An Adaptive Routing Protocol in Flying Ad Hoc Networks (FANETs)

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By

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DECLARATION

I declare that the thesis entitled "An Adaptive Routing Protocol in Flying Ad Hoc Networks (FANETs)" has been prepared by me under the supervision of Dr. Amit Sharma, Associate Professor, School of Computer Applications, Lovely Professional University, India. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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CERTIFICATE

This is to certify that the declaration statement made by the student is correct to the best of our knowledge and belief. She has submitted her Ph.D. thesis **—AN ADAPTIVE ROUTING PROTOCOL IN FLYING AD HOC NETWORKS (FANETs)** under our guidance and supervision. The present work is the result of her original investigation, effort, and study. No part of the work has ever been submitted for any other degree at any University. The Ph.D thesis is fit for the submission and fulfillment of the condition for the award of Ph.D degree in Computer Science and Engineering from Lovely Professional University, Phagwara**.**

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ABSTRACT

To monitor disaster situations or reach hard-to-reach areas, new wireless communication mechanisms have gained much attention in recent years because of their extensive range of aerial technologies, which is a kind of new technology or configuration. FANETs or flying ad hoc networks are related to a kind of ad hoc network configuration that consists of unmanned aerial vehicles (UAVs). Based on the collected images and sending them to a base ground station, UAVs are operated and helped monitor a particular area in a method termed as UAV-to-ground (U2G) communication.

A particular vehicle ad hoc network (VANET) and mobile ad hoc network (MANET) can be considered as FANET. Various distinctive challenges of design have been included in the FANETs, although they have common characteristics. Compared to the MANET and VANET, each node's degree of mobility is much higher in the FANET. The speed with the value of 30-460 km/h has included in UAV. From moment to moment, the UAVs' locations can change in other words. Among UAVs, the links are destroyed and established intermittently. By comparing with the VANET and MANET topologies, the FANET topology has been changed more frequently due to the higher value of the degree of mobility. A problem of link variation is resulted by the UAV network topology, which quickly changes the changes. In addition to these, the packet loss, latency, and control signaling overhead have increased by the changes in frequent topology. The mobility of multi-UAV systems could impact the flight plan changes, various UAV formations, and fast and sharp UAV movements directly in multi-UAV applications.

The standard requirements have involved all applications of FANETs, and they should faster the usage of multi-hop communications throughout the aerial nodes. For example, Helicopters, Aircraft, UAVs, etc. The applications of FANET's rely on the following categories like collaborations of UAV-to-VANET, multi-UAV cooperation, and UAV-to-Ground tasks. For providing an optimal and appropriate solution, several UAVs will perform a specific task cooperatively. The scope of this work considers the cooperation of multi-UAV in various improved applications like tracking and monitoring disaster situations, target detection, and accurate geographic localization. While differentiating between the divisions of FANETs, many concerns might appear that discuss earlier underline.

In this thesis, discusses implementing unmanned aerial vehicles (UAVs) for various civil and military areas by creating flying ad-hoc networks (FANETs) as recent applications include remotely aerial nodes. Adaptable, reliable, and delay-bounded communications among UAVs are required in FANETs due to the rapidly changing topology and increased number of UAVs by maintaining the desired network with quality services. In a FANET, routing of data between UAVs is a severe challenge, not the same as the MANETs with low portability mobility conditions. As indicated by topology changes, routing tables must be updated dynamically. Most of the existing routing algorithms' metric calculations are neglected in FANET to give a dependable correspondence between UAVs. Reliability of routes is also a real challenge due to the very high mobility in FANET. We have introduced a new routing protocol for FANETs that considers the node's current and future values of specific parameters the reliable routing path. This proposed routing scheme assigns weight to every node in the network by predicting the node's future. Due to this, the communicating nodes can establish a reliable path that lasts for a long time. This dynamic, future prediction-based routing scheme ensures better data delivery with minimum overhead and optimized energy consumption in all conditions than traditional routing protocols. The proposed protocol could achieve better results than others based on the assessment of simulation results.

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LIST OF ABBREVIATIONS

Abbreviation	Description
UAV	Unmanned Aerial Vehicle
FANET	Flying Ad Hoc Networks
MANET	Mobile Ad Hoc Networks
VANET	Vehicular Ad Hoc Networks
PRP	Proactive Routing Protocol
RRP	Reactive Routing Protocol
HRP	Hybrid Routing Protocol
MAC	Medium Access Control
P-OLSR	Predicted-Optimized Link State Protocol
GPS	Global Position System
HSR	Hot Stand by Routing
MDD	Mobile Driven Development
DCF	Distributed Co-ordinate Function
DMAC	Directional Medium Access Control
LODMAC	Location Oriented Directional Medium Access Control
UWSN	Underwater Wireless Sensor Networks
QOS	Quality of Service
WSN	Wireless Sensor Network
EQR-RL	Energy-Aware Quality of Service Routing-Reinforcement Learning
QOE	Quality of Energy

QGRID	Q-Learning based Grid Routing
QLAR	Q-Learning based Adaptive Routing
AODV	Ad Hoc On Demand Distance Vector
LEPR	Link Stability Estimated Pre-emptive Routing
LTA-OLSR	Link Quality & Traffic Load Aware Optimized Link State Routing
RL	Reinforcement Learning
DF	Discount Factor
CH	Cluster Head
CBLADSR	Cluster Based Location Aided Dynamic Source Routing
LET	Link Expiration Time
MDA	Mobility and Directional Aware
RREQ	Route Request
RREP	Route Reply
U2U	UAV-to-UAV Communication
SPDT	Successful Packet Delivery Time
HC	Hop Count
TR	Transmission Rate
FS	Flight Status
ES	Energy State
BS	Base Station
PDR	Packet Delivery Ratio
BIMAC	Bio-Inspired Mobility Aware Clustering
NS-2	Network Simulator-2

PF-WGTR	Predicted Future Weight based Routing Scheme
TWGHT	Total Weight
FWGHT	Future Weight
Sn	Speed of Node
Dn	Direction of Node
PSn	Predicted Speed of Node
LQn	Predicted Link Quality of Node
An	Acceleration of Node
Qn	Link Quality of node
PDn	Predicted Direction of Node
FSQOS	Fuzzy System based Quality of Service
QLF-MOR	Q-Learning and Fuzzy system based Multi Objective Routing
UDP	User Datagram Protocol
CBR	Cluster Based Routing
IEEE	Institute of Electrical and Electronics Engineers
EBDPS	Edge Based Disjoint Path Selection Scheme
ECAD	Energy-efficient Connectivity-Aware Data delivery
LST	Link Steadiness Factor
MDR	Minimum Energy Drain Rate
NC	Node Closeness
ETX	Expected Transmission Count

LA	Link Available Factor
Eres	Residual Energy
DRI	Drain Rate Index
Dij	Distance between Node i and Node j
R	Communication Radius
Dr	Reverse Delivery Ratio
Df	Forward Delivery Ratio
Tr	Transmission Range

CHAPTER-1

INTRODUCTION

1.1 Background

With current industrial developments in electronics, computers, different types of devices, and broadcasting systems, it has been possible to develop UAV systems. UAVs can be small aircraft, drones, and balloons [1]. It remotely controls disaster applications such as saturated and armed and civilian applications (rescue operations, forecast fire detection, etc.). Small UAV nodes have many advantages compared with large nodes [2]. Multi-UAV System with FANET is a network of small UAVs flying autonomously in the air. In FANETs, only one node connects with a base station or satellite, and the remaining UAVs connect in an ad hoc network mode. High mobility of nodes, efficient routing, and identification of neighbor locations are the features of FANETs [3].In some critical situations, when the infrastructure communication is not available, using FANETs [4]. It requires a good broadcasting architecture, routing protocol, and mobility model for robust and reliable communication [10]. FANETs Communication architecture provides information about how communication is established between the ground base, satellite, and UAV nodes or between UAV nodes. In FANETs communication architecture, UAV nodes deliver instantaneous announcements in an ad hoc style. It can eliminate the substructure requirement and detect the communication range restriction [4].

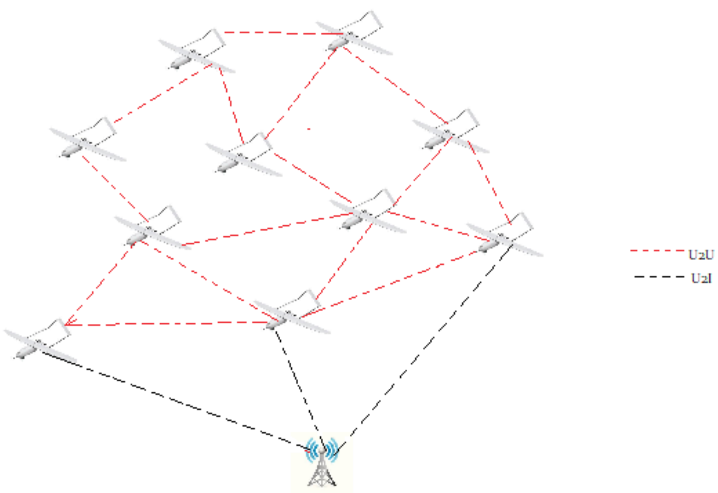


Figure 1.1: Flying Ad hoc Networks [1]

The communication range limitation and efficient communications are the main problems, but no chance to provide infrastructure; in such scenarios, FANETs communication architecture plays an important role. Compared with centralized control, decentralized communication is more convenient for robust and effective communication between UAV nodes [10].

1.1.1 Multi-Layer UAV Ad hoc Network

It is a kind of FANET communication, as shown in Fig-1.2. In this network, several groups consisting of various UAV nodes shape an ad hoc network within every group. One surface is for communication between UAV nodes, and another is for interaction among backbone UAV nodes of all linked clusters and ground base. Only one UAV node links with the base station, and the remaining nodes communicate ad hoc. Not essential to interconnect all groups with the base station to exchange data between UAV nodes [4]. This communication architecture decreases the broadcasting capacity and calculation on the base station [6]. In summary, we need a decentralized architecture for communication between multiple UAVs. Finally, this network is more convenient for FANETs.

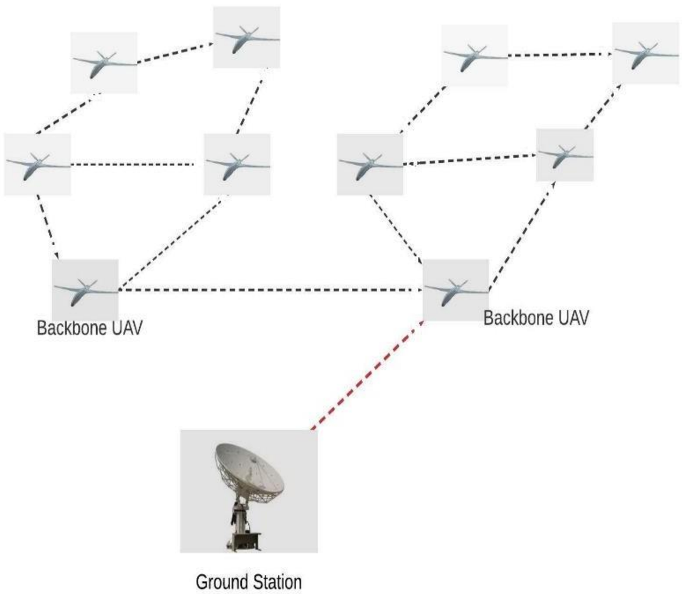


Figure 1.2: Multi-Layer UAV Ad hoc Network [25]

1.1.2 Advantages of Multi-UAV Systems

- The cost of small UAVs is meager and more efficient than the large UAVs
- Multi-UAV systems extend operation scalability using FANET more quickly than large UAVs; it covers a limited range of operations.
- Using a single large UAV may fail in a mission; there is no way to continue the process, and the mission can stop. However, if we use a multi-UAV system, the operation can continue with other UAVs [26].
- With the help of small UAVs, missions can be completed faster than large UAVs.

1.1.3 Unique Challenges of Multi-UAV Systems

- Compared with a single-UAV system, a multi-UAV system has some unique challenges.
- In both single-UAV and multi-UAV systems, the connection is confirmed between the UAV and infrastructure, but the difference is a topology variation. In multi-UAV systems, the number of nodes increases. Every time the topology changes, the distance between nodes is vast, and link quality also changes [30].
- Depending on these unique challenges, designing an efficient network architecture is a significant problem for data communication in multi-UAV systems. Entirely the multi-UAV system relies on an infrastructure-based approach. This approach faced many problems, like complicated hardware and collection limits among UAVs and base stations. Another clarification for multi-UAV systems is FANETs.

1.1.4 Difference between MANET, VANET, and FANET

FANET extends from Mobile Ad hoc to Vehicular Ad hoc Networks. There are some differences between FANET and traditional networks [32].

Mobility: FANET nodes' mobility is very high compared with traditional network nodes like MANET and VANET. Mobile Ad hoc and Vehicular Ad hoc nodes are near the ground, but FANET nodes fly in the air.

Topology: FANET network topology changes continuously compared with MANET and VANET due to the high mobility nature of UAV nodes

Distance: The distance between FANET nodes is very high compared with MANET and VANET.

Communication Range: In FANET, the distance between nodes is very long, depending on the communication range is longer than in MANET and VANET.

1.2 FANET Routing Protocols

The dominant reason for introducing steering procedures is establishing an effective network data transfer route [26]. In Flying Ad Hoc Networks, due to the nature of UAVs, Always the network topology will be changed [29]. The design of an actual steering arrangement for Flying Ad Hoc Networks is an essential task, and its process is still under research. In traditional ad hoc networks, almost the protocols are developed for MANET and VANET routing but cannot apply directly to FANETs because UAVs have some unique features [30]. For FANETs routing, some existing procedures have been adapted, and specific novel procedures have been suggested [40].

FANET protocols are divided into three categories:

Figure 1.3: Classification of Routing Protocols [110]

1.2.1 Table-Driven or Proactive Routing Protocols (PRP)

Proactive procedure stores all the steering info in a routing table. In FANET, other proactive procedures are not related to each other. The steering procedure conveys the newest info of nodes; that is the reason, no need to delay and choose the route between transmitter and receiver [39]. When the bandwidth is not used efficiently, this will not be suggested for massive transmission systems.

1.2.2 On-Demand or Reactive Routing Protocols (RRP)

These types of routing protocols do not maintain any information regarding network topology. They can discover the path from sender to receiver when the source node wants to send data to the receiver. On-demand protocols take more time to find a path from sender to receiver. Due to this reason, these type of protocols faces high routing overhead problems and high end-to-end delay [26].

1.2.3 Hybrid Routing Protocols (HRP)

HRPs control the drawbacks of PRP and RRP procedures as RRP needs additional time to discover paths, and PRP has routing overhead [37]. In HRP, a system distributes into regions; PRP is used for intra-region steering, whereas RRP is used for inter-region steering [38].

Previous works used different topology-based routing protocols and compared every routing protocol with each other to satisfy the requirements of FANETs and enhance the performance of FANET applications. However, still, no protocol satisfied FANET requirements such as efficient bandwidth, QoS, link connection, end-to-end delay, etc. Different routing techniques are available in ad hoc networks to relay the data packets strongly [41].

1.3 Comparison of Routing Protocols

In PRPs, each node preserves a complete address to the destination, but in the RRPs, it establishes a path when it is necessary to relay data [26]. HRPs combine both PRPs and RRPs [37] (Table 1.1).

Table 1.1
Comparison of Routing Protocols

Protocol	**Routing Structure**	**Periodic Updates**	**Control Overhead**	**Route Possession Delay**	**Bandwidth**
Proactive	Hierarchical & Flat	Yes, Some may use conditional	High	Less Delay	Need More Bandwidth

Reactive	Mostly Flat	Some nodes may require periodic beacons	Less	Delay is very high	Need Less Bandwidth
Hybrid	Flat	Yes	Average	Lower for Intra-Zone, Higher for Inter-Zone	Need Average Bandwidth

1.4 FANET Design Considerations

1.4.1 Adaptability

Due to the high mobility nature of nodes, the parameters can change during operation and continually change their location. In FANET, the distance between two nodes is vast and cannot be constant because of operational requirements [29]. Because of some reasons like technical problems or attack operation problems, some UAVs fail in mission operation. That failure decreases the number of UAVs. Maybe that failure mission requires additional UAV injection to maintain the network system. Automatically, the injection and failure of UAVs may change FANET parameters. Environment conditions and flight plan updates are also changing the FANET specifications so that we can design FANET with an effective communication architecture and an efficient routing protocol to adjust itself in crucial cases against failures.

1.4.2 Scalability

Equated with a single-UAV system, the UAV's swarm can increase the structure's presentation. FANET extends the scalability of operation [44]. For example, in search and rescue operations, the usage of more UAVs gives effective performance than single UAVs.

1.4.3 Latency

In every network, latency is a big challenging issue. UAV ad hoc networks also face this problem in different applications. In real-time applications, the data must be relay within a specific time. The latency is very high in the routing; it raises more problems such as collision, collaboration, etc. MANET/VANET routing protocols do not satisfy FANET latency requirements. So, we need to develop new routing protocols and algorithms [45-46].

1.4.4 UAV Platform Constraints

The weight of hardware and space limitation is platform-associated restrictions in FANET design. Weight of hardware means heavy payload. The space limitation is significant for mini UAVs [41].

1.4.5 Bandwidth Requirement

The main aim of the FANET application is to transfer the data from the collected location to the ground station. For example, in rescue operations, relaying target data with strict delay bound from the UAV to the command control center requires high bandwidth [34]. Developing an efficient and effective FANET routing protocol is needed to meet bandwidth needs.

1.5 Functionality of FANET

1.5.1 Scalability Extension of Multi-UAV Operation

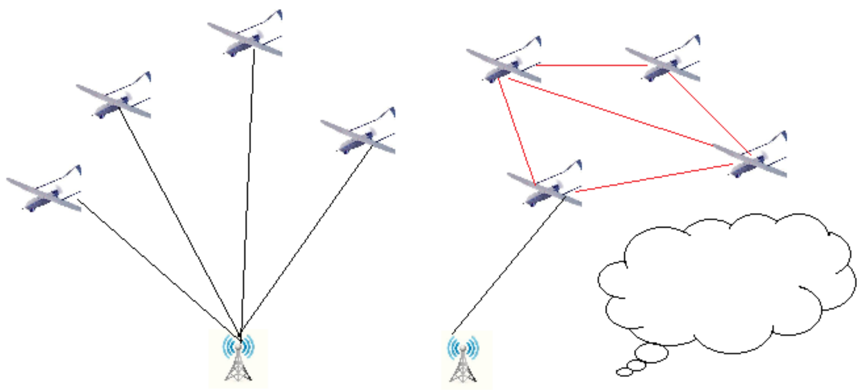
In a multi-UAV system, every UAV must converse with the ground control station or satellite for operation; otherwise cannot operate. However, in FANET, no need to communicate all UAVs with the ground base. At least one UAV communicates with the ground base, and the remaining will communicate ad hoc [5]. In single- UAV and multi-UAV systems use UAV-to-Structure-based communication links, but in FANETs, we use UAV-to-UAV communication links to extend the operation's scalability. FANET can operate a mission with

UAVs even with no communication link with infrastructure. For example, In FANET, one UAV cannot connect with the ground base, but no problem, with the help of another UAV, we can operate it.

In Infrastructure-based networks, the communication between nodes is also affected due to the environment. For example, obstacles like buildings, mountains, or large walls may block the signals to transfer the data between the ground base and UAVs, especially in urban areas. However, in FANET, operating behind obstacles can also increase the UAV operation range [41].

1.5.2 Trustworthy Multi-UAV Communication

In multi-UAV system operations, continuously the topology changes due to the high mobility nature of UAVs in a network. During the operation, the conditions may change in a mission. In a multi-UAV system, all UAVs are connected to infrastructure; there is no chance to establish an ad hoc network, as illustrated in Fig. 1.4a. In some cases, UAVs may discard their connection in multi-UAV systems due to problems occurring in the network, such as unknown persons entering into the network and taking absolute control into their hands, sudden drastic changes occurring in whether etc. [26]. However, in FANET, if one UAV fails and gets no problem, we can operate a mission with other UAVs, as shown in Fig. 1.4b. This feature increases the reliability of the multi-UAV systems.



(a) (b)

Figure 1.4: Trustworthy communication network using FANET

1.5.3 UAV Swarms

UAV Swarm is nothing but a group of small-UAV nodes coordinated together to produce a significant result. UAV swarms can handle complex missions with the help of coordination for every UAV node in the network. Due to the limited payload of small UAVs, it is tough to maintain large and heavy communication hardware [30, 41].

FANET uses much cheaper and lighter hardware to establish a network connection in small UAVs. UAV swarms can complete complex missions successfully with the help of FANET communication architecture.

1.5.4 FANET to Decrease Payload and Cost

In small UAVs, the payload is very low because small-UAV systems use lighter and cheaper hardware to establish a communication network. The payload problems occur not only in small UAVs; Higher Altitude UAVs also consider

Payload weights. Multi- UAV systems depend on UAV-to- Infrastructure links, every UAV must communicate with a ground station, and it carries higher hardware to data communication [41]. However, FANET uses the UAV-to-Infrastructure link and UAV-to-UAV link; only some UAVs communicate with the ground station, and the remaining UAVs can operate with FANET. FANET extends the performance of multi-UAV systems.

1.6 Motivation

The routing protocol plays a significant role in communication between UAVs in every application of Flying Ad hoc Networks (FANETs). Consequently, a well-made interacting model wants to be defined, which permits UAVs to communicate with every node so they can organize themselves into a network called Flying Ad hoc Network (FANET) [111]. On the other hand, many stimulating features are distinguished in the performance of UAVs, which should be well-respected, such as their high mobility, their unpredictable movements, and their non-uniform distribution over the network, which results in frequent topology changes, and therefore, makes the design of FANET routing protocols a highly complex task [83]. As a result, several routing protocols are suggested for FANETs trying to deliver contemporary routines, avoid packet losses, and to different scenarios and situations. Additionally, due to its similarity with MANETs, researchers have considered the probability of applying the routing methods used in those environments in FANETs [85]. Modifications have been made, but different requirements are overlooked, such as the mobility patterns, the energy constraints, the area of deployment, the node localization, and the QoS requirements. Consequently, the knowledge of the different routing protocols limits and the existing techniques allows us to continually develop new routing schemes according to the needs and know which near-optimal methods to apply among UAVs in a given situation.

1.7 Research Objective/ Scope of Study

Nowadays, most researchers are interested in working on wireless network systems because the reason is that compared with a wired network, the usage of a wireless network is very convenient and flexible to carry outside of the organizations or offices to complete our work or to give any presentations, etc.
An ad hoc network is one type of wireless network. It is an autonomous and unstructured network. The ad hoc network consists of a collection of mobile nodes, and it can relay the data from source to destination without any base station. During data transmission, every intermediate node acts as a router.
The ad hoc network is divided into different types, such as Mobile Ad hoc Network (MANET), Vehicular Ad Hoc Network (VANET) and Flying Ad Hoc Network (FANET), etc. Most of the research work doing on MANET and VANET. Many routing protocols are introduced for these traditional ad hoc networks. Less work has been completed on Flying Ad hoc Networks (FANETs).
In FANETs, the existing routing protocols face significant challenges due to their dynamic nature. No routing protocol provides a compatible routing to relay the data between UAV nodes. Mostly, the research is done on a survey of different types of existing routing protocols, various mobility models to control the mobility of a UAV node, different types of communication protocols, etc. However, it fails to achieve a flexible routing between nodes due to limited bandwidth, energy constraints, rate of change of speed, high mobility, etc.

This research introduced an adaptive routing protocol to overcome some of the frequent limitations in flying ad hoc networks.

The research work will pass through the following phases to achieve the objectives:

- A broad survey will be conducted to study various existing routing protocols, and their performance in FANETs accomplished in extreme knowledge of adaptive routing protocol.
- An Adaptive routing protocol will be proposed based on the knowledge and facts obtained from the different phases. The proposed routing protocol will discuss performance-related issues and evaluate FANET parameters such as end-to-end delay, packet delivery ratio, routing overhead, throughput, etc.
- The proposed routing protocol will be compared with other existing protocols against FANET performance parameters.
- The goal is achieved by considering the following objectives

1. To study and analyze the existing routing protocols for FANETs.
2. To design an adaptive routing protocol.
3. To verify and validate the proposed adaptive routing protocol.
4. To compare performance aspects.

Chapter 2 provides all the information about routing protocols in ad hoc networks. Different Q-learning-based routing protocols are also described—in the literature review regarding the routing schemes and algorithms of position-based and topology-based methods. The chapter also reviews various mobility models and zone-based algorithms.

Chapter 3 deals with PF-WGTR: A predicted future weight-based routing scheme that predicts the node's future behavior and dynamically adjusts the routing strategy. PF-WGTR assigns weight to every node by incorporating several parameters into the AODV routing protocol. The Route (TWGHT) Total Weight between the sender and receiver nodes defines as the mathematical representation of the following parameters.

Chapter 4 deals with the EBDPS scheme, a new metric called link steadiness, which defines the steadiness of the available link during data communication, is introduced in this scheme. The newly introduced link steadiness parameter evaluates the link steadiness of the selected links based the multiple parameters like link steadiness, minimum energy drain rate, node closeness, ETX & link availability factor. The proposed scheme selects and caches the possible paths in the source code. The selected primary path's steadiness is a monitor to reduce the possibility of link breakage during packet broadcast. So the packet delivery rate is not affected if the link breakage occurs. These selected disjoint paths control the number of hops essential for forwarding the info to the destination via minimum hops. It achieves energy efficiency during data transmission. The proposed scheme of EBDPS provides improved results in end-to-end delay and PDR and controls the overhead in the lower or higher mobility of network environments.

Chapter 5 summarizes the results and contributions of this thesis work. The future research potential of this research is also stated in this chapter.

1.8 Thesis Contribution

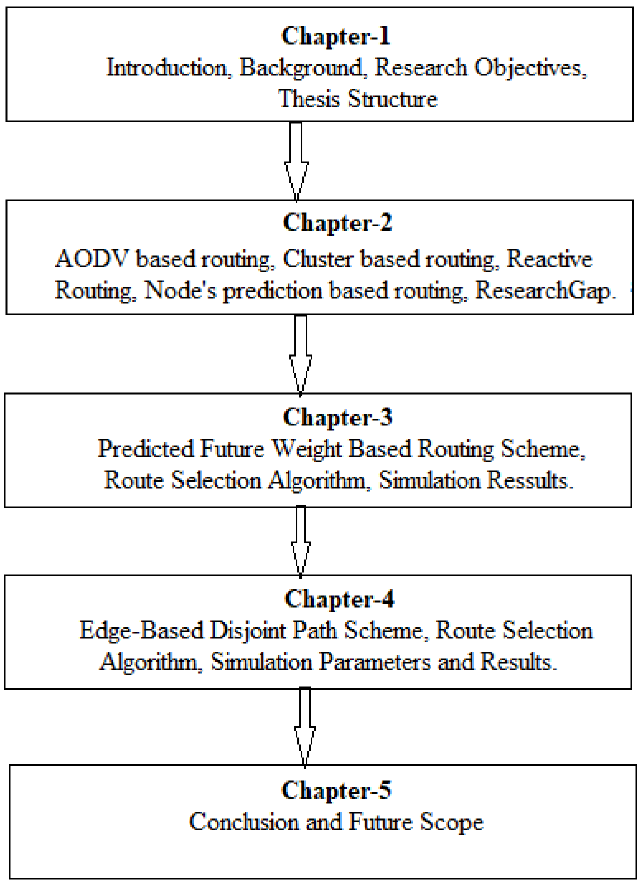


Figure 1.5: Chapter-wise Thesis Organization

CHAPTER-2
LITERATURE REVIEW

2.1 Introduction

Nowadays, ad hoc networks play a vital role in wireless communication. It is a temporary network to relay the data between nodes. Ad hoc network is divided into different types, such as MANET, VANET & FANET. FANET is a combination of MANET and VANET [25]. In FANET, routing is a big challenging issue due to unique characteristics like dynamic topology, frequent changes in link quality, mobility of UAV nodes, etc. Reliability of routes is also a real challenge due to the very high mobility in FANET. The determination of an appropriate path for the transmission of data is the primary purpose of routing protocols [26].

2.2 AODV Based Routing in Ad Hoc Networks

In this routing protocol, the source node can establish the path from the source nodeto the destination node. The source sends a route request to its neighbor nodes, and various messages of route requests might exist in the network. The sender nodesends a unique request-id to avoid mixing the sender node. Every node ofthe network must relate to route caches in which every one of the routes is available. Only one entry for each destination includes AODV, and next-hop information to each data communication [85] is stored. Three phases are contained in the AODV routing protocol: route maintenance, packet transmission, and route discovery. However, the routing message types of AODV include route error, route reply, and route request. It may not be practical to build direct communication between UAVs to the BS on the ground at particular times in extensive coverage areas. Based on the hop-by-hop manner, this problem can be overcome, and it requires a routing protocol for discovering the efficient path or route from source to destination [86]. It is essential to consider the UAV's mobility and spatial arrangement to determine the communication routes. The rearrangement of these routes completes as a result of the movement. It will lead to the continuation of interconnection between the UAVs. With the increment in the UAVs, the routing should perform dynamically, and the delay reduces in delivering data between source and destination nodes [87].

In both armed and citizen areas, UAVs have been used extensively. In recent years [95], FANETs containing multiple UAVs have been investigated for enabling complex submissions that are challenging for using conventional mobile ad hoc networks or individual UAVs. The exact and quick data delivery is required between UAVs in FANETs for applications such as wildfire monitoring and search and rescue operations. Several unique features are included in FANETs, such as frequent topology changes, high mobility, and challenges in network connectivity [97].

For data transmission, the shortest path is used by the reactive routing protocols like AODV in the route discovery process. An alternative approach is sought onlyif an active way is broken [98]. Link breakage is caused by frequent route discoveries in FANETs, characterized based on high mobility and significantly increased overhead [98]. This link failure causes two significant problems. All packets transmitted on the broken routehave dropped out, and the average packet delivery ratio (PDR) has reduced [99].Until a new way is discovered, the data transmission is stopped, and the averageend-to-end delay is increased.

If a UAV wants to engage in communication and the destination location is not known, the route discovery is adopted. [101] have discussed determining the shortest path to the destination using route discovery. In theroute reply (RREP) packet, the novelty is that position of the goal is included and shared with all intermediate nodes. UAVs exploit the greedy forwarding method if there is a disconnection until the destination. As any connectivity factor is considered, the chosen path included in the links can be broken quickly as a drawback. Many route discoveries result in consuming moreenergy and resources.

[102] present an on-demand discovery path to address the issuesof UAVs by considering the connectivity factor among UAVs. The sequence of UAVs near each other is required to establish a robust routing path.As this protocol cannot determine various alternative solutions, it cannot dealwith sudden link breakages on multiple path links.

2.3 Cluster-Based Routing in Ad Hoc Networks

[86] utilized the multi-cluster-based approach where a fixed number of UAVs are contained in each cluster, and the election of one UAV is considered a CH. Among neighboring UAVs, the information message of a node is exchanged initially. UAVs are grouped according to the node data "zone ID" field. Each node maintains a link quality table in the cluster. Here, the table includes the delays, SNR, and distance to the neighbors. According to link quality, CH is elected, and a node with the best link quality is chosen as a CH.

[87] proposed CBLADSR. According to the factors like the degree of connectivity, energy level, and relative velocity, the CHs are elected by CBLADSR. For intra-cluster and inter-cluster communications, CBLADSR has used short-range and long-range transmission communications correspondingly. Zang and Zang proposed an algorithm of mobility prediction clustering [88] for UAVs. Each node maintains a neighbor table-hop neighbor. The probability of a node that will persist in its table is contained in the neighbor table. With the use of a dictionary tree structure, this probability is determined. Using the neighbor node's moment and possibility link expiration time (LET) is anticipated. Each node's weight is computed by taking the assistance of degree and LET probability of the neighbor. A node that has the highest weight will be selected as a CH.

2.4 Reactive Routing in Ad Hoc Networks

If a UAV wants to engage in communication and the destination location is not known, the route discovery is adopted. Shirani et al. [103] have discussed determining the shortest path to the destination using route discovery. The novelty of the route reply (RREP) packet is that the destination's position is included and shared with all intermediate nodes. UAVs exploit the greedy forwarding method if there is a disconnection until the goal. As any connectivity factor is considered, the chosen path included in the links can be broken quickly as a drawback. Many route discoveries result in consuming more energy and resources.

Oubbati et al. [104] present the on-demand discovery path to address the issues of UAVs by considering the connectivity factor among UAVs. The sequence of UAVs near each other is required to establish a robust routing path. As this protocol cannot determine various alternative solutions, it cannot deal with sudden link breakages on multiple path links. Among UAVs, unbalanced energy consumption is a severe issue.

In [105], demonstrated that the network is categorized into clusters, where CH is chosen using its members' relative velocity, energy level, and connectivity degree. The intra-cluster communications use by member nodes for direct communication. Since the residual energy is sufficient for communicating with other CHs located are a little far; all communications will be made via the CH. The residual energy is minimized as successive communications transit via the CH. It will run out of energy faster than other UA, resulting in strategy failure.

In [106] , focused on minimizing the overhead through the clustering formation based on a higher energy level. The dynamic transmission power is considered based on the distance that separates the communications of UAVs. For good CH selection, clusters are formed using the K-means density (i.e., the neighborhood degree). This type of routing protocol is provided better performance for a path-planned mobility model, not in the case of FANET applications. Other schemes have been proposed for particular mobile nodes to overcome the UAV's energy constraints.

2.5 Node’s Prediction-Based Routing

In [89-90], the authors have demonstrated the MDA-AODV routing protocol, an extension of the AODV protocol. To build the routes with stability and efficiency between the source and destination nodes, the intermediate node’s speed and direction are used by the MDA-AODV protocol in the route reply and route discovery phases.

To enable a path between UAVs without compromising efficiency, the authors proposed a routing protocol in [93] and adapted and applied it for these situations based on the fuzzy system. Based on the most extended durability and best connection, the efficient route will be determined by the new routing protocols. Thus, the performance of a network will be improved. , But Routing complexity and overhead is increased when the UAVs are flying at higher and similar altitude (heights) and directions

A routing algorithm that integrates both reinforcement learning and fuzzy logic algorithms in FANETs was proposed by an author in [85]. By considering the successful packet delivery time (SPDT), hop count (HC), energy drain rate, residual energy, and transmission rate (TR), the routing path is determined by connecting the multiple UAVs. For deriving the reliable links between two UAV nodes, a fuzzy system is utilize-learning supports starting with providing a reward on the path. Routing overhead is increased in dense networks due to the multiple parameter estimation during route discovery.

2.6 Research Gap

After reviewing numerous researches regarding FANET routing protocols, the following research gaps are identified:

1. Adapting new paths dynamically is not enough standard for frequent changes in topology
2. Finding a reliable neighbor node is very difficult due to the unique characteristics of FANETs.
3. Most routing protocols are developed for small networks because of continuous link failures and congestions.
4. The QoS is significantly very less with surviving protocols ad hoc networks.
5. Optimal path determination can be required to handle the routing overhead.

CHAPTER-3

PF-WGTR: A Predicted Future Weight-based Routing Scheme

3.1 Introduction

Nowadays, ad hoc networks play a vital role in wireless communication. It is a temporary network to relay the data between nodes. The ad hoc network is divided into MANET, VANET & FANET. FANET is a combination of MANET and VANET. In FANET, routing is a big challenge due to unique characteristics like dynamic topology, frequent link quality changes, mobility of UAV nodes, etc. Reliability of routes is also a real challenge due to the very high mobility in FANET. In this research work, we have introduced an adaptive routing protocol, PF-WGTR - A predicted future weight-based routing scheme for FANETs that considers the node's existing and upcoming values of assured parameters to determine the reliable routing path. This proposed routing protocol assigns weight to every node in the network by calculating the node's future. Depending on the predicted future weight of every node in a network, the communicating nodes can establish a reliable path that persists for a long time. This adaptive, future prediction-based routing scheme ensures better data delivery with minimum overhead and optimized energy consumption in all conditions compared with the existing routing protocols. The NS-2 simulator compares the proposed routing protocol with previous protocols regarding FANET parameters. Finally, the simulation results show better performance than the existing works.

3.2 Flying Ad Hoc Networks (FANETs)

New wireless communication mechanisms have gained much attention in recent years because of their extensive range of applications in aerial technologies, a kind of new technology or configuration to monitor disaster situations or reach hard-to-reach areas. FANETs or flying ad hoc networks are related to a kind of configuration of ad hoc networks that consist of unmanned aerial vehicles (UAVs). Based on the collected images and sending them to a base ground station [73], UAVs are operated and help monitor a particular area in a UAV-to-ground (U2G) communication method.

A unique practice of VANET and MANET can be considered as FANET. Various distinctive challenges of design [74] have been included in the FANETs, although they have common characteristics. Compared to the MANET and VANET [93], each node's degree of mobility is much higher in the FANET. The speed with the value of 30-460 km/h has been included in AUAV [75]. From moment to moment, the UAVs' locations can be changed. Among UAVs, the links are destroyed and established intermittently.

3.3 Ad hoc On-Demand Distance Vector Routing Protocol (AODV)

In this protocol, the source node finds the path for relaying data to the destination node. The correspondent node sends a route request message to its nearest neighbor nodes; various messages of route requests might have existed in the topology. The correspondent node is sent a distinctive request-id to avoid the mixing of the correspondent node. In the AODV protocol, each node maintains a route cache. Only one entry for each destination is included in AODV, and the following hop information to each data communication [82] is stored. Three phases are contained in the AODV routing protocol: route maintenance, packet transmission, and route discovery [94]. However, the routing message types of AODV are included route error, route reply, and route request [95].

UAV's mobility and spatial management are used to find out the route. The rearrangement of these routes is done as a result of the movement. It will lead to the continuation of interconnection between the UAVs. With the increment in the UAVs, the routing should be performed dynamically, and the delay is reduced in delivering data between source and destination nodes [83].

3.4 PF-WGTR - A Predicted Future Weight-Based Routing Scheme

PF-WGTR assigns weight to every node by incorporating several parameters into the AODV routing protocol. The Route (TWGHT) Total Weight between the source and destination nodes defines as the mathematical representation of the following parameters.

- Flying Node Current Speed and Rate of Change of Speed
- Node Flying Direction
- Link Quality between Nodes

Flying Node Current Speed and Rate of Change of Speed

In PF-WGTR assigns weight to every node in a network. During data transmission, observes the current speed and variations in a range of current speed to calculate the total weight. Depending on the total weight, it predicts the future total weight for every node in a given path. In radio communication range, observes which node will stay much longer when flying at the same speed, Direction, and velocity assigns that total weight and considers such calculations are highly desirable conditions.

Vehicle Movement Direction

In the range of radio communication, vehicles will stay much longer in the same Direction logically. In determining TWR to the target, a direction vector also plays an important role. The route selection is determined with a direction parameter and will be demonstrated later.

Node Flying Direction

A direction vector is used to calculate the total weight to the destination node. The route selection can also evaluate the use of a direction parameter. By computing the angle between two driving directions, this value can retrieve.

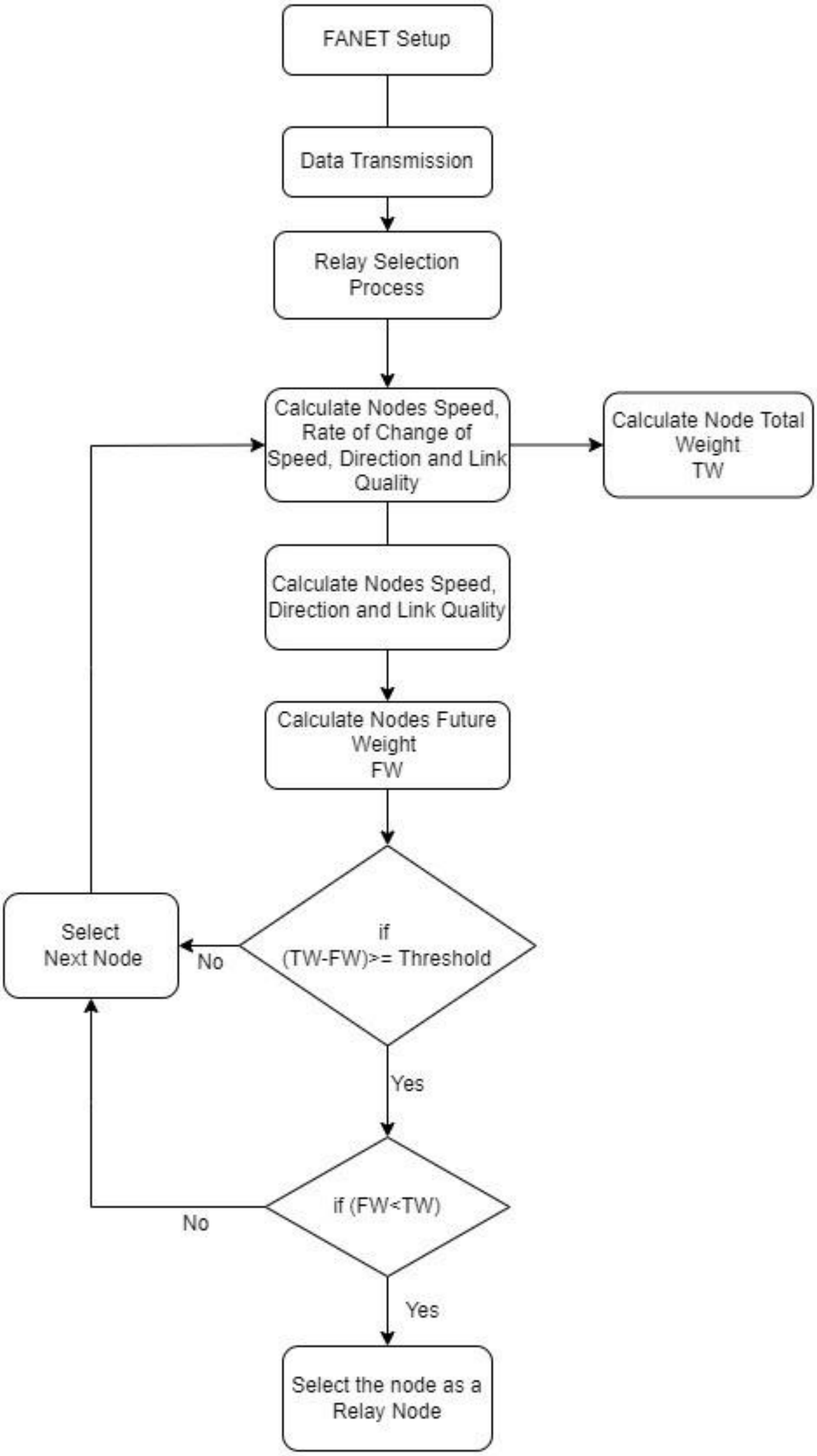


Figure 3.1: Flowchart of Proposed System

Link Quality between Nodes

In the TWGHT, another parameter is also considered, i.e., the link quality between nodes to the route's destination. The quality of a link between the flying nodes might impact by the neighboring nodes, obstacles, and buildings in FANETs. In the calculation of TWGHT, the factor of link quality must include.

So based on the above parameters, the TWGHT can be defined as follows equation (1)

$$\text{TWGHT} = \sum_{i=1}^{N}\{S_n + |\, NH_s - DN_s \,| + RS_n + D_n + LQ_n\} \quad (1)$$

Here, S_n denotes node speed, NH_s &DN_s denote next-hop speed & destination node speed, respectively, and RS_n denotes nodes rate of change of speed, D_n denotes direction vector, and LQ_n denotes the parameter of the link quality between the source and next-hop node.

Here, the rate of change in speed is described as the change in velocity Δv over the change in time Δt (the time it took to make that change in velocity Δv). It is usedto measure how fast velocity Δv changes in meters per second ($^{m}/_{s^2}$). The rateof change of speed RS_n can be described as follows.

$$RS_n = \frac{\Delta v}{\Delta t}$$

Compared to the destination node, the best next-hop node with the least TWGHT includes a similar Direction and speed observed from the above equation. The better link quality chooses what exists between a source node and the next-hop node.

By using the above equation, the TWGHT of a node can calculate. FANET has the significant characteristic of frequent changes in the topology, and the nodes may leave in the next moment in the current topology. To ensure a stable relay node relatively that can choose over a period in the future, the node's future TWGHT should be considered. Again the following parameters are considered for predicting the weight of the nodes for selecting the stable nodes.

Predict Node Speed

During data transmission, consider the shortest time interval between the current speed into the variation of the following speed, and that variation treats a constant to predict the speed of a node. It can be calculated as follows equation (2)

$$PS_n = Speed_n + (\frac{\Delta v_n}{\Delta t} * CURRENT\_TIME) \qquad (2)$$

Here, PS_n denotes the predicted speed of the node n, $Speed_n$ denotes thecurrent speed of the node n, Δv_n is the node n velocity.

Predict Node Movement and Direction

Node flying movement & Direction can calculate as follows equation (3)

$$PD_n = Position_n + (Speed_n * CURRENT\_TIME) \qquad (3)$$

Here, PD_n denotes predicted the Direction of the node n, $Position_n$ denotes the node's current position n, $Speed_n$ denotes the speed of the node n.

Predict Link Quality between Nodes

By using the current coordinate, the node's next coordinate determines,and the link quality between vehicles can estimate as mentioned below-equation(4):

$$LQ_n = \frac{1}{S_{ij}} \qquad (4)$$

We can get the stability index of the link (i, j) based on the node movement as follows.

$$S_{ij} = 1 - \frac{\sqrt{(i_x - j_x)^2 + (i_y - j_y)^2}}{r}$$

Where r is the maximum communication range between the two adjacent nodes; (i_x, i_y) & (j_x, j_y) are the coordinates of nodes i & j, respectively.

Here, LQ_n denotes the link quality of the node n, r denotes the radius of the node n, and T_r denotes the maximum transmission range of the node.

The node's future TWGHT can estimate through the above calculations and estimations. The relay selection rule can be stated as follows in Table3.1:

Table 3.1
The Relay Selection Rule

Node TWGHT	Node STATE	Future TWGHT	Result
Optimal	Unstable	Better	Select the relay
Optimal	Stable	Not Better	Select the relay
Sub Optimal	Unstable	Better	Select the relay
Sub Optimal	Stable	Not Better	Select the relay
Not Optimal	Unstable	Not Better	Do not Select the relay

Here, the node's STATE can state the difference between the node's current TWGHT and future TWGHT. The node's state is STABLE if the difference value exceeds the threshold value. Otherwise, it is UNSTABLE. The threshold value must be selected based on the above characteristics of the connectivity between the node's current weight, the node's state, and predicted future weight.

3.5 Predicted Weight-based Routing Process

For maintaining a routing, hello messages will be broadcasted by the nodes periodically in the AODV protocol. The current TWGHT, state, and future TWGHT can compute by the source node with the neighbor node's information and select by the relay node. The RREQ message multicast to relay node. The RREP message will be sent to the source node along the reverse path when one relay node is well-aware of the path to the destination node. The selection of multicast RREQ messages andthe next relay node has been made if no path is found to reach the destination bya relay node. Until determining a route to the destination node, this process has continued, or such destination cannot find.

3.6Route Selection

This algorithm calculates speed, continuous variations in the speed, and what is the direction of traveling a node from the initial position to the destination. The link quality is based on the fixed speed and location of intermediate nodes from the source node to the target node for a long time. It depends on these considerations, calculating the total weight of every node and predicting future speed, Direction, and link quality for every node using current speed, Direction, and link quality to estimate the future weight. However, the relay node is selected based on the current weight of every node in a network. For example, the weight of the next node n+1 is compared to that of the previous node n. Which node has less weight than the threshold value to check whether the weight is less than the threshold or not? If the value is less than the threshold, compare the future weight of a particular node(i.e., either n or n+1) with the current weight and select the relay node as either n or n+1. Repeat the same process for all the network nodes to find an adaptive routing path to relay the data between the source and the target node.

Algorithm

$\boldsymbol{S_n}$ = speed of the Node n;
RS_n = Rate of Change of Speed for Node n;
D_n = Direction of the Node n;
Q_n= Link Quality of Node n;
PS_n = Predicted Speed of the Node n;
PD_n = Predicted Direction of the Node n;
LQ_n= Predicted Link Quality of Node n;
TWGHT = Total Weight of the Node n;
FWGHT = Future Weight of the Node n;
for all Nodes n
    CalculateS_n, RS$_n$, D_n, Q_n
    Estimate TWGHT
    CalculatePS_n, LQ_n
    Estimate FWGHT
end for
for all Nodes n
    if ($TWGHT_n < TWGHT_{n+1}$)
        if ($|TWGHT_n - FWGHT_n| \geq threshold$)
        if ($FWGHT_n < TWGHT_n$)
        relay = n
        else
        relay = n+1
      end if
      end if
  end if
end for

3.7 Simulation Discussions

The simulation results of the proposed method PF-WGTR compared with the previously existing protocols such as FSQOS and QLF-MOR for analyzing the performances. In this work, network simulator NS-2 utilizes the results of the proposed method in energy consumption, routing overhead, network throughput, delay, and packet delivery ratio. The results demonstrate in detail in the below section.

In the simulation network, deploying 25 flying nodes over the free space network area of 1000 × 600 considers where the configuration of nodes is made with the IEEE standard of 802.15.4 to cope with the FANET standards. The initial energy of 100 joules provides for all nodes communicating with the wireless medium. Based on the RWM model, the UAVs move about the network at random Directions and speeds. Between the UAVs, UDP agents actas transport agents. At the interval of 0.1 ms, the packet size is 1024 bytes within the transmission range of 250 m with a simulation time of 100 sec in a network. Table 3.2 refers to the simulation table, which includes different parameters.

Table 3.2
Simulation Table

Parameters and Traffic model	**Value**
Background Traffic	CBR/UDP
Number of Connections	15
Packet Size	1024 bytes
Packet Rate	1.0
Propagation Type	Free Space
Simulation Time	100 sec
Simulation Parameters and Network Characteristics	
Simulation Version	NS-2.35
MAC & PHY Layer Protocols	IEEE 802_15_4
Transmission Range	250 m
Propagation Model	Two-Ray ground
Type of Antenna	Omni-Antenna
Parameters used for Mobility Model	
Dimensions of the Simulation Area	1000 m x 600 m
Number of Mobile Nodes	25
Mobility Model	Random Waypoint
Traffic Direction	Random

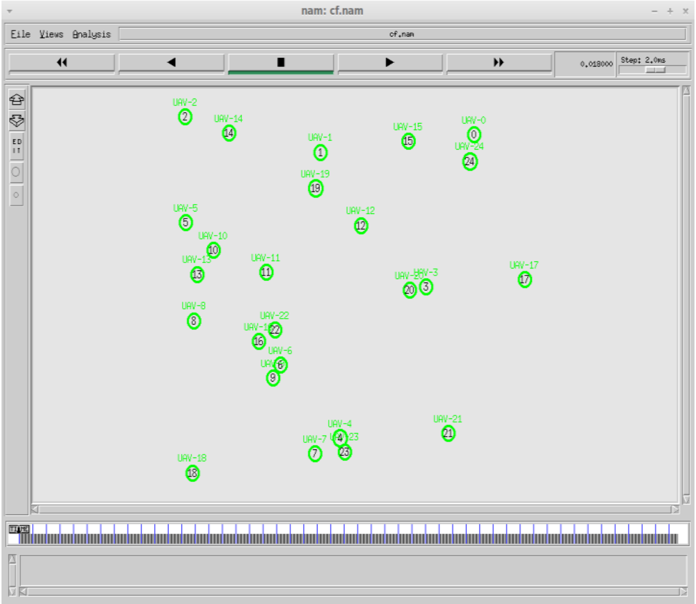


Figure 3.2: UAV Initial Deployment, Start to Flying

The UAVs are deployed in the network area with the size of 1000 x 1000 and represented in figure 3.2. Unique Id is assigned to UAVs for easyidentification. The nodes can fly (move) across the network area randomly.

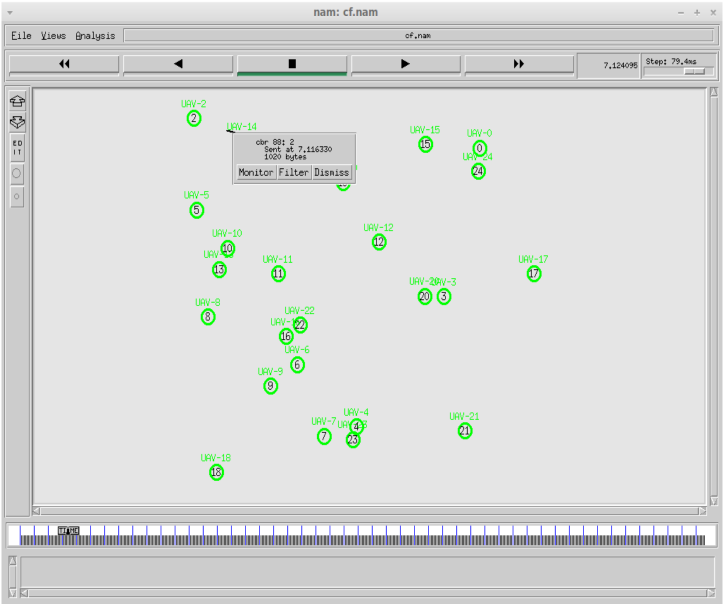


Figure 3.3: UAVs start transmitting the data to each other using a wireless medium

After deployment, the UAVs randomly start flying (moving) in the network area.

The routing protocol establishes the connectivity between thenodes. Nodes start transmitting the data of the size of roughly 1020 bytes through the established links, as shown in figure 3.3.

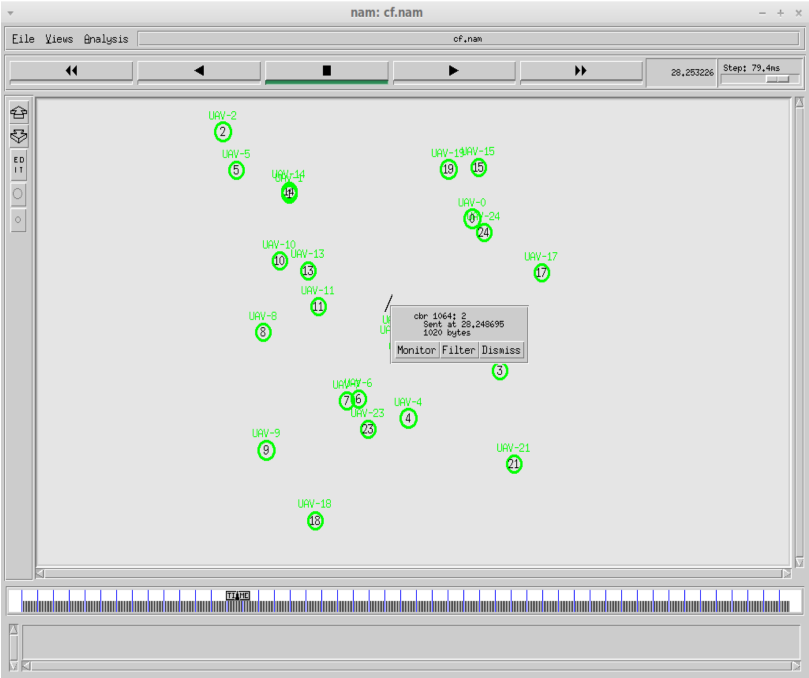


Figure 3.4: A data unit of 1020 bytes is shared between the pair of flying UAVs through the newly established path

The nodes obtained a new position due to flying and continued the data transmission irrespective of their location, as represented in figure 3.4. The proposed protocol predicts the node movement, speed, and link quality and establishes or maintainsthe connectivity through reliable nodes, despite the nodes moving.

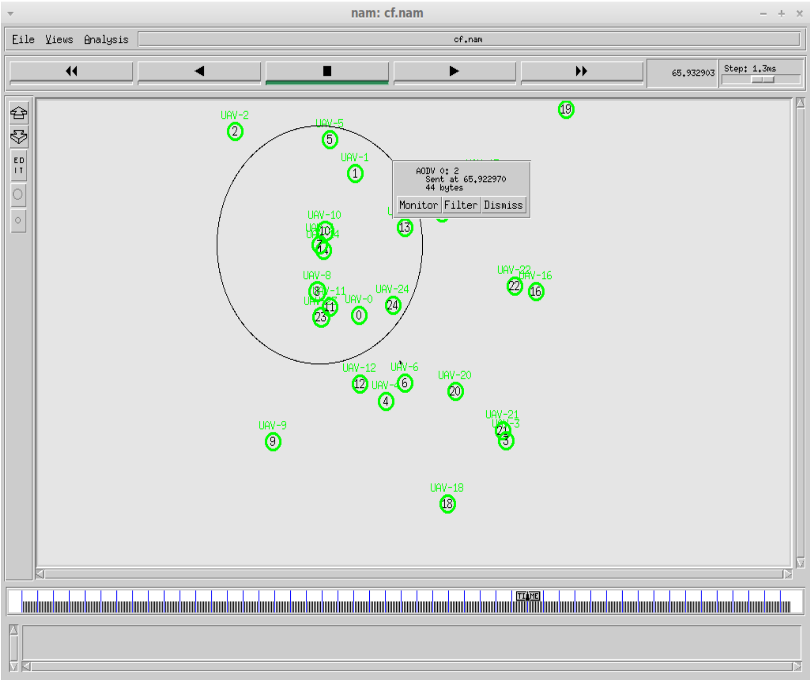


Figure 3.5: AODV keeps tracking the routing parameters using control packets throughout the communication period

During mobility, it is better to monitor the vital parameters of the nodes to maintain uninterrupted connectivity, as shown in figure 3.5. The proposed protocol maintains the parameters list by frequently exchanging the control packets and updating the routing table periodically despite the nodes' constant mobility.

```
Node # (recv) 14 is in permit table has  energy = 99.994116  at time = 2.562042
Node # (recv) 11 is in permit table has  energy = 99.994224  at time = 2.562042
Node # (recv) 10 is in permit table has  energy = 99.994224  at time = 2.562042
Node # (recv) 2 is in permit table has  energy = 99.994168  at time = 2.562042
Node # (recv) 20 is in permit table has  energy = 99.994180  at time = 2.562042
Node # (recv) 5 is in permit table has  energy = 99.994213  at time = 2.562042
Node # (recv) 22 is in permit table has  energy = 99.994213  at time = 2.562042
Node # (recv) 0 is in permit table has  energy = 99.994094  at time = 2.562042
Node # (recv) 24 is in permit table has  energy = 99.994116  at time = 2.562042
Node # (recv) 3 is in permit table has  energy = 99.994150  at time = 2.562042
Node # (recv) 13 is in permit table has  energy = 99.994135  at time = 2.562042
Node # (recv) 16 is in permit table has  energy = 99.994094  at time = 2.562042
Node # (recv) 6 is in permit table has  energy = 99.994168  at time = 2.562043
Node # (recv) 8 is in permit table has  energy = 99.994147  at time = 2.562043
Node # (recv) 9 is in permit table has  energy = 99.994150  at time = 2.562043
Node # (recv) 17 is in permit table has  energy = 99.994151  at time = 2.562043
Node # (recv) 4 is in permit table has  energy = 99.994213  at time = 2.562043
Node # (recv) 7 is in permit table has  energy = 99.994135  at time = 2.562043
Node # (recv) 23 is in permit table has  energy = 99.994195  at time = 2.562043
Node # (recv) 9 is in permit table has  energy = 99.994080  at time = 2.566316
Node # (recv) 16 is in permit table has  energy = 99.994023  at time = 2.566316
Node # (recv) 22 is in permit table has  energy = 99.994143  at time = 2.566316
Node # (recv) 7 is in permit table has  energy = 99.994064  at time = 2.566316
Node # (recv) 11 is in permit table has  energy = 99.994154  at time = 2.566316
```

Figure 3.6: Log file of energy consumption of every node during the communication period

The energy depletion happens in each node when the node participates in the network activity. Initially, all nodes are incorporated with equal energy, and the energy starts depleting for every activity the node performs. The node should possess a decent amount of energy to participate in the activity. Here logfile is represented in figure 3.6.

```
Node 19 has  Future speed = 2.732470 to its neighbors  at time = 2.560441
Current node future distance = 359.166767 at time = 2.560441
Current node future Quality = 2.549575 at time = 2.560441
Current node future Acceleration = 0.067710 at time = 2.560441
Current node PREDICTED FUTURE WGHT = 73.585721 at time = 2.560441
Node 19 has  Future speed = 15.406835 to its neighbors  at time = 2.560441
Current node future distance = 674.275301 at time = 2.560441
Current node future Quality = 251.000000 at time = 2.560441
Current node future Acceleration = 0.401353 at time = 2.560441
Current node PREDICTED FUTURE WGHT = 263.067439 at time = 2.560441
Node 19 has  Future speed = 26.548560 to its neighbors  at time = 2.560441
Current node future distance = 495.265203 at time = 2.560441
Current node future Quality = 251.000000 at time = 2.560441
Current node future Acceleration = 0.646529 at time = 2.560441
Current node PREDICTED FUTURE WGHT = 229.181854 at time = 2.560441
Node 19 has  Future speed = 35.636295 to its neighbors  at time = 2.560441
Current node future distance = 840.349600 at time = 2.560441
Current node future Quality = 251.000000 at time = 2.560441
Current node future Acceleration = 0.918467 at time = 2.560441
Current node PREDICTED FUTURE WGHT = 299.833831 at time = 2.560441
Node 19 has  Future speed = 3.010419 to its neighbors  at time = 2.560441
Current node future distance = 680.356475 at time = 2.560441
Current node future Quality = 251.000000 at time = 2.560441
Current node future Acceleration = 0.075134 at time = 2.560441
Current node PREDICTED FUTURE WGHT = 262.097992 at time = 2.560441
Node 19 has  Future speed = 0.000000 to its neighbors  at time = 2.560441
Current node future distance = 1052.187450 at time = 2.560441
Current node future Quality = 251.000000 at time = 2.560441
Current node future Acceleration = 0.000000 at time = 2.560441
Current node PREDICTED FUTURE WGHT = 335.937490 at time = 2.560441
Node 19 has  Future speed = 0.000000 to its neighbors  at time = 2.560441
```

Figure 3.7: PREDICTED WEIGHT of every UAV at every round of communication concerning proposed routing parameters

The routing table parameters with a predicted weight of each UAV at each communication round are displayed in figure 3.7. The link quality, acceleration, mobility, and Future Direction of nodes predict by the proposed PF-WGTR protocol and the weight assigned to each node. The strategy of future prediction-based weight assigning is to ensure the quality nodes selection for data transmission and a reliable data path.

3.7.1 Comparing the Performance by Varying Simulation time

Figure 3.8: Performance on Delay

The end-to-end delay versus simulation time for the proposed protocol is displayed in figure 3.8. The minimum delay is provided by the proposed method PF- WGTR compared to the previous techniques QLF-MOR and FSQOS due to delivering data to the target node within the estimated time. The shortest and interference-free path is always chosen by considering vital parameters such as link quality, acceleration, and speed.

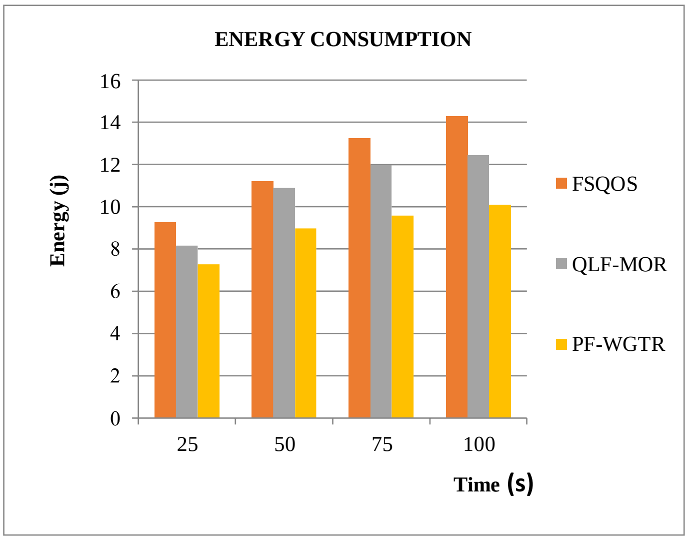


Figure 3.9: Energy Consumption

The energy consumption vs. simulation time graph is displayed in figure 3.9. The results show high energy efficiency achieved with the PF-WGTR than the previously proposed methods like QLF-MOR and FSQOS. It will happen due tothe reduction of improper retransmission of data by the shortest and interrupt-free paths.

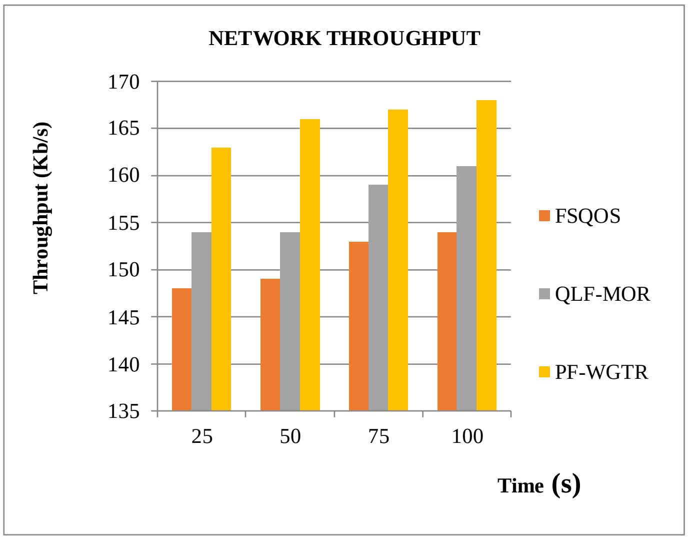


Figure 3.10: Network Throughput

The throughput vs. simulation time for a network represents in figure 3.10. The proposed protocol improves the network throughput by transmitting the information through the optimal and reliable path for the entire communication period. The simulation results show higher throughput for the proposed technique PF-WGTR than the other methods like FSQOS and QLF-MOR.

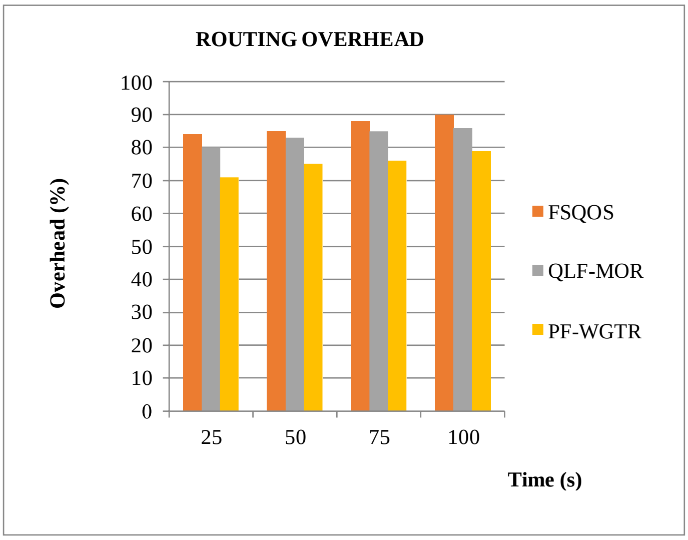


Figure 3.11: Routing Overhead

The simulation results of routing overhead vs. simulation time illustrate in figure 3.11. Based on the performance comparison graph, the reduced overhead achieves with the proposed protocol PF-WGTR compared to the existing protocols like QLF-MOR and FSQOS. It is due to the selection of a reliable path by predicting the future behavior of a node.

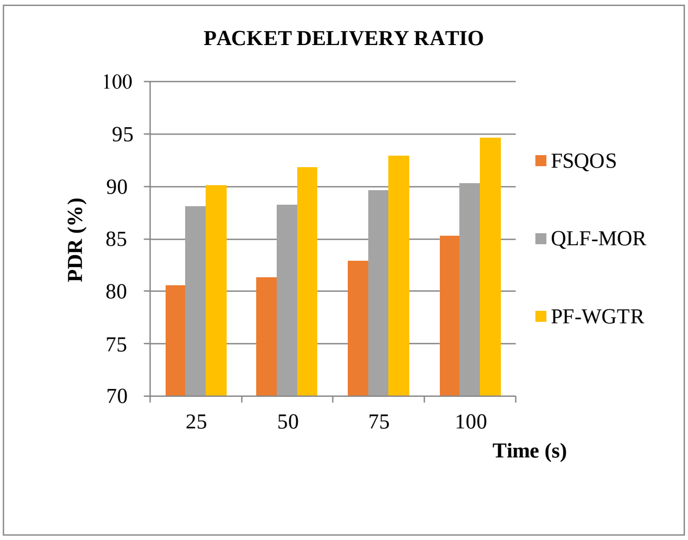


Figure 3.12: Packet Delivery Ratio

The packet delivery ratio vs. simulation time illustrates in figure 3.12. A high PDR rate achieves with the proposed protocol PF-WGTR than the previous protocols like QLF-MOR and FSQOS. It is possible to choose the reliable and optimal path to consider factors that impact the delivery rate of data transmission.

3.7.2 Comparing the Performance by Varying Mean Speed Value

The flying speed is adjusted from 2 to 8 ms for every flying node to evaluate the proposed algorithm's performance, reliability & stability under different speed conditions. The network area remains the same for the network, and the nodes are flying in different directions.

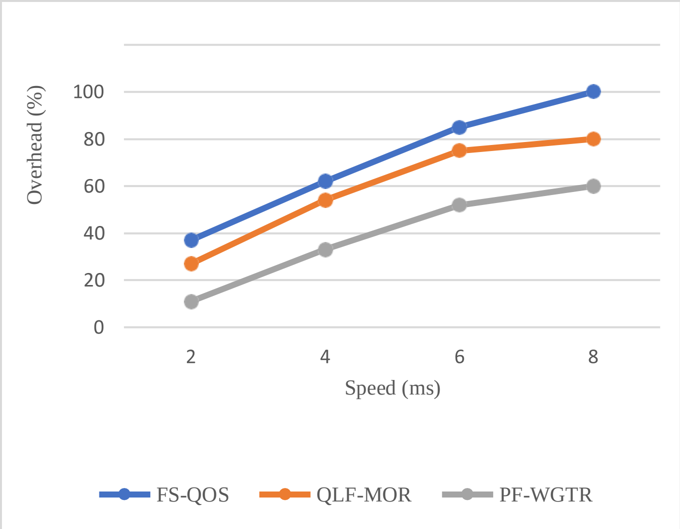


Figure 3.13: Mean Speed vs. Routing Overhead

Table 3.3
Mean Speed vs. Routing Overhead

Speed (ms)	PF-WGTR	QLF-MOR	FSQOS
2	11	27	37
4	33	54	62
6	52	75	85
8	60	80	100

The routing overhead vs. mean speed for a proposed protocol illustrates in Figure 3.13. The graph shows a lower overhead for PF-WGTR than for existing methods like QLF-MOR and FS-QoS. The low overhead is possible because predicting the nodes' future weight leads to maintaining a stable path for a more extended period. In the existing protocols, the variable speed affects the selection of a stable path.

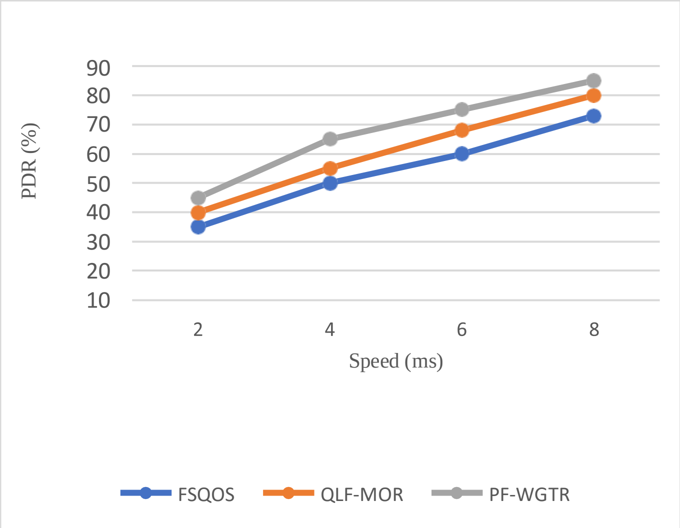


Figure 3.14: Mean Speed vs. Packet Delivery Ratio

Table 3.4

Mean Speed vs. Packet Delivery Ratio

Speed (ms)	PF-WGTR	QLF-MOR	FSQOS
2	45	38	34
4	69	50	50
6	74	60	60
8	86	72	72

The packet delivery ratio vs. mean speed describes in Figure 3.14. In a proposed protocol, the PDR is not affected positively by the variable speed of flying nodes. Hence, the data packets can deliver at a higher rate using a proposed method PF-WGTR compared to the existing techniques like QLF-MOR and FSQOS.

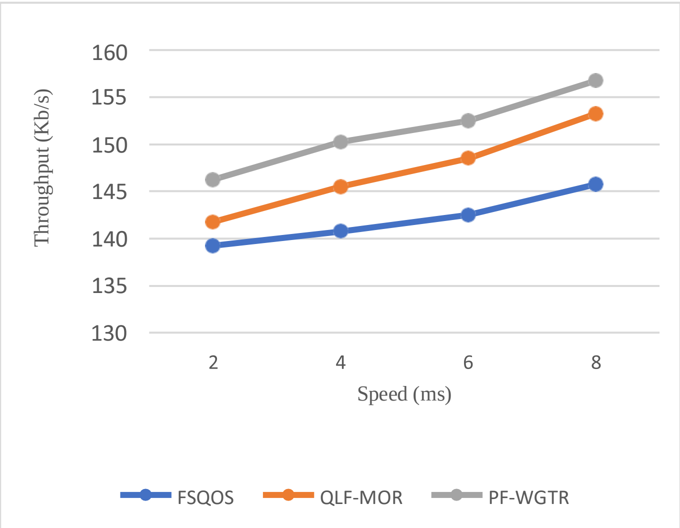


Figure 3.15: Mean Speed vs. Throughput

Table 3.5
Mean Speed vs. Throughput

Speed (ms)	PF-WGTR	QLF-MOR	FSQOS
2	146	142	137
4	150	145	140
6	153	148	143
8	156	149	145

The proposed algorithm and other existing methods simulation results of mean speed vs. throughput have shown in Figure 3.15. The proposed method's increased throughput provides despite the nodes flying in the high-speed mode. The throughput rate improves with the prediction property that prolongs the nodes' connectivity.

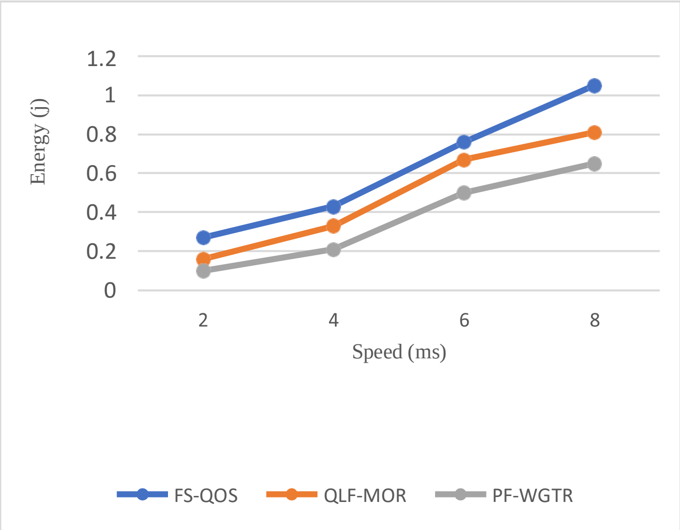


Figure 3.16: Mean Speed vs. Energy Consumption

Table 3.6
Mean Speed vs. Energy Consumption

Speed (ms)	PF-WGTR	QLF-MOR	FSQOS
2	0.1	0.16	0.27
4	0.21	0.33	0.43
6	0.5	0.67	0.76
8	0.65	0.81	1.05

The comparison of mean speed and energy consumption of a proposed algorithm PF-WGTR is displayed in Figure 3.16. The lower consumption of energy results ina proposed protocol due to the prediction of a future node weight that leads to an improved network lifetime.

Figure 3.17: Mean Speed vs. End to End Delay

Table 3.7
Mean Speed vs. End to End Delay

Speed (ms)	PF-WGTR	QLF-MOR	FSQOS
2	18	19	20
4	42	56	61
6	60	76	100
8	80	110	123

The end-to-end delay compares with the mean speed, which displays in Figure 3.17. The proposed algorithm shows a reduced end-to-end delay than the existing ones, such as QLF-MOR and FSQOS. Due to the longer duration of connectivity, the end-to-end delay reduces.

3.7.3 Performance Comparison by Changing Amount of Nodes

The network size increased from 25 to 100 with random node placement, and the flying speed of the node was maintained between 2 to 8 ms. The network size remains the same for the entire run time. A random waypoint model is used to determine the flying Direction of the nodes.

The number of nodes with delay, energy consumption, routing overhead, packet delivery ratio, and throughput for a proposed protocol PF- WGTR and other existing methods like QLF-MOR and FSQOS are illustrated inFigures 3.18-3.22, respectively.

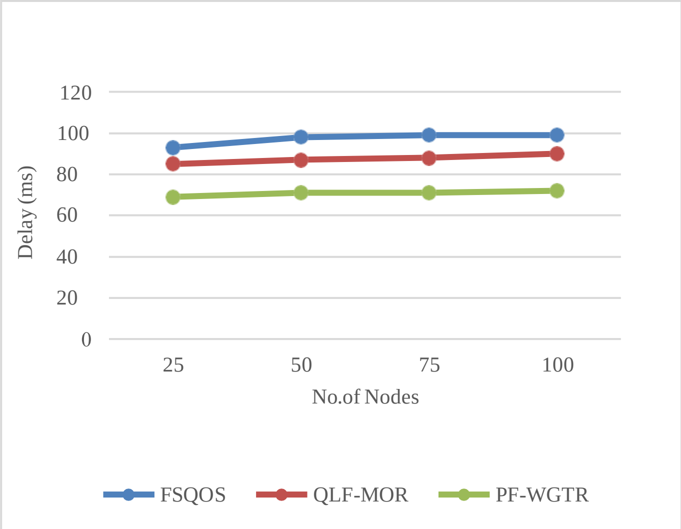


Figure 3.18: Number of Nodes vs. Delay

Table 3.8
End-to-End Delay

NODES	PF-WGTR	QLF-MOR	FSQOS
25	69	85	93
50	71	87	98
75	71	88	99
100	72	90	99

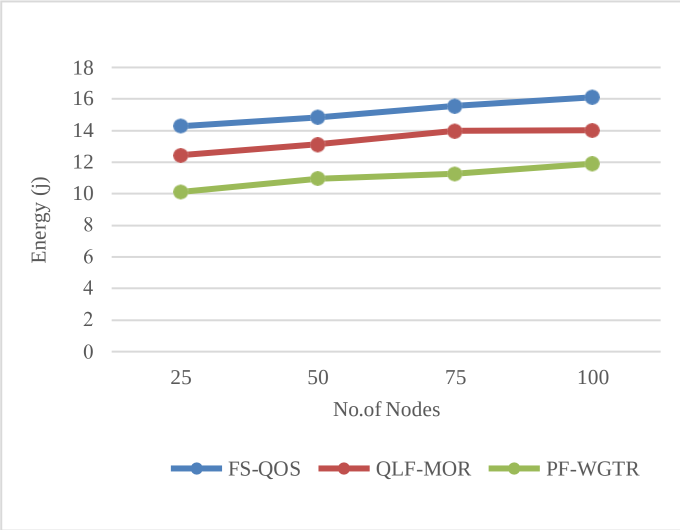


Figure 3.19: Number of Nodes vs. Energy Consumption

Table 3.9
Energy Consumption

NODES	PF-WGTR	QLF-MOR	FSQOS
25	10.11	12.44	14.28
50	10.96	13.12	14.85
75	11.25	13.98	15.56
100	11.9	14.02	16.11

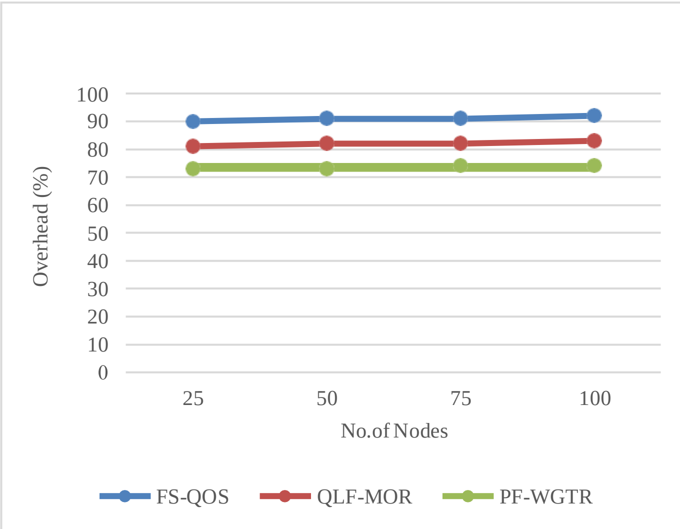


Figure 3.20: Number of Nodes vs. Routing Overhead

Table 3.10
Routing Overhead

NODES	PF-WGTR	QLF-MOR	FSQOS
25	73	81	90
50	73	82	91
75	74	82	91
100	74	83	92

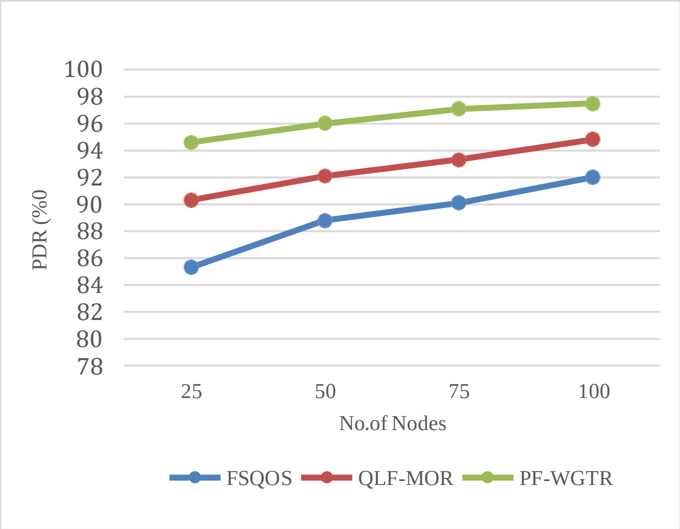


Figure 3.21: Number of Nodes vs. Packet Delivery Ratio

Table 3.11
Packet Delivery Ratio

No. of Nodes	PF-WGTR	QLF-MOR	FSQOS
25	94.6	90.3	85.3
50	96	92.1	88.8
75	97.1	93.3	90.1
100	97.5	94.8	92.0

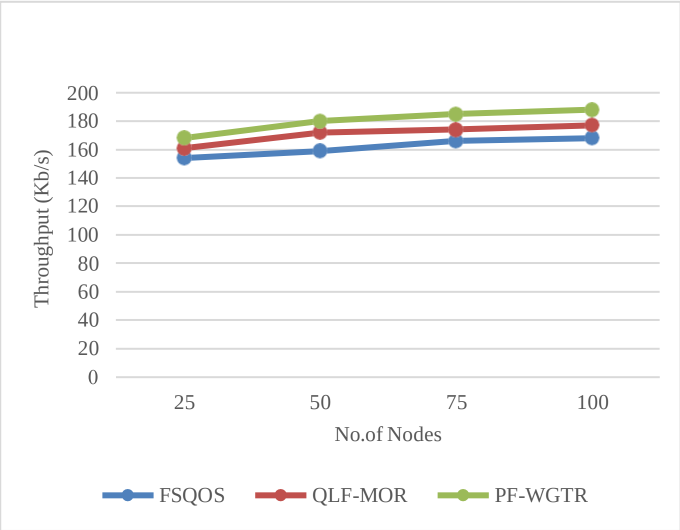


Figure 3.22: Number of Nodes vs. Throughput

Table 3.12
Throughput

NODES	PF-WGTR	QLF-MOR	FSQOS
25	168	161	154
50	180	172	159
75	185	174	166
100	188	177	168

3.7.4 Performance Comparison of Beacon-enabled Vs. Beacon-Less Networks:

Beacon or hello packets must be broadcast frequently to select a route correctly. The collisions with data packet andtransmission delay will result in a high beacon frequency, i.e., high overhead. Also, the FANET implemented as a beacon less depends on the application.

The simulation results of beacon MSGs have been compared with throughput, packet delivery ratio, routing overhead, energy consumption, and end-to-end delay for aproposed method shown in Figures 3.23-3.27correspondingly.

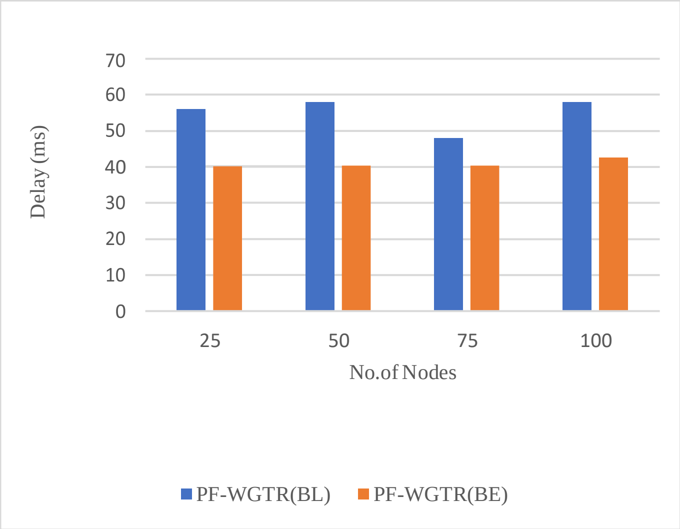


Figure 3.23: Beacon MSGs vs. End-to-End Delay

Table 3.13
Beacon MSGs vs. End-to-End Delay

No. of Nodes	BEACON-ENABLED	BEACON-LESS
25	4.01	56
50	40.4	58
75	42.5	48
100	42.5	58

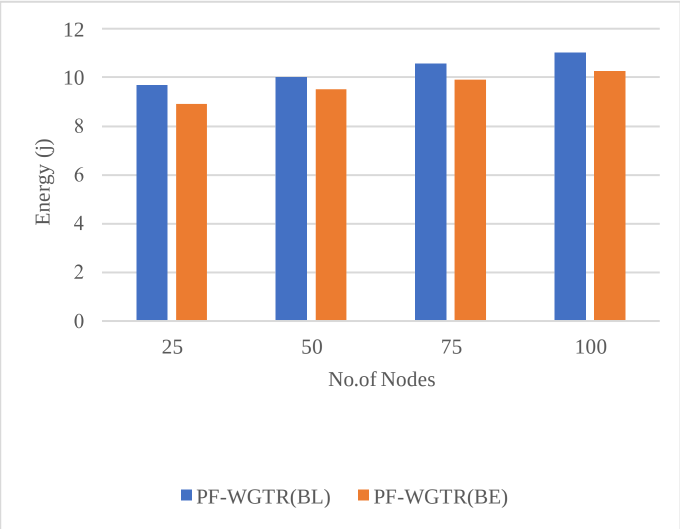


Figure 3.24: Beacon MSGs vs. Energy Consumption

Table 3.14
Beacon MSGs vs. Energy Consumption

No. of Nodes	BEACON-ENABLED	BEACON-LESS
25	8.91	9.66
50	9.51	10.01
75	9.9	10.56
100	10.25	11.01

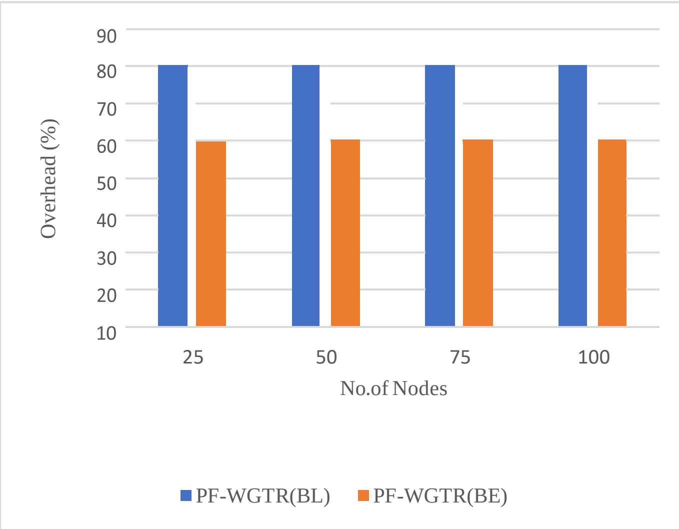


Figure 3.25: Beacon MSGs vs. Routing Overhead

Table 3.15
Beacon MSGs vs. Routing Overhead

No. of Nodes	BEACON-ENABLED	BEACON-LESS
25	50	71
50	52	71
75	51	72
100	51	71

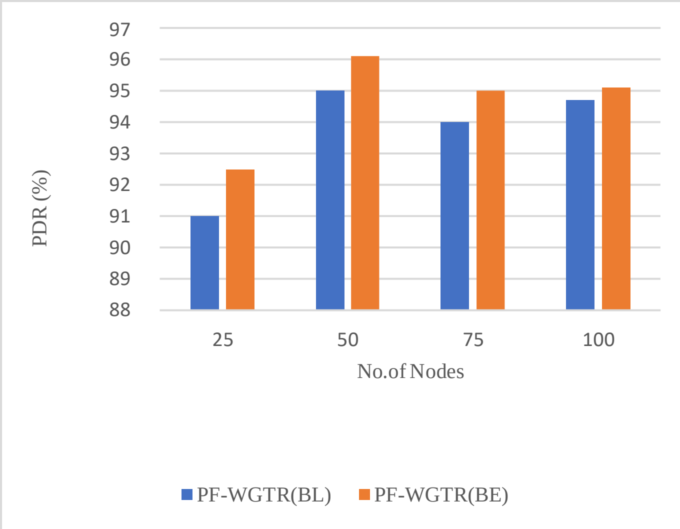


Figure 3.26: Beacon MSGs vs. Packet Delivery Ratio

Table 3.16
Beacon MSGs vs. Packet Delivery Ratio

No. of Nodes	BEACON-ENABLED	BEACON-LESS
25	92.5	91
50	96.1	95
75	95	94
100	95.1	94.7

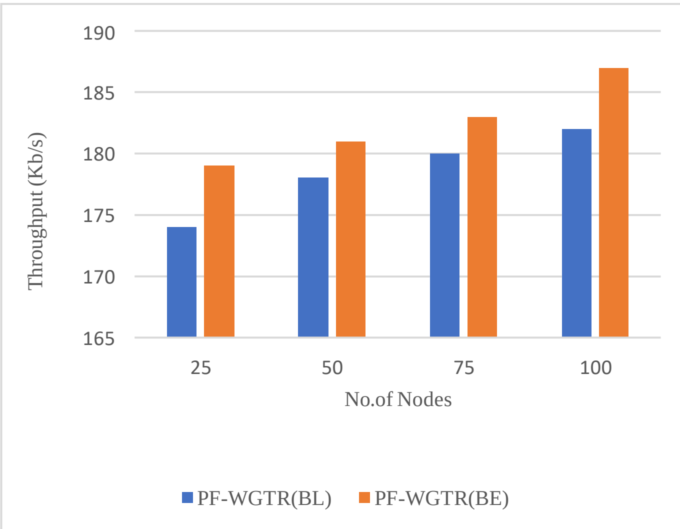


Figure 3.27: Beacon MSGs vs.Throughput

Table 3.17
Beacon MSGs vs. Throughput

No. of Nodes	BEACON-ENABLED	BEACON-LESS
25	179	174
50	181	178
75	183	180
100	187	182

3.8 Comparison of Routing Protocols

Most of the existing routing protocols face a problem considering an essential parameter: energy consumption due to its limited battery life. However, in our research, we considered the parameter energy consumption to give a better result with the help of our proposed routing protocol. The proposed routing protocol, Predicted Future Weight-based Routing Scheme, compared with existing routing protocols QLF-MOR and FSQOS in terms of FANET performance parameters such as end-to-end delay, energy consumption, network throughput, etc. by varying simulation time, speed of a node and number of nodes in a network topology. The comparison results in a proposed protocol giving better accuracy than existing protocols. Table 3.18 show the following.

Table 3.18
Comparison of Routing Protocols

Routing Protocol	Varying Simulation Time					Varying Speed					Varying No. of Nodes				
	End-to-End delay (ms)	Energy Consumption (j)	Network Throughput (Kbps)	Routing Overhead (%)	PDR (%)	End-to-End delay (ms)	Energy Consumption (j)	Network Throughput (Kbps)	Routing Overhead (%)	PDR (%)	End-to-End delay (ms)	Energy Consumption (j)	Network Throughput (Kbps)	Routing Overhead (%)	PDR (%)
PF-WGTR	70	10	168	78	95	80	0.65	156	60	86	72	11.29	188	0.074	97.5
QLF-MOR	85	13	160	87	90	110	0.81	149	80	72	90	14.02	177	0.083	94.8
FSQOS	93	15	153	90	85	123	1.05	145	100	72	99	16.11	168	0.092	92.0

3.9 Conclusion

FANETs have a unique nature than the other networks. The nodes in the FANETs are flying around the deployment area, unlike node mobility in MANETs or VANETs. This unique nature of the FANETs makes the conventional routing protocols such as AODV do not fit the flying networks. So, there is a need for a new routing protocol that can work well according to the nodes' flying nature. In this research, a new routing protocol considers the node's certain factors like speed, acceleration, link quality, etc. Due to the continuous flying of the nodes, there might be frequent modifications in the network topology. Each node in the network needs to keep track of it and refresh its routing table to have uninterrupted communication. The proposed protocol considers the nodes' current factors and predicts the node's future parameters, such as speed and rate of change speed, etc., to overcome such problems in existing protocols. Based on these predictions, the proposed protocol assigns weight to every node, and the routing decision is made according to node weight. This routing strategy ensures the transmission path is reliable and interference-free, resulting in decreased routing overhead and enhanced throughput.

Compared to the previously proposed protocols, the proposed protocol achieved better performance through the simulation results based on the consumption of energy, PDR, and other essential parameters.

CHAPTER-4

EDGE-BASED DISJOINT PATH SELECTION SCHEME

4.1 Introduction

In both military and civilian domains, UAVs have been used extensively. In recent years [95], FANETs containing multiple UAVs have been investigated for enabling complicated applications that are difficult to use conventional mobile ad hoc networks or individual UAVs. Precise and prompt data delivery is required between UAVs in FANETs for applications such as wildfire monitoring and search and rescue operations. Several unique features are included in FANETs, such as frequent topology changes, high mobility, and challenges in network connectivity [96].

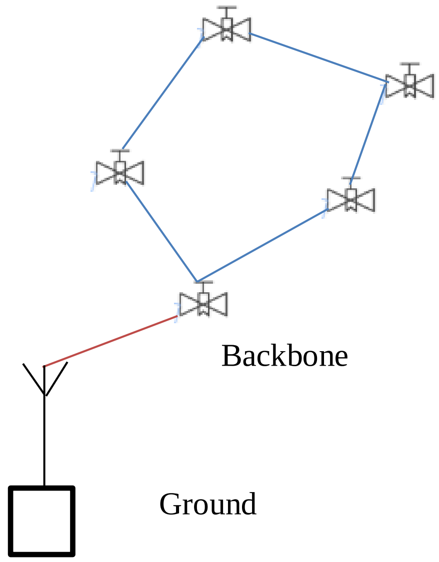


Figure 4.1: Flying Ad Hoc Networks [25]

Figure 4.1 shows the simplest, most straightforward ad-hoc network. For maintaining the link between BS and other sub-UAVs, the part of a gateway node is included in the backbone UAV for FANETs. Gateway UAVs will consider wireless communication equipment. It can work under the constraints of long communication with ground stations, contact with UAVs, low power consumption, and high power stations [97]. The same movement patterns, like Direction and speed, need to be included in all connected UAVs for FANETs to sustain a reliable connection. UAVs can be deployed to accomplish the missions of autonomous aerial surveillance [98].

For data transmission, the shortest path is used by the reactive routing protocols like AODV in the route discovery process. An alternative approach is sought only if an active way is broken [99]. Frequent route discoveries in FANETs cause link breakage, characterized based on a high degree of mobility, resulting in significantly increased overhead [100]. This link failure causes two significant problems. All packets transmitted on the broken route have dropped out, and the average packet delivery ratio (PDR) has reduced [101]. Until a new route is discovered, the data transmission is stopped, and the average end-to-end delay is increased.

The multiple routes establishment is allowed in the disjoint routing. Every link between a source and destination contains a unique set of nodes. Two different types of courses are link-disjoint and node-disjoint. The common nodes are not included in the node-disjoint paths other than source and destination. Similarly, any common link does not include in the link-disjoint paths, but common nodes may exist. Compared with the link disjoint links, less effective connections result from the lower number of such disjoint routes, although the node-disjoint guarantees the link's failure in case of main interest towards the fault tolerance during the path failure [102].In this research, we define a new metric called link steadiness, which defines the steadiness of the available link during data communication. The factors used to determine the link steadiness are the minimum energy drain rate, node closeness, ETX & link availability parameter. A new FANET routing protocol is proposed using this new factor known as EBDPS: an edge-based disjoint path selection scheme that eliminates the redundant path selection and improves the energy efficiency and network lifetime. The proposed EBDPS scheme aims to reduce the routing complexity & to improve energy efficiency on the links by avoiding redundant path selection using an edge-based disjoint path selection scheme. Two different components are included in the algorithm, such as route maintenance and route discovery process.

4.1.1 Contribution of the Work

- In the proposed EBDPS scheme, a new metric called link steadiness, which defines the steadiness of the available link during data communication, is introduced in this scheme.

- The newly introduced link steadiness parameter evaluates the link steadiness of the selected links based the multiple parameters like link steadiness, minimum energy drain rate, node closeness, ETX & link availability factor.
- In the proposed scheme, the possible paths are selected and cached in the source node, and the steadiness of the selected primary path is constantly monitored to reduce the possibility of link breakage during data transmission. So the packet delivery rate is not affected if the link breakage occurs.
- These selected disjoint paths control the number of hops required for forwarding the information to the destination via minimum hops. It achieves energy efficiency during data transmission.
- The proposed scheme of EBDPS provides improved delay and packet delivery ratio and controls the overhead in the lower or higher mobility of network environments.

4.2 Proposed Framework

The motive of the proposed EBDPS - an edge-based disjoint path selection scheme is to eliminate the redundant path selection and improve the energy efficiency and network lifetime. The proposed EBDPS scheme computes stable and multiple link disjoint paths based on the proposed link steadiness metric. A reliable alternative way is determined by using high steadiness during link failure. It is designed primarily for low and high-mobility FANETs and where link failures occur frequently. The new parameter of link steadiness is discussed for the route maintenance and route discovery of link-disjoint.

Link Steadiness Metric

The factors used to determine the link steadiness are minimum energy drain rate, node closeness, and ETX & link availability.

Table 4.1
Factors considered in the proposed method

Factors Considered	Description
LST	Link Steadiness Factor
MDR	Minimum-Energy Drain Rate
NC	Node Closeness
ETX	Expected Transmission Count
LA	Link Available Factor
E_{res}	Residual Energy
DRI	Drain Rate Index
D_{ij}	Distance between node i and Node j
R	Communication Radius
d_f,d_r	Forward Delivery Ratio & Reverse Delivery Ratio
T_x	Transmission Range

Let us assume the nodes i and j are in the communication range of each other. LSTij refers to the link steadiness between i and j, and it can formulate as an integration of the minimum energy drain rate MDR_{ij}, node closeness NC_{ij}, ETX as ETX_{ij} & link availability factor LA_{ij} as follows in the equation (1):

$$LST_{ij} = \alpha_1 MDR_{ij} + \alpha_2 NC_{ij} + \alpha_3 ETX_{ij} + \alpha_4 LA_{ij} \quad (1)$$

Where α_1, α_2, α_3 & α_4 indicate the weighting coefficients that constrained by the below equation (2):

$$\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1 \quad (2)$$

The parameters used in the link steadiness estimation process are explained as follows:

Minimum Energy Drain Rate

The energy dissipation rate is measured at the node's minimum energy drain rate. Each node n_i monitors the energy consumption through reception, transmission, and overhearing activities. The minimum energy drain rate MDR_i, for every t seconds, has been computed basedon the average energy consumption value, and the energy dissipation per second is computed during the past t seconds. The remaining energy-based energy-saving mechanisms cannot establish the best route every time. The nodewilling to accept all route requests due to its high residual energy eventually ends with high traffic passing through it. In this case, the actual energy consumption is high in that particular node, leading to the sharp reduction of battery energy. The node is soon to die of quick exhaustion of energy consequently. Introduce the minimum energy drain rate parameter to overcome this issue.

The residual energy and the drain rate index (DRI) are considered for a given node based on the minimum energy drain rate for measurement of energy dissipation rate. Each node i monitor the energy consumption, and it is causeddue to transmission, overhearing, and reception activities. The average energy consumption is used for estimating the energy drain rate DRI for eacht second, and the energy consumption per second is estimated based on the pastt seconds. The previous and newly calculated values have been considered for calculating the actual value of DRI_i:

$$DRI_{curr}, i = DRI_i\ (t)$$

$$DRI_i\ (t) = \alpha * DRI_i\ (t-1) + (1-\alpha) * DRI_{curr}, i \quad (3)$$

Finally, the minimum energy drain rate can be estimated based on the available energy on the node such as E_{res} as follows equation (4),

$$MDR_{ij} = \frac{E_{res}}{DRI_i\ (t)} \quad (4)$$

Node Closeness

The node closeness NC_{ij} indicates the node i and j closeness related to the distance between nodes. This node closeness parameter helps to identify the node with less distance so that the energy to send the data to longer distances could be saved. The greater closeness indicates that closeness of two nodes' movement and the longer time will take for the link breakage. This parameter can be represented as follows in equation (5):

$$NC_{ij} = \frac{R - D_{ij}}{R} \quad (5)$$

Where D_{ij} represents the two nodes' Euclidean distance and R is the node's communication radius. The below equation (6) is used to calculate the Euclidean distance between nodes i and j:

$$D_{ij} = \sqrt{(X_j(t) - X_i(t))^2 + (Y_j(t) - Y_i(t))^2 + (Z_j(t) - Z_i(t))^2} \qquad (6)$$

X, Y, and Z represent the flying coordinates of nodes i and j at time t.

ETX

Based on the required number of data transmissions for sending a data packet through the link, including retransmissions, the ETX of a link is estimated. The route ETX is the summation of the ETX for each link in a route. The link's reverse and forward delivery ratios calculate the ETX.

The forward delivery ratio d_f is defined as the measured probability of an arrived data packet at the recipient, and the reverse delivery ratio d_r is the probability of successfully received packets. Equation (7) is used for estimatingthe ETX:

$$ETX = \frac{1}{d_f \ x \ d_r} \qquad (7)$$

Link Availability Factor

The link availability is estimated using the current coordinate and the linkquality between nodes. It can be represented as follows equation (8).

$$LQ_n = \frac{1}{(1 - {}^{R_n}/_{Tx_n} + 1)} \qquad (8)$$

Here, LQ_n denotes the link quality of the node n, R_n denotes the radius of the node n, Tx_n, and denotes the maximum transmission range of the node.

Route Discovery

The control packet structures are modified to determine the multiple and stable link-disjoint paths between source and destination pairs, and two additional fields called ini_hop and $\boldsymbol{LST}$ are added. Each routing table entry structure is shown in the below figure. The novelty in the route discovery mechanism is that every link is estimated with a link steadiness factor which comprises minimum energy drain rate, node closeness, & link availability factor. The computed $\boldsymbol{LST}$ is added to the route discovery mechanism and considered the primary parameter for route selection. Since all have estimated the link steadiness metric, it is easier for the proposed method to share the $\boldsymbol{LST}$ value with the neighbor nodes during the route discovery process. Since LST is the primary route selection parameter, it is easier for the source node to select and establish the route based on the estimated route stability.

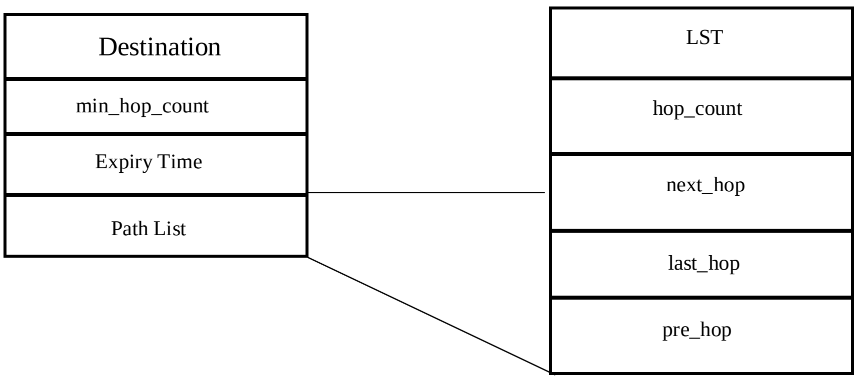


Figure 4.2: Routing Table Structure in Nodes

Here, min_hop_count indicates all paths' minimum hop count to the same destination. The constraint of min_hop_count plus one is not shorter than the hop count should satisfy by each path in a route. Otherwise, it leads to routing loops. The pre_hop field indicates the previous hop address from the packet received; the last_hop is the last hop address to the destination.

Route discovery is initiated by broadcasting the control packet to theneighbors if a source node requires communication with another node for whichactive routes are not in its routing table. If a new link-disjoint path can provide to the source rather than the duplicate packets discarded, the control packets received by the intermediate nodes have recorded the information that contains the packet to the routing table. Although intermediate nodes canprovide a route to the destination, they exclude from sending a reply message tothe source directly to assure the disjoint paths' accuracy. For sending a reply to the source, the destination is only qualified. In the case of intermediate nodes,the reverse routes update by the destination on receiving a packet. The destination prepares to generate a response packet to the source. All arriving response packets will not be replied to the node, and those generating a new disjoint path will be replied to the node. A different reverse route will be taken to the source by an intermediate node when it receives the response packet. An extreme constant route is chosen for data broadcast after receiving the response packet by the source node.

Consider the below example for a better explanation of the route discovery process. The quantity near the connection represents the connection's steadiness *LST* metric.

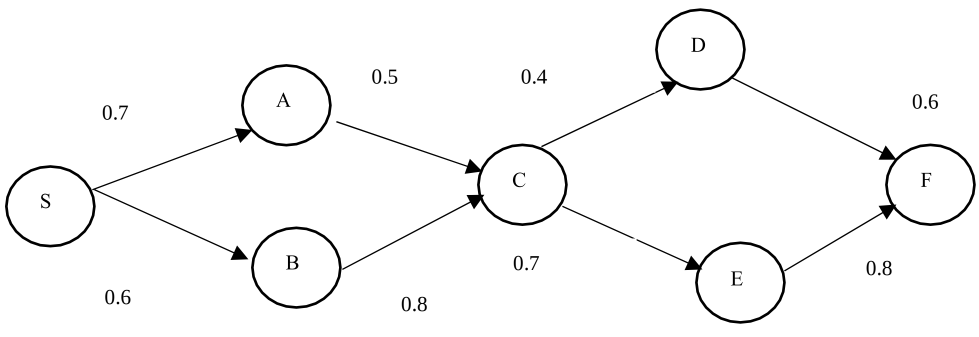


Figure 4.3: Route Discovery

Node C is combined with the converse path, which has the biggest metric if it receives the message from neighbor D. A whole path (S-A-C-D-F) is formed by transmitting a response message via node A. Some predefined threshold is smaller than the corresponding path metric difference if the previously arrived metric (0.4) is much smaller than the response copy from node E, which has link_st (0.7). Both routes will not achieve good stability when a new response packet transmits via the new converse path, ex: C-B-S. These two link-disjoint paths' combinations, like S-B-C-E-F and S-A-C-E-F are shared to maximize stability. The response message of 0.7 metric will send via node A and the additional message with 0.4 metric will send through node B.

Route Maintenance

The proposed link steadiness metric determines the link breakage time in this scheme. The parameter of link steadiness is computed with the neighbor for each node on the path during data packet transmission. Intimation message generates and is sent to the destination through the primary path after the metric value is dropped below the threshold. The information about the source, destination, sequence number, and link metric below the threshold have been recorded in the intimation message. The particular messages carrying an additional flag to the source are sent by the destination upon themessage reception via different paths based on the routing table for detecting allbackup paths' steadiness. The source has used the path from backup directly to relay the data in case of a significant distance than predefined threshold link steadiness, or it is required to initiate the route discovery to determine a more reliable path.

4.3 Edge-Based Disjoint Path Selection (Pseudo code)

This algorithm calculates all the factors, like link steadiness, minimum energy drain rate, expected transmission count, etc., for all the nodes in a network. The calculated factors are stored in the routing table and implemented in the route discovery process. However, the route is established from the source node to the destination node, and the source node broadcasts control packets to the destination node through the intermediate nodes and waits for a response. An intermediate node checks whether the received packet is redundant or not; if the packet is not redundant, it is forwarded; otherwise, discard the packet.

Algorithm

MDR- Minimum energy drain rate,
NC-node connectivity,
ETX-Expectedtransmission count,
LA-link availability,
LST – link steadiness metric
$NODE\_LST$ – LST value of the node;
$SELECT\_LST$ – threshold
LST value to select the node;
$DIFF\_THRESHOLD$ – Difference of LST value between two responsepackets
$BREAK\_THRESHOLD$ – Predefined threshold to consider the path issupposed to be broken

for all nodes n
    Calculate MDR, NC, ETX, LA
    Calculate LST
End for
Node n store LST in the routing table
Route discovery phase
    $SOURCE$ broadcast control packets
    $DESTINATION$ send $response\_packet$
    if $new\_response\_packet$
`   Intermediate node n checks for $NODE\_LST$
            if ($NODE\_LST$ > $SELECT\_LST$)
            Add node n into $forwarder\_list$
    End if
    if $duplicate\_response\_packet$
        if ($NODE\_LST$ > $DIFF\_THRESHOLD$)
            Add node n into $forwarder\_list$
        else
            Discard the packet

    End if
Route Maintenance Phase
    if ($NODE\_LST$ > $BREAK\_THRESHOLD$)
    $DESTINATION$ Intimate the link breakage
    $SOURCE$ Check for $BACKUP\_PATH$
        if $BACKUP\_PATH$ exists
            Retransmit the data through $BACKUP\_PATH$

        else
        End if   Reinitiate the route discovery process

    End if

4.4 Results and Discussions

The proposed protocol comparative analysis is done with the existing ECAD and BIMAC protocols. 25 nodes are considered and placed randomly in the network for the simulation requirement. Since our network is FANET, the random waypoint model movement was given to the nodes. MAC

802.15.4 is utilized in order to facilitate the FANET communication property. An initial energy capacity of 100J is configured with every node in the network, with each node in the Omni-Antenna direction. The CBR (constant bit rate) traffic producer is recycled to produce consistent traffic during document transmission. UDP carries out data communication as no acknowledgment is needed from the receiver node. The protocol implementation is done in NS-2, and performance is compared with ECAD and BIMAC protocols. Table 4.2 represent the simulation table of the network process.

Table 4.2
Simulation Table

Parameter	**Value**
Number of Nodes	25
Network Area	1000 x 1000 m2
Initial Energy	100j
MAC Type	802_15_4
Routing Protocol	AODV
Simulation Time	100 s

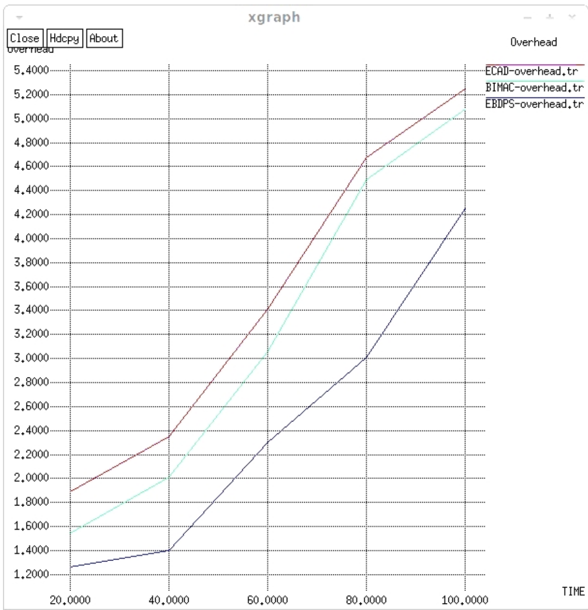


Figure 4.4: Routing Overhead

Table 4.3
Time vs. Routing Overhead

Time	ECAD	BIMAC	EBDPS
20	1.89	1.54	1.26
40	2.35	2.01	1.40
60	3.41	3.06	2.30
80	4.68	4.49	3.01
100	5.25	5.08	4.25

Fig. 4.4 shows the simulation results of routing overhead for the proposed algorithm and previous existing techniques. Routing overhead refers to the transferred or transmitted total number of packets from one node to another. The routing process overhead, packet preparation, and routing table in a node are included. Our proposal minimizes the routing overhead by avoiding path redundancy and calculating the path steadiness metric. It avoids the selection of unstable routes, thus fewer path failures. The simulation results in table 4.3 prove that the proposed method reduces the overhead up to 0.12compared with the existing methods.

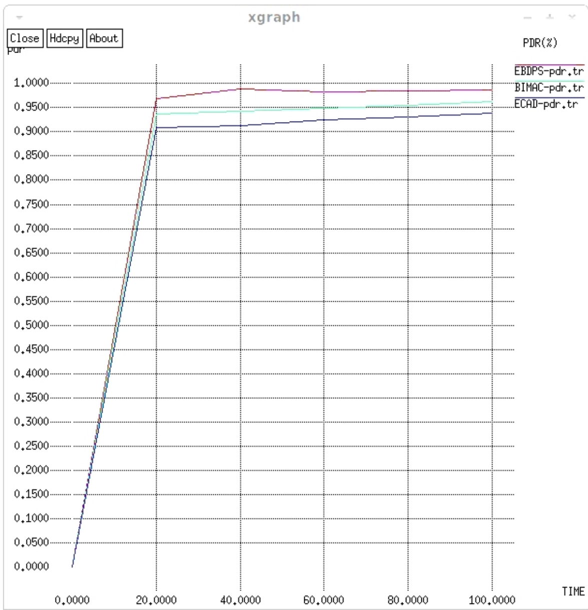


Figure 4.5: Packet Delivery Ratio

Table 4.4
Time vs. Packet Delivery Ratio

Time	ECAD	BIMAC	EBDPS
20	0.9085	0.9369	0.9695
40	0.9124	0.9430	0.9891
60	0.9238	0.9497	0.9826
80	0.9317	0.9548	0.9839
100	0.9397	0.9635	0.9861

Figure 4.5 displays the results of the PDR for the proposed algorithm EBDPS and other previous methods like ECAD and BIMAC. The maximum quantity of data packets is reached at the destination node. The efficient route selection improves the PDR by selecting the efficient relay nodes.The proposed mechanism measures the link stability using the steadiness metric;hence the appropriate nodes are only selected for routing. Based on the analysisof simulation results, it gives more efficiency than previous algorithms in termsof PDR listed in the above table 4.4.

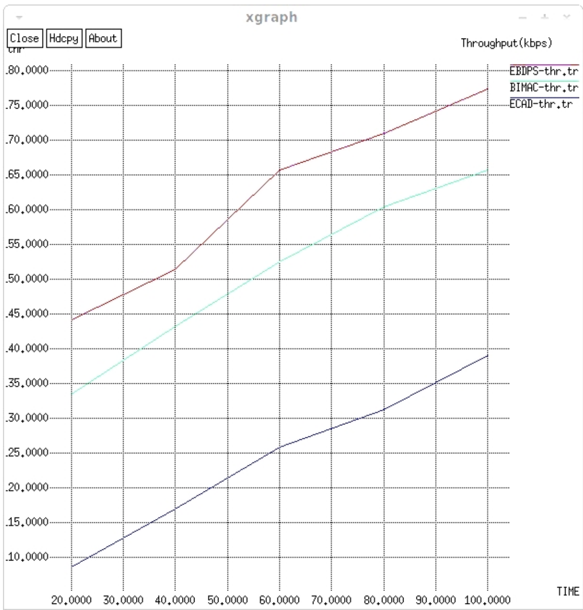


Figure 4.6: Throughput

Table 4.5
Time vs. Throughput

Time	ECAD	BIMAC	EBDPS
20	108.56	133.42	144.13
40	116.87	143.17	151.42
60	125.78	152.46	165.75
80	131.20	160.42	171.01
100	139.05	165.64	177.39

Fig. 4.6 displays the throughput results of proposed algorithms and existing methods. Throughput is the total data units in a system that can be processed for a given time. The high throughput rate ensures high data deliverability to the intended destination. The quick path change affects the network throughput majorly. Our proposal tackled the path change issue by selecting reliable relay nodes and estimating every link's steadiness.

Moreover, the relay nodes are selected based on their steadiness and available energy.Due to this, the selected path will be stable for a long time and ensures a high data delivery rate. Thus, the proposed method shows better throughput results in table 4.5 than the existing ones like ECAD and BIMAC.

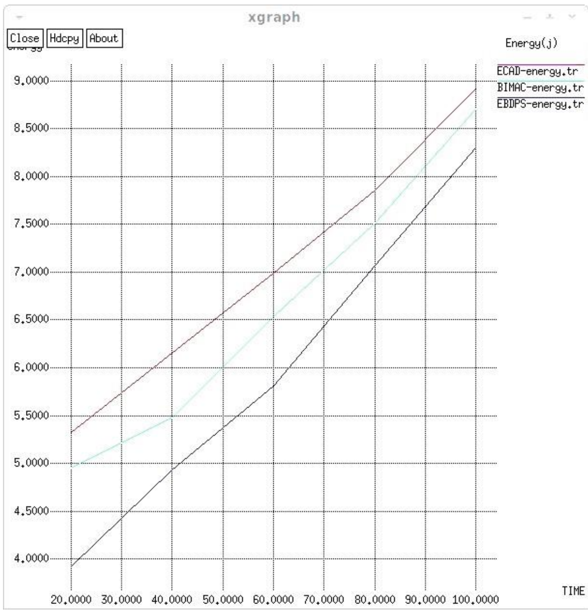


Figure 4.7: Energy Consumption

Table 4.6
Time vs. Energy Consumption

Time	ECAD	BIMAC	EBDPS
20	5.328	4.954	3.920
40	4.987	5.480	4.933
60	6.987	6.540	5.811
80	7.854	7.510	7.067
100	8.918	8.70	8.296

Fig. 4.7 shows the simulation results of energy consumption for the proposed algorithm and previous existing techniques. Maintaining sufficient energy helps the UAVs to fly high and longer duration. The UAV's flying ability is directly connected to the available energy. The high energy consumption leads to quicker energy drain, and they lose their flying capability. The proposal method ensures optimized energy utilization by selecting the appropriate relay nodes andavoiding path redundancy. By comparing the existing methods of BIMACand ECAD, the proposed method, EBDPS, saves a considerable amount of energyto improve the network lifetime it has listed in the above table 4.6.

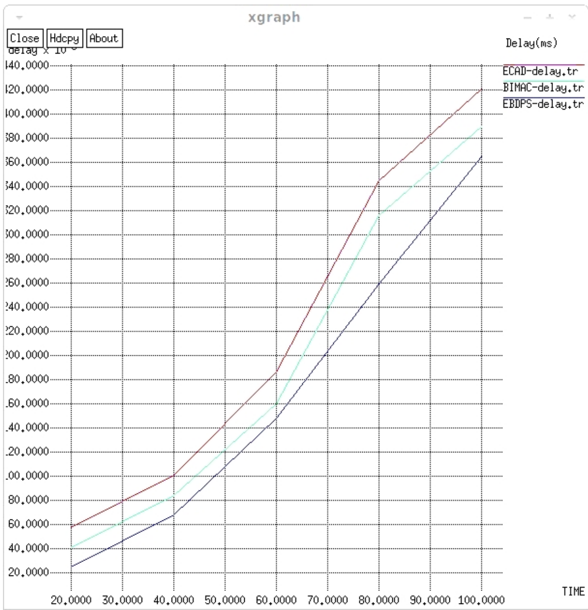


Figure 4.8: End-to-End Delay

Table 4.7
Time vs. End-to-End Delay

Time	ECAD	BIMAC	EBDPS
20	0.058	0.041	0.025
40	0.101	0.084	0.068
60	0.187	0.160	0.148
80	0.345	0.316	0.259
100	0.421	0.390	0.365

Fig. 4.8 illustrates the end-to-end delay results of the proposed method, EBDPS. Delay is a crucial QoS parameter for forwarding data in a time constraint environment. The selection of relay nodes for communication ensuresa high data delivery rate within the estimated time. Also, considering the link steadiness metric provides the participation of stable relay nodes for datacommunication. The simulation shows effective results in table 4.7 in end-to-end delay compared to other ECAD and BIMAC.

4.5 Comparison of Routing Protocols

The proposed routing protocol, Edge-based Disjoint Path Selection Scheme (EBDPS), is compared with the existing routing protocol in terms of QoS parameters such as routing overhead, PDR, throughput, energy consumption, and end-to-end delay. The proposed protocol outperforms the previous protocols.

Table: 4.8
Comparison of Routing Protocols

Routing Protocol	Performance Parameters				
	Routing Overhead	**Packet Delivery Ratio**	**Throughput**	**Energy Consumption**	**End-to-End Delay**
ECAD	5.25	0.9397	139.05	8.918	0.421
BIMAC	5.08	0.9635	165.64	8.70	0.390
EBDPS	4.25	0.9861	177.39	8.296	0.365

4.6 CONCLUSION

The high mobility and frequent topology changes are the primary concern in achieving efficiency in FANETs. It includes various challenges, from the dynamic topological structure to selecting an effective, reliable relay node without redundancy. Redundant link and relay node selection are played avital role in controlling the communication load and energy efficiency. In this work, we introduce an EBDPS - an edge-based disjoint path selection scheme, which eliminates the redundant path selection and improves the energy efficiency and network lifetime. The proposed method uses minimum energy drain rate, node closeness, ETX & link availability factor to estimate the link steadiness metric. The selected disjoint paths effectively control the communication load and the energy efficiency during the data transmission phase. The existing schemes outperform the proposed algorithm regarding the end-to-end delay, packet delivery ratio, and control overhead in either lower or higher mobility.

CHAPTER -5

CONCLUSION AND FUTURE SCOPE

FANETs have a unique nature than the other networks. The nodes in the FANETs are flying around the deployment area, unlike node mobility in MANETs or VANETs. This unique nature of the FANETs makes the conventional routing protocols such as AODV do not fit the flying networks. So,there is a need to introduce a new routing protocol that can work well according to the node's flying nature. In this research, a new routing protocol considers the node's particular factors like speed, variations in speed, link quality, etc.Due to the continuous flying of the nodes, each node in the network may need to keep track of itand refresh its routing table to have uninterrupted communication. To restrict this hustle, the proposed protocol considers the node's current factors and predicts the node's future parameters, such as speed, link quality, etc. Based on these predictions, the proposed protocol assigns weight to every node, and the routing decision is made according to node weight. This routing strategy ensures the transmission path is reliable and interference-free, resulting in decreased routing overhead, reduced energy consumption, and enhanced throughput.

The high mobility and frequent topology changes are the primary concern in achieving efficiency in FANETs. It includes various challenges, from the dynamic topological structure to selecting an effective, reliable relay node without redundancy. Redundant link and relay node selection are played a vital role in controlling the communication load and energy efficiency. In this work, we introduce an EBDPS - an edge-based disjoint path selection scheme, which eliminates the redundant path selection and improves the energy efficiency and network lifetime. The proposed method uses minimum energy drain rate, node closeness, ETX & link availability factor to estimate the link steadiness metric. The selected disjoint paths effectively control the communication load and the energy efficiency during the relaying data period. The existing schemes outperform a proposed methodology regarding the end-to-end delay, routing overhead, and packet delivery ratio in either lower or higher mobility. These evaluations will enhance the current thesis value and help it to get acceptance in the industry.

The high mobility and the low density of UAVs are the major issues in designing an adaptive routing protocol ensuring a robust data exchange between UAVs. These issues' severity increases when UAVs move in a 3D space (i.e., at different altitudes). Different techniques have been proposed across the literature based on a single situation encountered in the network. However, they cannot deal with all issues that can be met with a network such as FANET. Consequently, there is a severe need to propose new protocols that could deploy the appropriate technique in a given situation.

We have identified the less investigated open research challenges and requirements for FANET routing protocols. Moreover, we have provided possible solutions and recommended references for scientists who would like to explore more deeply in this research area. In conclusion about this work, we can say that FANET routing protocols must deal with the fragmentation of the network and the highly dynamic topology of the network. As future perspectives, we are currently studying to specialize in UAV-assisted concept, which has been less investigated and recently has attracted the interest of an actual number of sciences. Moreover, we plan to conceive an efficient routing protocol that can be adapted to every situation while considering the different studied constraints.

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List of Publications

1. Aruna, O. and T. Singh. "Energy-Aware Cross-Layer Opportunistic Routing Protocol in Flying Ad hoc Networks (FANETs): A Survey." (2019). (Scopus-Published)

2. Aruna, O., and Amit Sharma. "An adaptive and opportunistic based routing protocol in flying ad hoc networks (fanets): A survey." *International Conference on Computer Networks, Big data and IoT*. Springer, Cham, 2019.

3. Aruna, O., and Amit Sharma. "A Comprehensive Bibliographic Survey of the Standard Routing Protocols in Flying Ad Hoc Networks." *Solid State Technology* 63.4 (2020): 1475-1483.

4. Aruna, O., and Amit Sharma. "An Edge-Based Disjoint Path Selection Scheme for FANETs." *International Conference on Computer Networks, Bigdata and IoT*. Springer.

5. Aruna, O., and Amit Sharma. "An Adaptive Routing Protocol in Flying Ad Hoc Networks." *Journal of Discrete Mathematical Sciences and Cryptography. Volume 24, Issue 6, 2021.*

6. Aruna, O., and Amit Sharma. "A Reliable Data Transmission using an Adaptive Routing Protocol for FANETs." Indonesian Journal of Science andTechnology.