the average routing reliability obtained by FL-AODV is approximately 18% higher than that of AODV with a similar low delay. This indicates considerable routing reliability gains for MANETs.

ML Aspects of Fuzzy Routing

The adaptability of ML/AI techniques is the major advantage; these models routinely shift strategy upon the discovery of new data. Additionally, a majority of the ML methodologies are model-free, and they have the capability of deducing optimal solutions without having to apply pre-specified models of networks.

There are many examples of the application of ML to UAV routing. Route discovery and maintenance can be aided by Q-learning, and network behavior modeled or link quality predicted by neural networks. Nature-inspired processes can be used to find optimal solutions, and can also be considered from an AI perspective using bio-inspired algorithms such as Ant Colony Optimization.

Performance metrics show that ML/AI routing methods can gain considerable improvements in packet delivery ratios, reduced delays, and lower overhead in simulations.

Comparison:

|  |  |  |
| --- | --- | --- |
| **Feature** | **Fuzzy Logic** | **Machine Learning/AI-Based** |
| Integration | Frequently collaborates with ML/AI techniques | Fuzzy logic often enhances ML/AI methodologies |
| Decision Making | Rule-based, leveraging linguistic variables | Learning-based, derived from data and environmental interaction |
| Handling Uncertainty | Directly addresses imprecise information | Learns from underlying patterns in uncertain environments |
| Need for Model | Often operates without requiring precise models | Many techniques (like model-free RL) forgo explicit models |
| Adaptability | Adapts through the tuning of rules and parameters | Inherently adaptive, revising policies over time |
| Interpretability | Rule-based framework offers high interpretability | Some models may function as "black boxes" (e.g : deep learning) |
| Expert Knowledge | Easily incorporates insights from expert knowledge | Learns from data, which may not always include explicit expert rules |

Conclusion:

In conclusion, both fuzzy logic and machine learning/AI techniques provide powerful solutions to the complex challenges faced by UAV networks. Fuzzy logic effectively captures expert knowledge and addresses uncertainties, while machine learning brings the capacity for continuous learning and adaptation. By leveraging the strengths of both approaches, significant advancements in the performance and reliability of UAV routing systems can be achieved, paving the way for more robust and efficient networks.