RESEARCH ARTICLE

Reliable Data Exchange in UAV Swarm Networks Using Advanced Networking Techniques

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Abstract

In recent decades, there has been a growing demand for eco-friendly unmanned aerial vehicles (UAVs) in both civilian and military domains. This has created interest among scholars and industry experts who envision Flying Ad-hoc Networks (FANETs) supplanting conventional networks in contexts such as surveillance, disaster management, precision agriculture, and logistics. Despite the constraints of UAV resources, it is crucial to optimize UAV resource utilization to extend network lifespan and uphold a satisfactory quality of experience (QoE). This study examines the application of the Fisheye State Routing (FSR) protocol to facilitate communication among multiple UAVs within a dynamic network framework, utilizing a 3×3 Manhattan Grid mobility model that captures continuous node movement and network topology changes. The effectiveness of FSR in FANETs is evaluated using various network performance metrics, including packet delivery ratio, packet drop rate, end-to-end delay, channel utilization, throughput, and jitter. The analysis is performed in two distinct network scenarios with twenty and thirty nodes, respectively. The routing system employs UAV resources to attain packet delivery ratios of 46% and 53% across both scenarios, while preserving channel utilization and throughput. Furthermore, as compared to other routing protocols, FSR exhibits minimal end-to-end latencies of 0.010 and 0.244 seconds, along with reduced jitter. Overall, the proposed technique outperforms prior topology-based routing protocols in terms of resource utilization and performance.

Keywords: ITS, UAV, FSR, green UAV communications, internet of aerial vehicles, flying ad-hoc networks, routing protocol.

1 Introduction

Recent global market studies approximate the present value of UAVs to be $127 billion [1, 2]. UAVs are extensively used for many purposes such as search and rescue missions, surveillance of civil fields, strategic reconnaissance, and traffic monitoring, among other

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applications [3–7]. They are fundamental components of the Unmanned Aerial System (UAS) or Drones, allowing Air-to-Air (A2A) and Air-to-Ground (A2G) communication. Data transfer success in A2A and A2G communications is heavily dependent on speed and 3D mobility capabilities [8]. UAVs are classified into two primary categories: Rotary-Wing (RW) and Fixed-Wing (FW). Unmanned Aerial Vehicles with Rotor Wings can take off from a variety of locations and fly at low altitudes. These models are classified into many categories based on their rotor configurations, including hexacopter, quadcopter, tri-copter, single-rotor, and hybrid types [9, 10]. However, Fixed-Wing UAVs are highly proficient in extended surveillance operations owing to their exceptional aerodynamic structure and wide range of flight speeds (30-460 km/h). Figure 1 depicts the predominant categories of commercially employed UAVs.

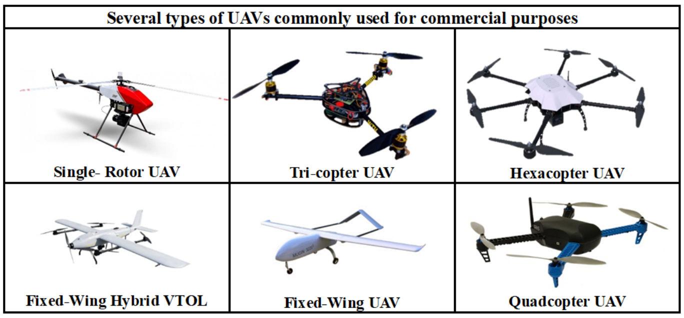


Figure 1. Typical types of UAVs.

These UAVs are appropriate for various deployment circumstances due to their tradeoffs in attributes including flying height, battery life, mobility, and hovering capability. Table 1 provides a brief comparison of the primary differences between RW and FW UAVs.

In recent decades, eco-friendly UAVs have opened up advanced applications in precision agriculture and product transportation, while their use in surveillance remains limited. At the same time, Intelligent Transportation Systems (ITS) have emerged as a key solution to address the growing challenges of urbanization [11–14]. The development of Sixth Generation (6G) ITS designs has enabled the widespread implementation of autonomous vehicles in smart cities [15, 16]. To realize a fully automated ITS, it is important to automate the entire communication process among vehicles, traffic safety, and on-site security [17]. UAVs play a crucial role in facilitating automation in ITS, buildings, hospitals, emergency systems, and security, as illustrated in Figure 2.

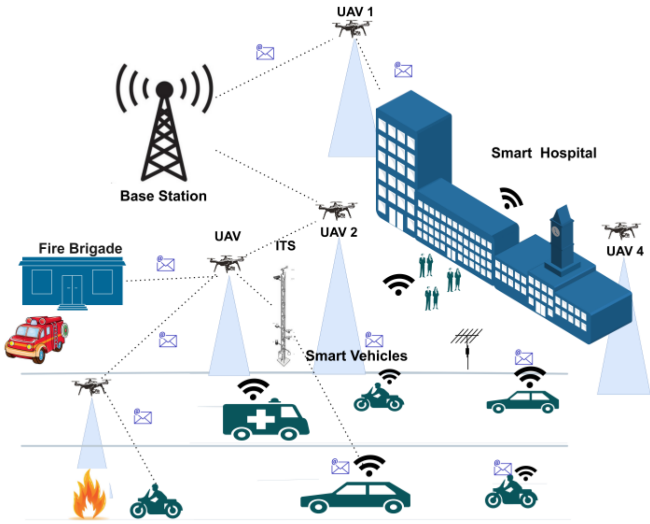


Figure 2. Urban automation and the role of UAVs.

FANETs have several advantages when compared to other forms of ad hoc networks, such as those utilized in maritime vessels, automobiles, or robotics. FANETs offer advantages such as simplified hardware deployment, increased resilience in challenging environments, decreased environmental strain, improved security and privacy, and compatibility with blockchain management systems [18–22]. They are specifically used for sensitive applications that require assured data transmission, effectiveness, dependability, and extremely low latency rates. However, frequent topology changes in FANETs can cause signaling cost, packet loss, and latency

Table 1. Features of UAVs with fixed and rotating wings.

Dimensions	UAV category	Energy Usage	Movability	Hovering Static	Elevation
Small UAVs	RW	Minimum	Nominal	Yes	Low
	FW	Maximum-Average	Rapid-Moderate	No	Med-Low
Large UAVs	RW	Minimum-Average	Rapid-Moderate	Yes	Med-High
	FW	Maximum	Nominal	No	High

problems [23].

Although FANETs have many benefits, their 3D mobility and speeds ranging from 30 to 460 km/h make it difficult to employ resources efficiently and establish connection between UAVs and target base stations [24]. The main reason for this is that UAVs need energy for both propulsion and communication, presenting a dual energy burden on UAV systems. The energy consumed by propulsion substantially surpasses the energy utilized for communication [25, 26]. Moreover, the implementation of mobility models significantly contributes to the improvement of Quality of Experience (QoE) and Quality of Service (QoS). This study aims to resolve current challenges by presenting the FSR protocol, which utilizes a 3×3 Manhattan Grid Mobility Model. The study of the results shows that the FSR with the Manhattan Grid (MG) routing protocol performs better than other routing methods.

This paper contributes to the advancement of network surveillance and the establishment of green UAV communications.

- Initialization of FANETs using the Fisheye State Routing Protocol.
- The 3x3 grid and probabilistic technique of the Manhattan Grid Mobility Model are used here; forward and backward directions each with probability 0.5, and right and left directions each with probability 0.25, respectively.
- Two case studies were conducted in the MG, using twenty and thirty nodes individually. The simulation duration in the first scenario was twenty seconds, while in the second scenario, it was thirty seconds.
- The study was conducted on six protocols employing specific performance indicators such as Packet Drop and Packet Delivery Ratio, Bandwidth Utilization, Throughput, Packet Drop Behavior, End-to-End Delay, and Jitter.
- The advantage of our technique is demonstrated through evaluation in contrast to topology-based routing protocols.

The present study is structured into several sections to facilitate a comprehensive understanding of the proposed research. Section 2 comprises a literature review aimed at providing the necessary context for the suggested strategy. Section 3 outlines the recommended approach. Section 4 contains simulated data, comparative analysis, and discussions, while Section 5 presents the conclusion.

2 Related Work

Academics are concentrating more and more on creating Self-organizing and Self-healing networks as a result of the use of green UAVs in both domestic and industrial contexts [27–29]. FANETs are networks that consist of nodes capable of movement in all three dimensions [30]. Disruptions in A2A and A2G communications may arise from dynamic alterations in network architecture, resulting in routing constraints [31]. Hence, routing protocols, categorized based on their functional methodology, are essential for preserving the effectiveness and QoS of wireless networks.

In topology-based routing protocols, nodes build a network by exchanging topology data with their neighbors. FANETs include many routing types, including Topology-based, Swarm-based, Hierarchy-based, Position-based, Delay-tolerant, Heterogeneity-based, and Energy-based [32]. Several routing protocols belonging to these classes have been established and evaluated in various network scenarios, as demonstrated in different research articles. This group of routing protocols typically have three operational steps: neighbor and route discovery, route exchange messages (RREP and RREQ), and topology table updating by identifying and sharing IP addresses with surrounding nodes. Routing protocols can be classified as static, hybrid, proactive, as well as reactive [33].

The proactive routing strategy known as Optimized Link State Routing (OLSR) has proven to be effective in both 2D and 3D environments. Link State (LS) techniques, derived from the network's topology, are employed by the system to build connections between nodes. This is achieved by transmitting a specific data packet referred to as the 'H-Packet.' The exchange of TT information among nodes is vital for maintaining all crucial network information. The protocol employs the Multi-Point Relay (MPR) technique to resolve challenges associated with looping and point-to-point communication [34, 35].

Directional antennas are incorporated in Directed Optimized Link State Routing (D-OLSR), an advanced version of OLSR as described by [36]. The implementation of this approach enables a decrease in MPR counts and effectively tackles concerns associated with overhead. An activation occurs if the Maximum

Distance/2 exceeds half of the value among the initial and final nodes; otherwise, traditional OLSR is employed. In [37], the proactive routing approach known as the Distance Sequence Distance Vector (DSDV) was detailed. In this technique, nodes verify their sequence numbers before exchanging information with nodes in the surrounding area. The topology database only updates the most recent sequence number because every node communicates its current position to every other node. In large-scale networks, a reactive routing method called the Multicast Ad-hoc On-Demand Distance Vector [38] is used to connect specific groups of UAVs.

Dynamic Source Routing (DSR) is a reactive on-demand source routing protocol based on topology that uses Self-regulating and Self-restoring procedures. This protocol employs the minimal vertex cost in conjunction with hop counts to determine routes for forwarding data packets. The most efficient route from the source UAV to the ultimate destination is ascertained with the D-Bellman Ford algorithm. As part of communication, the network routinely receives route requests and uses them to keep track of the paths that go from the source to the destination. In order to communicate updated route information, UAVs send a route error packet message whenever the topology is modified [39].

The reactive topology-based routing protocol, Temporally Ordered Routing Algorithm (TORA) is developed for dynamic networks. The system utilizes a technique that locally modifies information, using control packets to efficiently manage overhead. TORA incorporates multipath routing algorithms in order to reduce the impact of connection failures. Furthermore, it guarantees that any alterations in the physical position of a UAV are rapidly transmitted to nearby nodes in order to avoid excessive data flow in the network. The network functions similarly to a Directed Acyclic Graph (DAG), allowing UAVs to communicate through the broadcasting of route requests that include the IP address of the destination in order to establish a routing path [40]. An alternative routing class, Swarm-based Routing, applies concepts from ant and insect swarm behavior to unmanned aerial vehicle (UAV) systems [41]. The Bee-Ad hoc routing protocol, inspired by bees' living and communication ways, assigns equal obligations to nodes, which are separated into two groups: the Forager Bee and Scouting Stage. The networked UAVs communicate with each other in both directions, sending their unique identification numbers, energy levels, and Topology Tables. This allows them to choose the best route from their starting point to their final destination. Finally, a response is delivered via Forager Bees to initiate the conversation [42].

To reduce latency between nodes, hierarchically structured routing protocols use UAV locations to separate the network into groups [43, 44]. Utilizing the geographic coordinates of UAVs, the Position-Based Ant Colony Routing Algorithm (POSANT) finds the shortest and most efficient communication pathways as a multi-agent protocol. Node clustering efficiently diminishes energy consumption and enhances resource usage in UAVs. A hierarchical routing design, the UAV Mobility Prediction Clustering Algorithm (MPCA) divides the network into clusters and makes location, velocity, and speed predictions for UAVs. This forecast takes into account the vocabulary's composition and the termination of connections. The initial stage involves evaluating the speed and position of UAV pairs, thereafter calculating the likelihood of their remaining inside specified geographical areas, hence extending the network's longevity. The types of communication used for both inter- and intra-cluster communication include route requests, which are necessary for communication among UAVs in a cluster, and direct packet broadcasting inside the same zone. A three-tier approach is used by the Extended Hierarchical State Routing Protocol (EHSR) for UAV networks. The cluster head at each level is responsible for data transmission among the different levels of the cluster [45–47]. The UAVs in subordinate clusters select an intermediary cluster that forms a backbone network for transmitting data to upper tiers. The EHSR system utilizes a proactive methodology to routinely oversee the connectivity status of each UAV inside a cluster. To achieve this, it exchanges routing tables with neighboring cluster leaders and creates a hierarchical structure that associates all possible routes [48].

The Disruption Tolerant Mechanism (DTM) is a kind of delay-tolerant routing that deals with problems like node connectivity issues caused by things like mobility, energy limitations, long distances, and spotty radio coverage [49]. Clusters are established in DTM by employing the AODV routing algorithm, which leads to a small amount of network overhead. Nodes within a cluster have the ability to communicate with each other directly, whereas data transfer to clusters outside of the current one happens in a step-by-step way. The formation of clusters takes into consideration a variety of elements, including position, velocity, and speed.

Table 2. Advantages and disadvantages of routing protocols.

Categories	Protocols	Merits	Limitations
Topology Based	AODV	On-demand route discovery reduces control overhead	UAVs detected within a network result in significant data delay.
	DSDV	Loops are eliminated from networks	When a network has congestion and delays, it becomes unsuitable for critical or real-time applications.
	OLSR	Multipoint relay helps to reduce overhead issues inside a network.	Data delivery delays and overhead make it ineffective in dense (FANET) networks.
	TORA	Enhances the nodes' organization	Unsuitable for high mobility
	DSR	Establishing a complete route to the destination	A network's increased latency
	D-OLSR	Overhead is minimized by using a limited quantity of Multipoint relays	Network longevity, which is affected by higher energy and bandwidth use, is another indicator of network performance.
Swarm Class	POSANT	Fragmentation of networks is also supported	The topology is based on quasi-static
	Bee Ad-hoc	The UAVs have enhanced memory	Sophisticated UAV network modeling
Energy Efficient Class	CBLADSR	Get a high percentage of packets delivered	This leads to severe delays and overhead
Hierarchical Class	DTM	Improves the throughput and packet delivery ratio (PDR)	It is decided to handle delay-related issues
	EHSR	A network's scalability is taken into account	The network as a whole will be interrupted if the backbone fails
	MPCA	Potential connectivity failures between UAVs are predicted.	Ignoring the UAVs' moments caused problems to arise

The Time-to-Live (TTL) of the data lifecycle is a metric used to determine the duration of time following a link failure until a new route is created. Furthermore, each cluster head in the network maintains link awareness by transmitting hello packets to neighboring cluster heads [50–52].

Table 2 outlines the basic constraints of current routing protocols that are not sufficiently discussed in the literature. A number of studies have attempted to improve the QoS and QoE of FANETs by addressing issues with propulsion and energy consumption. While performance analysis metrics including PDR, throughput, end-to-end delay, and jitter are often used in previous research, real-time networks like FANETs often fail to meet these requirements [53–55]. Reliable routing protocols are crucial in FANETs to maximize UAV resource utilization and improve the QoS and QoE in these networks.

3 Proposed Approach

FSR is a proactive link-state routing method that improves data packet flow and maintains the dependability of route information in the topology-based class of routing protocols. The development of environmentally friendly communication has been greatly enhanced by including FSR into the 3x3 Manhattan Grid mobility model, a revolutionary technique in FANETs. This has addressed problems in earlier routing protocols.

Each UAV must handle essential components, including the Neighbor List (Ln), Topology Table

(TTL) and Routing Table, via FSR, as illustrated in Figure 3.

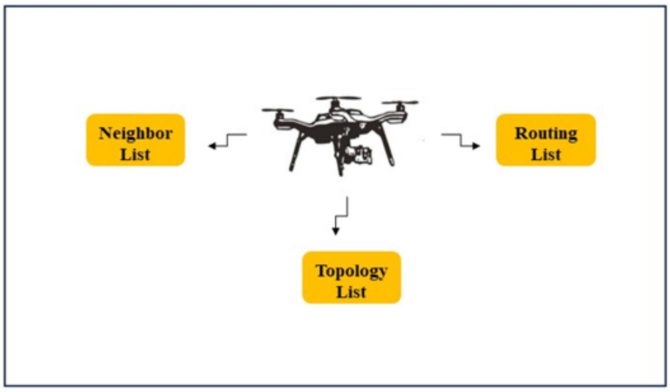


Figure 3. UAV with FSR technology.

A node is immediately deleted from the list if it fails to transmit link state data to its neighbors for a specific amount of time. Furthermore, when the position of mobile nodes changes, their IP addresses are distributed by neighboring nodes in a similar approach. To manage the network's scalability, FSR employs a sub-scope decision-making strategy that minimizes routing cost by executing several exchange cycles in the routing tables. As the range decreases, data is transmitted at higher frequencies by neighbors. The major steps in FSR involve identifying neighboring nodes and calculating routes using Dijkstra's algorithm.

UAVs initiate the neighbor discovery phase by means of a hello packet (Ba), which is a unique and specific message. This packet is exclusively received by adjacent nodes that have response times falling within the range of the aerial vehicle. In the second step, the information flooding approach is used to distribute link-state packets in order to assemble the full topology table (TTL). At the same time, a UAV broadcasts a weighted function and the highest sequence (Seq) number to all neighboring nodes whenever its physical location changes. The best network path is determined by selecting edge nodes with the fewest weighted connections. The data in the topology table is updated by UAVs using Equations 1 and 2.

$$d[u] + c(u, v) < d[v] \tag{1}$$

$$d(v) = d[u] + c(u, v) \tag{2}$$

The flow chart illustrating the FSR protocol technique is depicted in Figure 4. Algorithm 1 and its corresponding notation specification are included in Table 3.

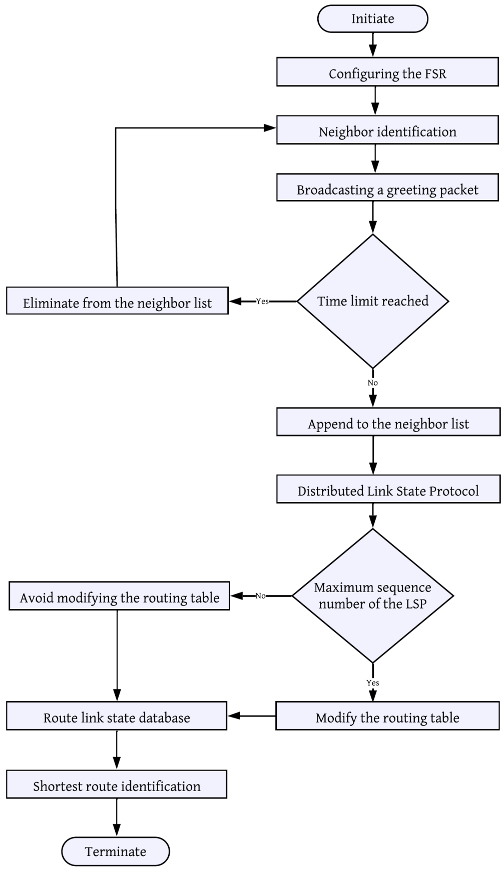


Figure 4. Fisheye state routing protocol flow chart.

Table 3. Notational Index.

Annotations	Description
TTL	Topology table
L_L	Neighbor list
B_c	Broadcast message
Nx-hop	Next hop
Seq	Sequence no. of packets

3.1 Simulating Environment

The development of effective wireless networks in real-time applications relies heavily on mobility models [56]. The movement of UAVs is controlled using the Manhattan Grid mobility concept in this scenario. This model utilizes a Probabilistic method, where probabilities of 0.5 are assigned for forward and backward movement for forward and backward movement, and probabilities of 0.25 are assigned for right and left directions for the UAVs, as depicted in Figure 5.

Figure 5. Manhattan grid-based UAV mobility model.

Algorithm 1: FSR

Input: –
Output: The most efficient path from the origin to the destination
Objective: Ascertain the most efficient path from the origin to the destination;
Configure L_L, seq, TTL, Nx-hop;
if $L_L = empty$ **then**
    $B_c \leftarrow$ Broadcasting of a message within the spatial range of UAVs;
    if $UAVs = Acknowledgments$ **then**
        $L_n \leftarrow$ Append neighbor;
    else
        $L_L \leftarrow$ Eliminate UAVs;
else
    $L_L \leftarrow$ Table update;
Broadcast LA to every single network;
if $seq > previous\ seq$ **then**
    Revision;
else
    $TTL \neq$ Revision;
$I =$ Dijkstra's route search;
Iterate $L_L =$ empty;
Close;

The omnidirectional antenna properties of each UAV ensure that radiation covers the geographical area uniformly, as determined by Equation 3.

$$U = [\sin(\theta)], \quad 0 \leq \theta \leq \pi, \quad 0 \leq \phi \leq 2\pi \qquad (3)$$

The approach suggested in the MG mobility model, which was put into operation on a 3×3 grid, has been validated using two case studies. Two scenarios were considered: one with twenty UAVs and a twenty-second simulation time, and another with thirty nodes and a thirty-second simulation time. The simulations require additional parameters, which are shown in Table 4.

Table 4. Configuration of simulation.

Specification	Value
Simulator	NS-2 (2.3 version)
Area of Topology	1000 x 1000 (m)
Mobility Model	Manhattan Grid
Simulation time	20 s in first scenario & 30 s in second scenario
Number of nodes	20 & 30
Traffic Type	CBR
Radio frequency	Two rays grounded
Pause Time	One s
Total Bases	One
Minimum Velocity	One m/s
Maximum Velocity	10 m/s

This paper compares the performance of FSR with the topology-based routing approaches listed below.

- Optimized Link State Routing (OLSR)
- Ad-hoc On-Demand Distance Vector (AODV)
- Dynamic Source Routing (DSR)
- Temporally-Ordered Routing Algorithm (TORA)
- Distance Sequence Distance Vector (DSDV)

4 Outcomes and Analysis

The network parameters employed to analyze the optimal routing protocol are detailed in this section.

4.1 Ratios of Packet Delivery and Dropped

A crucial parameter in FANETs is the PDR, defined as the aggregate of all packets successfully transmitted by each UAV within a specified timeframe. The packet drop ratio is the percentage of packets dropped to the total number of transmitted packets.

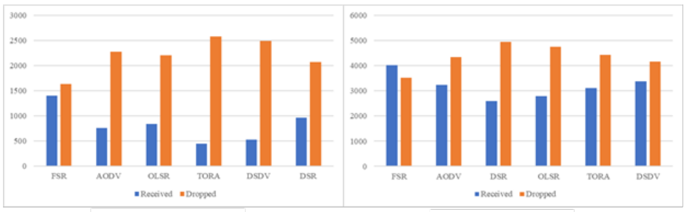
Table 5. Routing protocol PDR containing 20 nodes.

Protocol	Transmit	Acknowledged	Dropped
TORA	3038	456	2584
DSDV	3038	536	2504
OLSR	3038	832	2208
AODV	3038	761	2279
DSR	3038	965	2075
FSR	3038	1402	1638

The FSR protocol proved to be superior to alternative routing protocols in both cases when comparing dropped and delivery ratios. In the first scenario, the FSR attained a drop rate of 53.88% and a data delivery ratio of 46.11%. In the second scenario, it achieved a Drop Ratio of 46.85% and a Packet Delivery Ratio (PDR) of 53.14%. The efficacy of these routing protocols exceeded that of the alternative protocols, as demonstrated by the data in Tables 5, 6, 7, 8 and the graphical representations in Figures 6(A) and 6(B). The high PDR of FSR in networks with dynamic topologies underscores its efficiency.

4.2 End-to-End delay

A data packet's overall transit time across a network is called the End-to-End Delay (D), which is also called the one-way delay. The calculation is carried out using Equation 4, which takes into consideration the packet's receiving time (t_r) and transmitting time (t_s).



(A) Twenty Nodes (B) Thirty Nodes

Figure 6. Analysis of received and dropped packets in routing protocols.

Table 6. Percentages of PDR and Drop Ratio for Routing Protocols having 20 nodes.

Protocol	Percentage of PDR	Percentage of Drop Ratio
TORA	15	85
DSDV	17.63157895	82.36842105
AODV	25.03289474	74.96710526
OLSR	27.36842105	72.63157895
DSR	31.74342105	68.25657895
FSR	46.11842105	53.88157895

Table 7. Routing protocol PDR with 30 nodes.

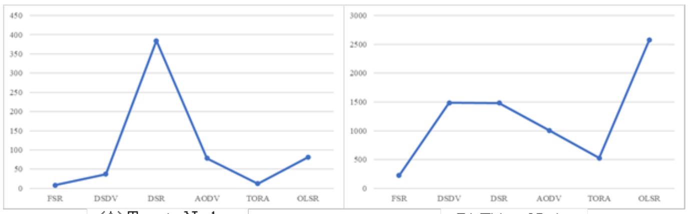
Protocol	Transmit	Acknowledged	Dropped
DSR	7540	2602	4938
OLSR	7540	2794	4747
TORA	7540	3085	4455
AODV	7540	3216	4324
DSDV	7540	3377	4163
FSR	7540	4007	3533

Table 8. Packet Delivery Ratio (PDR) and Drop Ratio Percentages for Routing Protocols having 30 nodes.

Protocol	Percentage of PDR	Percentage of Drop Ratio
TORA	40.9151194	59.08488064
AODV	42.6525199	57.34748011
OLSR	37.0557029	62.94429708
DSR	34.5092838	65.49071618
DSDV	44.7877984	55.21220159
FSR	53.1432361	46.85676393

$$D = t_r - t_s \tag{4}$$

The FSR protocol has a lower end-to-end latency than topology-based routing approaches in both scenarios, as illustrated by Figures 7(A), 7(B) and Tables 9, 10.



(A) Twenty Nodes (B) Thirty Nodes

Figure 7. End-to-End delay of all routing protocols.

Table 9. End-to-end routing protocol delay with 20 nodes.

Protocol	Delay (ms)
DSR	382.8846867
OLSR	80.60518873
AODV	77.8061071
DSDV	40.93648628
TORA	12.5727104
FSR	10.49642941

Table 10. End-to-end delay routing protocol with 30 nodes.

Protocol	Delay (ms)
TORA	531.78
OLSR	1013.89
AODV	1482.48
DSDV	2570.13
FSR	243.53
DSR	1480.41

4.3 Bandwidth Utilization

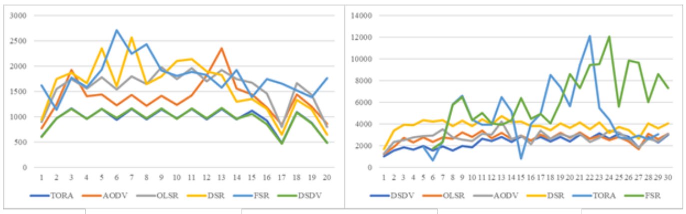
It is crucial for wireless networks to optimize the use of available bandwidth over time. The assessment is based on the optimal use of a connection for a certain duration, calculated using Equation 5. In this context, the variables P and T represent the total amount of packet delivered and total time length respectively, and the channel's bandwidth utilization, measured in packets per second (PPS).

$$U = \sum \frac{P_s}{T_{(pps)}} \tag{5}$$

The available bandwidth has been effectively utilized by FSR throughout a restricted time frame, as illustrated in Figures 8(A) and 8(B).

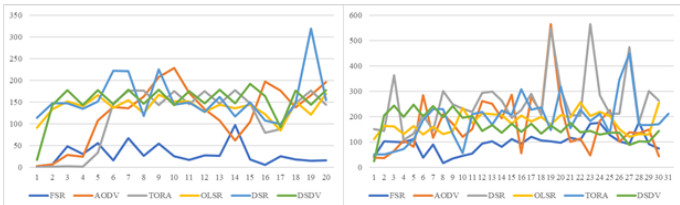
4.4 Analysis of Packet Drop Rates

Packet drop behavior reflects the stability of a routing protocol under dynamic network conditions. As illustrated in Figures 9(A) and 9(B), FSR consistently exhibits the lowest packet drop counts in both the twenty-node and thirty-node scenarios. In the twenty-node case, FSR maintains drop values predominantly below 100 packets per step, while TORA, DSDV, OLSR, DSR, and AODV show considerably higher and more volatile drop behavior throughout the simulation. In the thirty-node scenario, although all protocols experience increased absolute drop counts due to higher network density, FSR remains the most stable, with values generally between 100 and 200 packets per step. By contrast, DSR and OLSR exhibit sharp isolated spikes exceeding 400 packets per step, consistent with route invalidation events caused by frequent topology changes. The low and stable drop behavior of FSR is attributed to its proactive fisheye scoping mechanism, which maintains up-to-date routing tables and avoids the stale route entries and route discovery delays that lead to burst packet losses in other protocols.



(A) Twenty Nodes (B) Thirty Nodes

Figure 8. Bandwidth utilization in routing protocols.



(A) Twenty Nodes (B) Thirty Nodes

Figure 9. Protocols for Routing and Their Packet Drop Behavior.

4.5 Throughput

The throughput of a routing system is its ability to efficiently and reliably send packets over a communication media, be it a wireless or wired connection. In Equation 6, the quantification is shown in kilobytes per second (Kbps), with throughput denoted as G and the total number of packets received during time T represented by $\sum P_r$.

$$G = \sum \frac{P_r}{T_{(Kbps)}} \tag{6}$$

Figure 10(A) and 10(B) show that in both cases, the

FSR routing protocol outperforms the competition and allows for the maximum amount of data transfer.

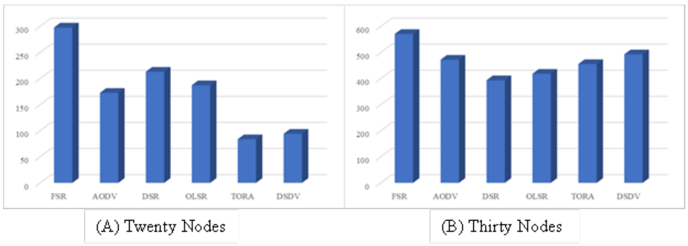


Figure 10. The rate of throughput for routing protocols.

4.6 Jitter

Jitter is a complex phenomenon that arises when there is a discrepancy between the sending and receiving periods of successive packets. This discrepancy can be caused by several circumstances, including network congestion, the choice of the longest data routing route, or connections with limited bandwidth. This leads to a significant increase in network latency and the ratio of packet loss, both of which have a significant effect on the overall efficacy of a routing system. As shown in Figures 11(A) and 11(B), FSR effectively reduces congestion through the usage of network scopes, which improves network performance by reducing packet jitter.

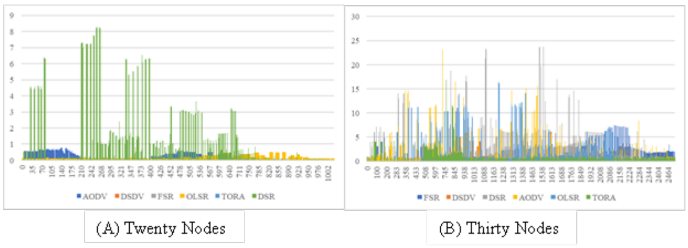


Figure 11. Routing Protocol Jitter.

The update mechanism of FSR protocol is mostly reliant on the system's mobility. Due to scope interval updates, this may result in quick changes to the network's architecture, which may affect routing efficiency. Nevertheless, FSR has shown significant enhancements in routing efficiency when compared to alternative routing protocols predicated on topology or table-driven approaches.

5 Conclusion

The FANET is an expanding field of study within wireless sensor networks (WSNs), offering significant capabilities and a diverse array of applications. FANET is esteemed in both academics and industry for its reliability and adaptability throughout various contexts. FANETs function in three-dimensions, so surpassing the operating limitations of MANETs and VANETs, which predominantly operate in two-dimensional environments. A fundamental challenge of FANETs is their insufficient resources for extensive and thorough long-term network monitoring. This study aims to address resource restrictions by analyzing many measures, including throughput, end-to-end delay, jitter, packet drop behavior, bandwidth capacity, and packet delivery and drop ratios. This study applies the FSR protocol in two distinct network scenarios utilizing a 3x3 Manhattan Grid (MG) Mobility model. There are two scenarios: one with twenty nodes and twenty seconds of simulation time, and the other with thirty nodes and thirty seconds of simulation time. The results consistently demonstrate that FSR exceeds expectations by demonstrating exceptional resource utilization. The effectiveness of FSR has greatly improved the adaptability of networks while also decreasing the energy consumption related to connectivity and propulsion. Future study will examine data encryption methodologies and attack mitigation strategies to improve the security of networks utilizing FSR.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

James Adu Ansere served as an Associate Editor of the ICCK Transactions on Advanced Computing and Systems at the time of manuscript submission. To ensure the integrity of the peer-review process, James Adu Ansere was not involved in the editorial handling, peer review, or decision-making process for this manuscript, which was handled independently by another editor. The remaining authors declare no conflicts of interest.

AI Use Statement

The authors declare that no generative AI was used in the preparation of this manuscript.

Ethical Approval and Consent to Participate

Not applicable.

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