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Fuzzy adaptive routing protocol for packet dissemination in FANET

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Abstract

In the development of networks, a new paradigm called flying adhoc networks (FANET) has evolved recently. FANET's are comprised of unmanned aerial vehicles like drones, autonomous flights, etc. Drones are mainly used for surveillance, logistics, etc. On the verge of this FANET, many issues are arising regarding their proper usability, one among them being the routing of packets from the ground station to the destined drone. In this research work, we have developed a protocol for packet delivery called fuzzy adaptive routing protocol. This protocol uses factors like signal quality, signal to inference and noise ratio, hop count, and timestamp of the packet to decide on the broadcasting of route requests and reply messages. This protocol mainly contains two phases namely: controlled route request/reply broadcasting and optimal route selection for packet delivery. The performance of the proposed protocol is compared with recent techniques and the comparison depicts that the proposed protocol outperforms them and provides consistent service quality.

Keywords: FANET, Routing protocol, Drones, Fuzzy, Controlled broadcasting
2020 MSC: 03B52

1 Introduction

FANET is a new kind of mobile ad hoc network (MANET) that makes use of drones or unmanned aerial vehicles (UAV) as nodes. FANET is formed by many drones linked in a wireless ad hoc manner and providing multi-hop communication to each other. Drones may be fitted with various networking technologies to communicate with other drones and other systems such as Wireless Sensor Networks (WSN), Ground Control Stations (GCS), and on-ground robotics, as well as with others drones. In a FANET design, drones provide ad hoc real-time communication, in circumstances where actual communication and range limits are the primary concerns, and infrastructure provision is challenging, the FANET architecture plays a critical role. Ad hoc networks between drones have been proven to be the ideal option in most circumstances in FANETs since the drones join and disconnect from the network often. Drone-to-drone communications and drone-to-ground control stations are the two main types of communication paradigms used in a FANET [15]. In drone to drone Communications, drones communicate with each other via Line-of-Sight (LOS) propagation links in a multi-hop manner to extend the communications range. In drone-to-ground control station communication, the drone communicates directly with the ground control station (GCS). Hybrid techniques, which

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reflect a mix of both the communications and where the drone may communicate its data directly to the GCS in a one-hop or multi-hop way through the various drones in the mission area, are based on combining these two communication paradigms. The topology of these networks is more dynamic than that of typical mobile ad hoc networks (MANETs) and of typical vehicle ad hoc networks (VANETs). A pictorial representation of these three networks is given in figure 1.

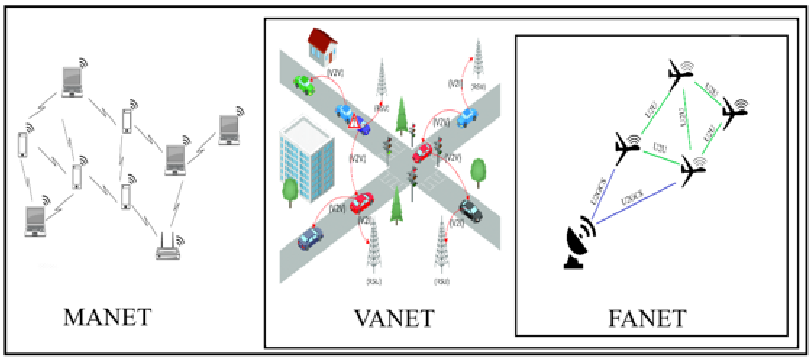

Figure 1: Types of ad-hoc networks

As a consequence, the existing routing protocols designed for MANETs partly fail in tracking network topology changes. In fact, due to the rapid and erratic movement of the drones, the topology of a FANET can vary rapidly and the nodes must react by automatically updating their routing tables. Therefore, in a FANET it is crucial to employ a fast and reactive routing procedure. FANET routing must meet the following five criteria [2, 14]

- Due to the dynamic network architecture with low node density and link disconnections and network splits, drones must be very adaptable. The establishment and maintenance of data dissemination routes must thus be sufficiently adaptive to increase route dependability in FANETs, as must route discovery (i.e., the establishment of data dissemination routes). Routing tables must be regularly updated and dependable routes found in order to keep up with the ever-changing expenses of travel.
- High node density or low node density drones are needed to handle large-scale applications requiring many drones. As a result, drones must collaborate and coordinate in order to increase the scalability of the network.
- Longer route lifespan requires high residual energy in drones since node failures may cause links to be disconnected and networks to be partitioned, and this is a problem when using battery-powered drones.
- Real-time applications like collision avoidance and disaster relief and rescue need low latency for unmanned aerial vehicles. There is a need to lower the latency of route finding and maintenance, as discussed in References.
- In order to analyze and make decisions, drones need a lot of bandwidth since they collect data and sense results from a variety of places. Route discovery and management hence necessitate establishing routes with enough bandwidth.

To handle this uncertainty feature of FANET, this research proposes a fuzzy adaptive routing protocol for data dissemination among drones. The rest of the paper is organized as: section II provides information about various routing protocols of FANET in literature, and section III depicts the terms used for the proposed fuzzy adaptive protocol in detail. Section IV provides detailed information about the proposed protocol workflow and algorithm. Section V illustrates the performance comparison of the proposed protocol with a few protocols discussed in the literature. Section VI concludes the paper with possibilities for future research directions.

2 Related work

Routing is the process of sending and receiving data between source and destination nodes in a network. Existing routing protocols cannot be easily used for FANET due to their unique characteristics. FANET routing protocols are classified into two categories: topology-based and position-based which is illustrated in Figure 2 [1, 5].

Topology-based routing is a type of routing that takes into consideration the network's topology, forwarding data packets depending on the network's nodes' topological information. An appropriate route from the source to the

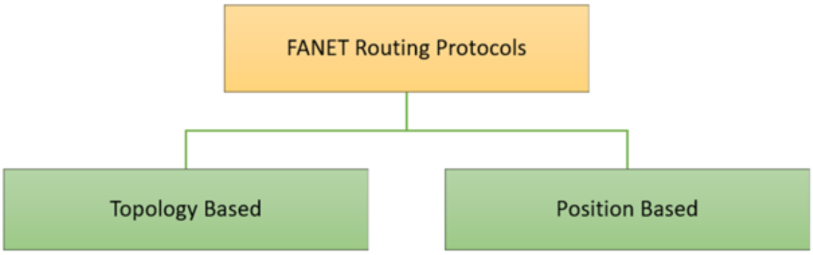

Figure 2: Classification FANET routing protocols

destination must be built before data transmission can occur. Proactive, reactive, and hybrid are the three main types of topological routing protocols that were found in this study [7]. One of the most commonly used types of proactive routing protocols is the Optimized Link State Routing Protocol (OLSR). Based on the OLSR protocol, some new protocols have been proposed, such as Directional OLSR (D-OLSR), Predictive OLSR (P-OLSR), and Mobility and Load Aware OLSR (MLOLSR) [10]. When packets need to be transmitted, reactive routing, also known as on-demand routing or passive routing, is a kind of routing protocol that may be used to select a routing path. Dynamic source routing (DSR) is a reactive routing protocol and creates the routes only if they are needed. DSR enables networks to self-configure and self-organize without the need for any network infrastructure. Ad Hoc On-Demand Distance Vector (AODV) routing is a popular routing protocol of this kind. Because FANETs may include a large number of UAVs, Time Slotted Ad Hoc On-Demand Distance Vector (TSAODV) employs a time-division approach to avoid information transmission collisions, reduce packet losses, and expand available bandwidth. The AODV flooding technique for establishing a channel from the source node to the destination needs a lot of internal communication, which may cause network congestion and a considerable drop in energy efficiency [11]. AODV is an extension of DSR, but DSR packets contain the route and data in the same packet, so it needs a lot of bandwidth if the network coverage is large. In AODV packet path is not included with the data. AODV maintains routing information in a table for all routes depending on a specified time; if any information expires in the routing table it is deleted. It avoids loops and rejects old or broken routes by using several sequences at the destination [9]. To prevent network loops, DSDV utilizes a number sequence to keep the routes fresh. However, route updating requires a significant amount of bandwidth [4]. The energy-efficient and Packet Delivery Ratio (PDR) of AODV is better than DSDV. The geographical location information of the nodes is utilized for position-based routing. those that should be able to identify where they are by using their onboard GPS device or other ways to find their location, two types of position-based routing are Nodes in delay-tolerant (DTN) and non-delay-tolerant (Non-DTN) [14, 1]. In the research [8], the authors proposed a fuzzy logic-based routing scheme for flying ad hoc networks. Their protocol consists of a route discovery phase and a route maintenance phase. In the route discovery phase, the routes are discovered based on the movement of UAVs, residual energy, etc. In the route maintenance phase, each route's failure threshold is detected and new routes are established for packet delivery. In this work, the route maintenance phase makes more packets shared among the UAV which in turn leads to higher overhead in the network. In research [13], the authors proposed an adaptive routing protocol based on the fuzzy rule set. In this work, a Gaussian fuzzifier was used due to its inherent ability to reduce the noise of input variables. It takes the values from the factors namely: received signal strength indicator, mobility level, and flight autonomy. This work could not control the broadcast storm as the number of packets shared among the drones is higher in number to share the above-said values. The rule set also makes the system inefficient in terms of response time. The RTORA routing protocol is TORA based used in high-density UAVs, which are often deployed in harsh locations and need high coordination and contact among UAVs. Due to UAV mobility, particularly in highly dynamic networks, or UAV failure, the possibility of link failure may rise significantly, resulting in failure transmission or high delay. So, a fast and efficient route restoration mechanism is needed. To address the problem caused by TORA's link-reversal failure, RTORA uses a low-overhead method. RTORA utilizes the link reversing mechanism also the height metric in the same way as TORA does [12]. GPSR was the first geographic routing system for unmanned aerial vehicles [6]. Two mechanisms are employed in GPSR. When a greedy source node compares its neighbor's distance to the destination node to its own distance to the destination, it chooses the shortest path. However, if the distance is greater than the source node's own distance, the source node uses the perimeter technique, which is based on the right-hand rule clockwise, and this process is repeated frequently. As a consequence, there is reduced overhead in the GPSR routing protocol. Reactive-Greedy-Reactive (RGR) is a suggested combination of on-demand routing and geographic forwarding [3]. To overcome the multiple issues in FANET routing, this work proposed a fuzzy adaptive routing protocol which describes in the following sections.

3 Fuzzy adaptive routing Protocol-Terms

To handle the uncertainty feature of FANET, this research proposes a fuzzy adaptive routing protocol for data dissemination among drones. For effective utilization of this protocol, there are certain factors that need to be understood and their values are important in implementing this protocol for routing. The factor which is under consideration are as follows:

- Location of the Drone
- Link Quality and Signal to Interference and Noise Ratio (SINR)
- Hop Count
- Request/Reply Message Structure

3.1 Location of the drone

With GPS, satellite signals are triangulated to establish the relative position and speed of the drones. Typically, three or four satellite signals are used, but some drone GPS modules may lock on to as many as seven or eight different satellite signals for best performance.

The GPS location of the drone is represented in equation 1.

$$L(D) \rightarrow (x, y) \tag{1}$$

wWhere L(D) represents location of the drone; X, Y represents the corresponding numerical values or coordinates (latitude and longitude) with respect to the axis as mentioned.

3.2 Link quality and signal to interference & noise ratio (SINR)

The drones are communicating with nearby drones which are all within direct communication range. For this communication, drones generally use broadcasting techniques. As drones are highly vulnerable to environmental conditions, it is important to consider the signal quality before considering the data received through the signal or link. In order to measure link quality, Received Signal Strength Indicator (RSSI) and Signal-to-Inference and Noise Ratio (SINR) parameters may be used. Received Signal Strength Indicator (RSSI) is a relative value that measures the power of the received signal. RSSI is a measurement of how good the radio signal is between transmitter and receiver. The RSSI value is calculated as defined in the following equations 2 and 3.

$$RSSI = -klogd + a \tag{2}$$

$$d = 10[\frac{(a - rssi)}{K}] \tag{3}$$

Signal-to-Inference and Noise Ratio (SINR) is considered when receiving information using datalinks. SINR compares the level of the desired signal to the level of background noise. The higher the SINR, the better the signal quality. The SINR value is calculated using equation (3)

$$SINR = \frac{P_{signal}}{P_{noise}} \tag{4}$$

Where P is average power.

3.3 Hop count

In a routing scheme, it is a mandatory requirement that the scheme uses minimum hop counts. In a network, hop represents the nodes in the network like switches, routers, etc. In FANET the hops are representing the intermediate drones that are able to forward the packets toward the destination. Hence this proposed protocol considers the hop count between source and destination so that the selected optimal route uses a very less number of hops which results in minimized delay and latency.

4	2	2	8	4	4	8
Message Type	Hop Count	Location of D	Intermediate D List	RSSI	SINR	Timestamp
RREQ/RREP Message ID						
Destination D ID						
Destination Message Sequence Number						
Source D ID						
Source Message Sequence Number						
Padding (0000000…..0000000)						

Figure 3: Request/reply message structure

3.4 Request/reply message structure

The route request message is the message which is generated by the drones when it needs to find a destination drone. The route request message structure is given in the following figure 3.

In the above figure 3, the contents are represented as

Message Type – Request message or reply message

Hop Count- Hop count (intermediate drones) when it is a reply

Location of D – the location (x,y) of the sending drone is updated in the message

Intermediate D list – ID of intermediate drones when they are forwarding the reply messages

RSSI – Received Signal Strength Indicator.

SINR – Signal to Interference and Noise Ratio

Both RSSI & SINR are used in the reply message

Timestamp – Timestamp value when the message is created at all the drones.

RREQ/RREP Message-ID – ID of the message to differentiate between request and reply messages

Destination D ID – ID of the destination drone

Destination Message Sequence Number – Sequence number of the messages generated by the destination

Source D ID-ID of the source drone

Source Message Sequence Number – Sequence number of the messages generated by the source.

4 Fuzzy adaptive routing protocol algorithm

4.1 Routing protocol workflow

The proposed algorithm consists of two phases namely: controlled route request/reply and the optimal route selection. The operational workflow of the proposed protocol is given in the following figure 4.

Figure 4 consists of two sub diagrams where figure 4. a provides the operational workflow of the controlled route request and reply, and figure 4.b provides the operational workflow of the optimal route selection process. The controlled route request and reply are applied based on the verification of duplicate messages, the location of the intermediate receiver, and the timestamp of the message to deal with packet drop scenarios. The optimal route selection is based on the value of SNIR of packets received at the ground station and the optimal path is selected utilizing hop count. A detailed description of the process is given in the routing algorithm section.

4.2 Routing algorithm

By using the above-discussed factors, the fuzzy adaptive routing algorithm is developed for finding an optimal path between source and destination. The algorithm consists of two phases namely:

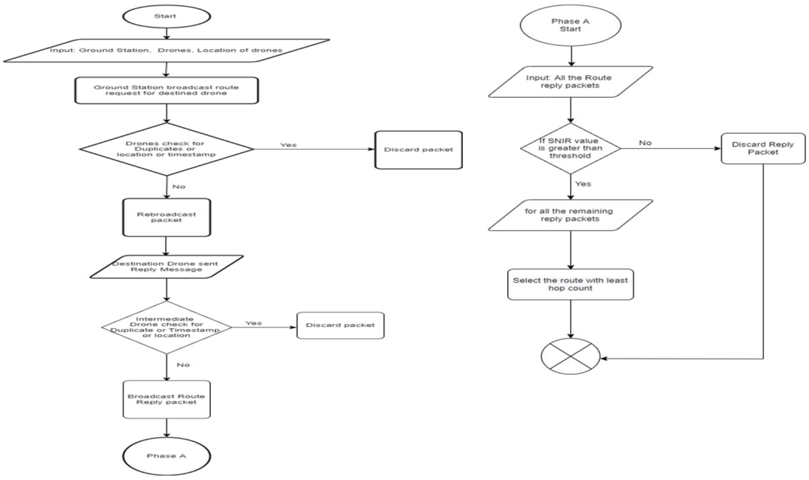

Figure 4: a) Controlled route request/reply b) Optimal route selection

- Controlled Route Request and Reply
- Optimal Route Selection

The controlled route request and reply phase is mainly to control the bandwidth utilization in the network thus achieves the flooding elimination in the network. The controlled route request and reply algorithm is given in following table 1.

Table 1: Controlled route request and reply algorithm

```
Start
Input: GS, ∀ U, ∀ UL, RREQ
Output: {RREP}
Initiate Request:
  GS → DT(DUid) [RREQ (DUid)]
      For all {U}
          For i = 1 to x
            Uxi → BC[RREQ(DUid)}
      For all intermediate U
          For j = 1 to z
            If L (Uxi) < L (Uzj)
                If TS[RREQ] > TSth
                      BC [RREQ(DUid)]
                Else
                      Discard
          End
      End
      End
End
Initiate Reply: DUid
  If TS[RREQ] > TSth
      BC [RREP(GS)]
      For i = 1 to x
        If L(Uxi) < L[RREP]
          If TS[RREP] > TSth
              Update (Uid) in Intermediate U List of RREP
                  BC[RREP]
      End
End
```

The operational procedure of the controlled route request and reply algorithm is as follows

1. Ground Station (GS) generates a request message for the destination and broadcasts the message directly.

2. The nearby drones of the ground station receive the message and update the timestamp of the message and the location of the sender. Then the messages will be broadcasted immediately
3. If the received message's RSSI or SINR values are less, then it will be discarded at the receiver drones.
4. The intermediate drones which receive the broadcast messages, check for the location of the sender, if the location is less than the current location of the drone, then it will check the timestamp of the message. If the timestamp is greater than the timestamp threshold (here it is set as 5 seconds) then the request message will be broadcasted with an updated timestamp and location.
5. If the condition fails, it indicates that the message is a duplicate and will be discarded at the received drone. By applying this, the broadcast storm is avoided.
6. This process continues until the destination receives the route request message.
7. Once the destination drone received the route request message it will generate the reply message if the timestamp of the received message is greater than the timestamp threshold.
8. The generated reply message will be broadcasted immediately by updating the drone location, and timestamp.
9. Once the intermediate drone receives the reply, it will check for the location of the destination drone. If the location is greater than the current location of the drone it will check for the timestamp of the message. If the timestamp is greater than the timestamp threshold (here it is set as 5 seconds) then the request message will be broadcasted with an updated timestamp, location, and intermediate U list along with the incremented hop count.
10. If the condition fails, it indicates that the message is a duplicate and will be discarded at the received drone. By applying this, the broadcast storm is avoided.
11. This process will continue until the reply message reaches the ground station.
12. Once the ground station receives multiple reply messages, it will move to the next phase called optimal route selection which is given in the table 2.

Table 2: Optimal route selection

```
Start
Input: ∀[RREP]
Output: Route (GS → DUid)
For all [RREP]
   For i = 1 to x
      If SINR [RREP] < SINRth
        Discard the RREP
      Else
        For j = 1 to x
           If HC[RREPj] > [RREPi]
               Discard the RREP
           Else
               Update (route)
        End
   End
End
```

The operational procedure of the controlled route request and reply algorithm is as follows

1. For all the route reply messages, the ground station checks for the SINR or RSSI values to confirm the data correctness in the messages. If the values are greater than the threshold, the messages will be further processed or the message will be discarded.

2. Once the first condition is satisfied, the messages are compared with other messages for the hop count, and the message with the least hop count will be selected and the intermediate drones list will be used for forwarding the messages from the ground station to the destination.

Based on the two algorithms, the first algorithm will reduce the number of requests and replies in the network and the second algorithm finds the optimal path between the ground station and the destination with a minimum hop count. Thus the proposed algorithm achieves the elimination of broadcast storm, reasonable delay, reduced packet drop, etc.

5 Performance evaluation

To evaluate the performance of the proposed protocol, it is simulated in an NS3 simulator and the parameters which define the simulation are given in table 3.

Table 3: Simulation parameters

Simulation Parameter	Value
Simulation Area	2500 * 2500 * 1500
Number of Drones	150
Simulation Time	2000 Seconds
Speed of Drones	10 m/s
Mobility Model	Random Way Point
Communication Range	150 m
Packet Size	1024 bytes
Physical Layer	IEEE 802.11 a

The performance of the proposed fuzzy adaptive routing protocol (FARP), is compared with the other two protocols proposed in recent literature namely: EAPFR [8] and FSARP [13]. Both protocols were developed based on the fuzzy nature of the network. Hence the proposed fuzzy adaptive protocol is compared with those two protocols for the following measures namely: Delay Time, Packet Delivery Ratio, Throughput, and Routing Overhead. Figure 5 illustrates the comparison in terms of delay time.

Even though the number of nodes in the network is less or more, the proposed protocol outperforms both the compared protocols. From the comparison, it is clear that the proposed protocol performance is consistent in terms of delay time, whereas FARP performance is lesser and EAPFR performance is nearing the proposed protocol in a few cases. This EAPFR protocol is having deviations in its performance when the number of nodes is increasing. Having a lesser delay time is important for reducing the number of active packets in the network thus the bandwidth of the network is less utilized. Figure 6 depicts the performance comparison of the protocols in terms of packet drop ratio. The packet drop ratio should be less in a network so that, the number of retransmission would be lesser in the network.

From figure 6, it is evident that the proposed protocol outperforms the compared protocols. The packet delivery ratio is lower when the number of drones in the network is lesser for all the protocols, whereas the proposed protocol reaches near perfection when the number of drones increases. This leads to lower bandwidth utilization as the number of retransmission of packets is lesser when compared with other protocols. The compared protocol EAPFR also nearing the perfection in terms of packet delivery when the number of drones is higher in the network. Figure 7 provides the comparison of protocol performance in terms of throughput in the network.

In the figure 7, the throughput of the proposed protocol outperforms other methods is shown. In practical network scenarios, throughput depends on various factors, one among them is network traffic. As this protocol reduces the

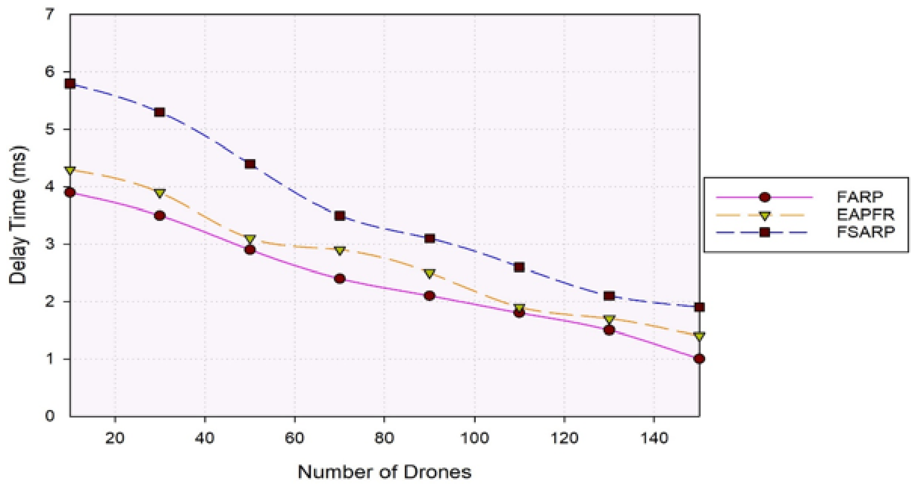

Figure 5: Delay time comparison

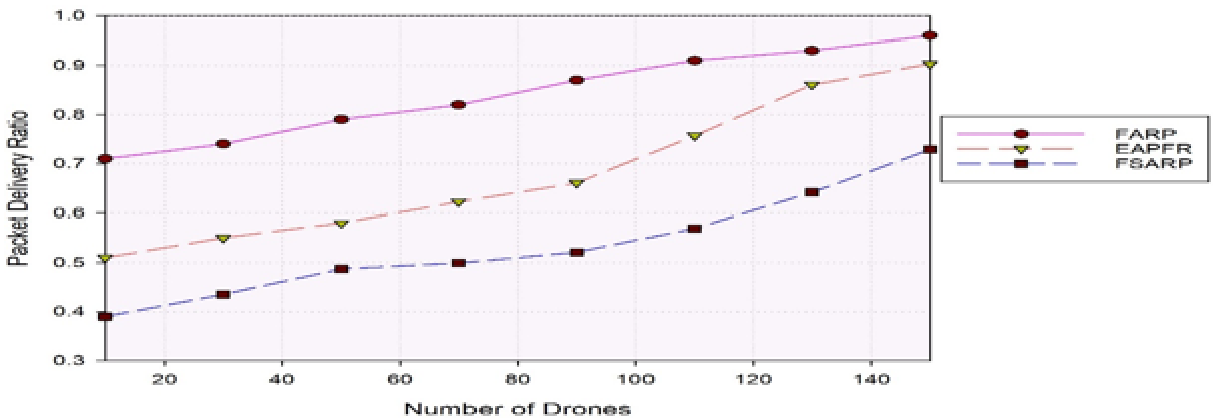

Figure 6: Packet Delivery Ratio

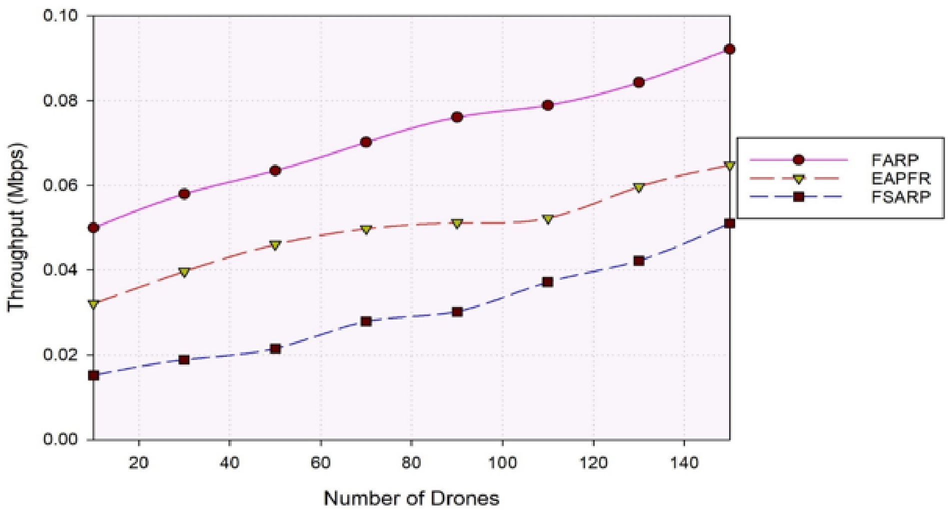

Figure 7: Throughput comparison

rebroadcasting of the packets which in turn increases the packet delivery ratio, resulting in increased throughput directly proportional to the number of drones in the network increases. The other compared protocols are not achieving this because of their lower performance in packet delivery ratio as well as delay time. From the comparison, it is clear that the proposed protocol provides a consistent increase in throughput performance in terms of throughput. Whereas the other two protocols are not providing consistent increment in throughput of the network. Figure 8 illustrates the performance comparison of the proposed protocol in terms of routing overhead.

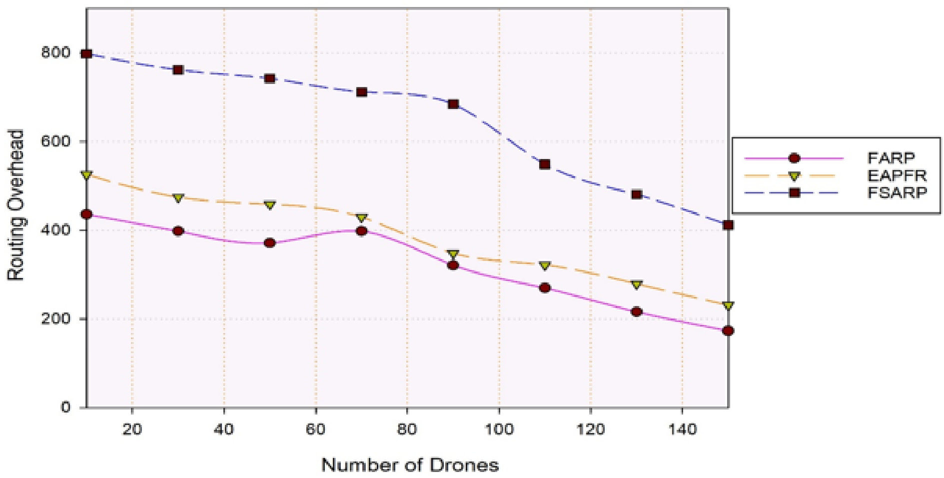

Figure 8: Routing overhead

Routing overhead is defined as number of packets generated by the drones in the network for successful transmission of messages from source to destination. This load will be very higher in general if the number of nodes in the network are limited and are separated by a vast distance. From the figure 8, it is evident that the number of packets generated for message transmission is lesser when compared with the other two methods. This is achieved because of the controlled rebroadcasting mechanism of the proposed protocol. Even EAPFR is performing near to the proposed protocol, it is not controlling the broadcasting during the route discovery which increases the load on the network. From all the performance metrics comparison discussed above, it is shown that the proposed fuzzy adaptive routing protocol is performing well and it maintains its consistency even in lesser number of nodes in the network or in higher traffic in the network.

6 Conclusion

In recent technological advancements, unmanned aerial vehicles are playing a major part in transportation, especially in critical environments which are called Flying Ad hoc Networks (FANET). Drones are now in use for logistics in many parts of the world and are expected to grow on a larger scale. This opens up many challenges for the proper implementation of drone-based transportation where one among them is the routing of information among the drones. In a drone-based network, generally, broadcasting is used for message dissemination. This leads to a well-known issue called a broadcast storm. In this research, we have proposed a fuzzy adaptive routing protocol that controls the rebroadcasting of route discovery and reply messages and enables the ground station to identify an optimal route for the destination. For this, factors like signal quality, Signal to Inference and Noise ratio, hop count, and timestamp of the packet are used to decide on message rebroadcasting. The proposed protocol controls the rebroadcasting of the route request and reply messages and thus eliminating the well-known problem called a broadcast storm. The proposed protocol is compared with two of the recently proposed routing techniques and the results show that the proposed protocol outperforms them and provides consistent service quality.

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