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# DLSA: Delay and Link Stability Aware Routing Protocol for Flying Ad-hoc Networks (FANETs)

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**Abstract**
Flying Ad-hoc Network (FANET) is a new class of Mobile Ad-hoc Network in which the nodes move in three-dimensional (3-D) ways in the air simultaneously. These nodes are known as Unmanned Aerial Vehicles (UAVs) that are operated live remotely or by the predefined mechanism which involves no human personnel. Due to the high mobility of nodes and dynamic topology, link stability is a research challenge in FANET. From this viewpoint, recent research has focused on link stability with the highest threshold value by maximizing Packet Delivery Ratio and minimizing End-to-End Delay. In this paper, a hybrid scheme named Delay and Link Stability Aware (DLSA) routing scheme has been proposed with the contrast of Distributed Priority Tree-based Routing and Link Stability Estimation-based Routing FANET's existing routing schemes. Unlike existing schemes, the proposed scheme possesses the features of collaborative data forwarding and link stability. The simulation results have shown the improved performance of the proposed DLSA routing protocol in contrast to the selected existing ones DPTR and LEPR in terms of E2ED, PDR, Network Lifetime, and Transmission Loss. The Average E2ED in milliseconds of DLSA was measured 0.457 while DPTR was 1.492 and LEPR was 1.006. Similarly, the Average PDR in %age of DLSA measured 3.106 while DPTR was 2.303 and LEPR was 0.682. The average Network Lifetime of DLSA measured 62.141 while DPTR was 23.026 and LEPR was 27.298. At finally, the Average Transmission Loss in dBm of DLSA measured 0.975 while DPTR was 1.053 and LEPR was 1.227.

**Keywords** FANET · UAV · Link stability · PDR · DPTR · LEPR · DLSA

## 1 Introduction

As modern scientific enhancements and their application needs, different kinds of wireless ad-hoc networks have arisen as Mesh networks, Sensor networks, and Ad-hoc networks. One of them is Flying Ad-hoc Network (FANET). FANET is a special class of MANET that deals with the nodes which are normally known as quadcopters or Unmanned Aerial

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Vehicles (UAVs). These UAVs fly in the air independently which involves no human personnel [1]. UAVs are typically controlled by a Ground Control Station (GCS), which wirelessly interconnects with the UAV to build a data-control loop composed of an upstream flow of control messages and a downstream flow of telemetry and sensor data [2]. The latest development of wireless technology has been countersigned in our everyday life. Mainly, due to the massive accessibility of low-cost Wi-Fi radio interfaces and other devices such as sensors, micro-embedded computers, GPS, etc. These novel devices have paved the path for the development and design of flying vehicles known as UAVs, which form a novel type of network called FANETs [3]. There are two types of communications in FANETs (i) UAV-to-Infrastructure and (ii) UAV-to-UAV. In the Infrastructure based network or UAV-to-Infrastructure, all the UAVs are linked to a satellite or a ground base station [4]. The communication between UAV-to-UAV, UAVs to BS is known as UAV-to-Infrastructure, and the overall communication setup can be operated and administered from Ground Control Center (GCC) [4].

FANETs consist of coordination, communication, and sensing capabilities through which it communicates and forms an ad-hoc network by a collection of UAVs where its nodes fly in the air. Every UAV is equipped and embedded with sensors, onboard monitor, autopilot, and Global Positioning System (GPS) receiver. These UAVs are motionless wings aircraft with autopilot, talented at flying from 12 up to 300 m/s in disaster circumstances. UAVs are presented in various sizes for different uses; these are Micro-UAVs, Small altitude and low survival UAVs, and high altitude and high survival UAVs. The group of UAVs interconnects with each other and with the ground station [5]. In UAV-to-UAV communication, UAVs interconnect with one another to complete the assigned duty. Two UAVs may have straight interconnection with each other or over other UAVs. For indirect communication using multi-hops, a communication path is decided based on different routing schemes like pro-active, reactive, and hybrid. UAVs have long or short-range communication that depends on the required data transmission rate. While in UAVs to ground station communication, UAVs communicate with the ground station to deliver or collect information about various processes [6]. FANETs are considered with a high degree of mobility that using multi-UAVs and single UAVs. The capability of single UAVs is insufficient. The routing and cooperation of multi-UAVs can generate a network that is beyond the ability of single UAVs [7]. By addressing the functionalities and advantages of FANET it seems an efficient and accurate ad-hoc network for the upcoming advanced technologies. Apart from that, the nodes of FANET have a high degree of mobility which ultimately affects the routing by movies in 3-D ways at the same time [8]. These networks need to be divided into partitions as Ground, Aerial, and by using Relay nodes as an intermediary between them. Also, these networks need reliable and robust routing algorithms for link stability along with the estimation of stability metric (threshold) value from source to destination [9]. Ground coordinated flying ad hoc networks are the set of simultaneously operating two ad hoc systems; one operating on the ground and another in the air. These can be treated as a single ad hoc formation to perform data transmission between them [10].

The proposed work is based on the two FANET's existing routing protocols that are DPTR and LEPR. Each protocol performs a different kind of functionality according to its algorithms and methodologies. The only thing that differentiates the proposed work from the existing work is that in the proposed work two [11] parameters Network Lifetime and Transmission Loss were applied but that was not in the simulation results with the existing work. Due to some lack in the existing schemes, the current research work has focused to overcome it and by taking the positive features of both schemes. In both schemes, the network partitioning by using the R-B tree and using the link stability metric are separate features. By merging these functionalities make the proposed schemes different from the existing works. In short, the proposed work is motivated by the existing work by taking their algorithms and methodologies into considerations and by merging their positive features in a proposed hybrid routing protocol named DLSA. This keeps apart/differs the proposed scheme from the existing schemes by merging their positive features and applying them in stand-alone hybrid routing protocol for the sake of FANET's link stability and choosing the highest priority node selection.

The main problems with the existing routing protocols are high delay and high packet loss. To overcome these problems, a hybrid routing protocol named Delay and Link Stability Aware (DLSA) routing protocol for FANET has been proposed. Contribution of the study as The nodes of FANETs have high mobility and dynamic topology, therefore, to maintain communication among these high mobility nodes is a research challenge. DPTR and LEPR are routing schemes that are used for node-link stability and selection of nodes having the highest priority in FANETs. In DPTR (Distributed Priority Tree-based Routing) protocol, the communication becomes possible by combining two ad-hoc networks of ground and aerial to solve the problem of network partitioning. This protocol assumes a neural interface (relay nodes) for communication between sending and receiving nodes. Though, this scheme doesn't consider link stability among nodes that causes higher delay and packet loss ratio. On the other hand, LEPR (Link Stability Estimation-based Preemptive Routing) protocol utilizes a link stability metric procedure for the connectivity of links between nodes. This protocol uses the above procedure for the pre-emptive estimation of link stability. The selection criterion is carried out via the maximum metric (threshold) value of the nodes from sender to receiver to find the suitable route. This scheme undergoes unnecessary requests at the link formation stage, which eventually affects the nearby nodes and in the end, the network becomes dense results in an increasing packet loss ratio.

- To design Delay and Link Stability Aware (DLSA) Routing Protocol for FANETs.
- To evaluate DLSA with DPTR and LEPR routing schemes in terms of End-to-End Delay and Packet Delivery Ratio.

The rest of the paper is organized as follows: In Sect. 2, we discuss related work. Section 3 presents the methodology. In Sect. 4, we describe the simulation results and analysis of the experimental setup. Section 5 concludes.

## 2 Related Work

This section explains all the previous reviews in which the works have been done on the routing for FANETs. This chapter summarizes the solution of the open issues and challenges that causes a severe problem to the network. Some of the previous works like seamless handover procedure, node placements, network stability period, node mobility with highly dynamic topology, and many more are discussed in the previous papers. Most of the researchers used mobility models and novel routing schemes for the sake of the improvement of FANETs. The stability metric was used to measure the link dis-joint paths between source and destination. Due to the exponentially increasing dissemination of UAVs, the development of effective communication frameworks supporting their operations has received considerable attention in recent years [11]. The interested reader can find in [12] a detailed survey on the challenges of UAV communications in terms of mobility, fast topology changes, connectivity, and network partitioning, and link stability. An investigation of IEEE 802.11 s/ac applied to UAV-to-ground links can be found in [13]. However, an organic and comprehensive solution to these issues is still missing. In [14] the authors have proposed an accurate solution for the sake of network improvement in FANET by utilizing the evaluation of different routing protocols to check and efficiency and performance of each one in different scenarios. These protocols were AODV, DSR, TORA, OLSR. From the experimental results, each protocol had given different utilized results in contrast to each other. In [2], the authors performed an experimental performance evaluation of available mobility models that can generate realistic scenarios for FANET applications. Both reactive (AODV and DSR) and proactive (OLSR) routing protocols were compared for Reference Point Group, Gauss Markov, Random Waypoint, and Manhattan Grid Mobility models. Average routing overhead, PDR, and end-to-end delay were used as performance metrics. In [8], the authors suggested a novel tree-based routing scheme that had divided the FANETs into mutually connecting two ad-hoc networks with the collaboration of the network partitioning between the ground and aerial ad-hoc networks. For the network partitioning and mutually coordinating of two ad-hoc networks, they had proposed a novel hybrid routing scheme that resolved the issues that were associated to formation of topology and routing between concurrently in operation of nodes of two different ad-hoc creations. The suggested routing scheme was originated and had extended the properties of the distributed Red–Black (R-B) tree, which had formed a priority based network that permits the selection of the appropriate nodes also selection of the channels as a relaying nodes. This novel scheme named Distributed Priority Tree-Based Routing (DPTR) Protocol. The DPTR scheme was examined and analyzed using NS-2 and MATLAB with the comparison of the current state-of-the-art routing schemes. The simulation results showed that DPTR had significantly gained higher performance in terms of PDR, End-to-End Delay, and network throughput, probability of connectivity, channel utilization, and routing overhead. In [9], the authors presented a novel routing scheme named Link Stability Estimation-based Pre-emptive Routing (LEPR) scheme that had aimed FANET with the help of AODV, a current routing scheme for the ad-hoc network. To take information regarding GPS location, a new metric was introduced named link stability metric procedure, which uses the link threshold value for the upcoming-targeted node. The working procedure of this new stability metric was to estimate the safety degree, mobility, and link quality, to take into consideration the past, current, and future statuses of the link stability correspondingly. With the help of this novel stability approach, the LEPR could calculate many robust link-disjoint routes at the time of the route discovery process. In accumulation, a semi-proactive process of route maintenance was also generated to check for the link stability in advance when an anticipated path is about to break. This new scheme had reduced the number of broken paths and latency of packets by discovering and handovers early to an efficient and reliable path. The suggested approach had shown and demonstrated that LEPR had efficiently and significantly best performed two existing AODV and DSR routing schemes based on PDR, Delay, and routing overhead, in highly or either low settings of mobility. In [15], the authors compared the main ad-hoc wireless networks i.e. VANET, MANET, and FANET. Furthermore, Mobility is the greatest interesting problem for the FANET network. In [16], the authors presented a geo-location-based routing protocol for FANET with multi-hop network communication. Their proposed protocol showed the robust and reliable performance of the dynamic multi-hop network topology. In [17], authors proposed a Stable Ant-based Routing Protocol (SARP) for Flying Ad Hoc Networks. SARP is based on the Ant Colony Optimization meta-heuristic, which selects the next-hop node according to the stable value, pheromone, and the energy of the link. The stable value was calculated by the transmission range of the node and the distance between the current node and the next-hop nodes. SARP let the nodes broadcasted HELLO messages periodically to obtain the neighbor information. In [18], the authors proposed a bio-inspired routing protocol for UAVs on the board in the agribusiness area. In exactness agribusiness, the nearness of parasites or the unexpected climatic changes speaks to a significant issue for ranchers as a result of the debasement of yields and development quality. At that point, the utilization of the new advancements, for example, UAV gadgets, the new systems, for example, FANET, and the usage of new sensors and actuators inside UAV sweep speak to a significant guide to the keen horticulture area. In [19], the authors proposed a routing scheme suitable for highly dynamic FANET for the rapid change of topology in complex scenarios. In this scheme, the moving nodes sense changes of the surrounding network topology periodically, and the current mobile scenario was confirmed according to the perceived result. Furthermore, a suitable routing protocol was selected for maintaining network performances at a high level. The concerned performance metrics were packet delivery ratio, network throughput, average end-to-end delay and average jitter. In [20], authors proposed an adaptive novel hybrid communication scheme having a new Position-Prediction-Based Directional MAC (PP-MAC) and a Self-learning Routing Protocol on the basis of Reinforcement Learning (RLSRP) routing schemes. The simulated results of the PP-MAC had showed that this scheme countersigned and overcome the problem of directional deafness along with the directional antenna. In [21], authors combined cooperation protocol for human-UAV order and control frameworks, where the human administrator helps in verifying the UAV by discontinuously performing geo area errands to affirm its announced area.

## 3 Proposed DLSA Routing Protocol

In our proposed mechanism, the first step is the initialization phase. The next step is the deployment phase in the perspective of the routing phase which ultimately checks for the routing i.e. to check for the communication that is about to take place from source to destination. Then comes the network partitioning phase, in this phase the network will be divided into partitions i.e. to separate both the aerial and ground ad hoc networks. For this procedure, in the next step, the given condition will check firstly that if the collaborative mode is active. The collaborative model will express either the communication is one-sided or from both collaborative modes (ground and aerial). After network partitioning and collaborative communication, the next phase is here to construct the Red Black (R-B) priority tree for three networks (M, N, and K) i.e. Aerial (M), Ground (N), and by using the Neural interface as a virtual layer works an intermediary as a Neural (K). N, M, and K are symbols that represent three separate networks as described. The R-B priority tree selects the nodes based on the highest priority. After that, the top node selection phase will come which was derived from the previous phase. Now here comes the condition that if the highest priority node is selected then proceeds and if not then repeat the highest priority node selection phase. After the node priority, the next phase is to check for the link stability, as the highest priority nodes are selected but to maintain the communication through link stability. The next step is based on the condition, in which the node's stability metric values will be pre-defined. This condition will check that either the threshold value of the current link stability is greater than the defined value. If yes, then the data will direct transfer through the direct transfer phase. If no, then the link stability metric procedure will be followed. In the link stability metric procedure, the first task will be route discovery to discover the nearby link disjoint paths. The Route Request (RREQ) and Route Reply (RREP) process will be obtained to find the nodes which have the highest stability metric value, and which are fully in the range of communication. By doing this process the next phase will select the highest stability metric path to transfer the data. The second last step will take place by forwarding data in a mutual mode in which when the ground and aerial i.e. sender and receiver interact with each other via the wireless link then the process will become stop in the last step. The prepoused flow chat is shown in Fig. 1. Table 1 demonstrates that the desired study has used diverse aspects for the analysis of simulations.

**Algorithm-1**: DLSA routing protocol for the proposed mechanism:

```
1.  Initialization phase;
2.  Deployment phase;
3.  Network partitioning;
4.  IF (collaborative mode = true); THEN
        GoTo Step 5;
            Else
            Repeat Step 1;
5.  ENDIF;
6.  Construct $R - B$ priority tree for Ground $(N)$, Aerial $(M)$ and (K);
7.  Selection of nodes on the basis of highest priority;
8.  IF (top priority node is selected); THEN
        GoTo Step 8;
            Else
                Repeat Step 6;
9.  ENDIF;
10. Check for link stability;
11. IF (Stability Metric $\geq$ TH(Threshold)) THEN;
                                Direct Transfer;
            Else
12. Use route discovery for estimation of
                                stability metric;
13. ENDIF;
14. Use highest stability metric path for
                                data transfer;
15. Forward data in Mutual mode;
16. END;
```

**Algorithm-2:**Pseudocodefor R-B priority tree of ground, aerial and neural set:

```
Require: $M \geq 3 \& N \geq 3$
Ensure: $Neurons \leftarrow K \geq 3$
Ensure: $Aerial\_Network: A(M) \leftarrow initialized$
Ensure: $Ground\_Network: G(N) \leftarrow initialized$
    while $final\_route \neq true$ do
        $fetch\_g \leftarrow node\_data(G)$
        $\mathcal{P}_{x1} \leftarrow max(\mathcal{P}_x[N])$
  $P\_Tree(G, \mathcal{P}_{x1}, Guider)\ T_1$ /* ground network
        $fetch\_a \leftarrow node\_data(A)$
        $\mathcal{P}_{y1} \leftarrow max(\mathcal{P}_y[M])$
  $P\_Tree(A, \mathcal{P}_{y1}, Guider)\ T_2$ /* aerial network
     $find(G) \leftarrow priority\_node(G)$
     $find(A) \leftarrow priority\_node(A)$
$Re - initialize \leftarrow neurons\_tree(K)$
  $P\_Tree(A, G, K, Guider) \rightarrow T_3$ /* neural tree

            if priority tree = true then
  identify link ← link_matrix(weight with highest priority)
     update ← $T_3(link)$
        else
     T3 ← no_update
                  set path = true
  end if;
   follow priority order of nodes
            if (R − B priority tree = true) then
  | proceed accordingly to the proposed scheme
  |          maintain highest priority for N M and K
                 end if
```

### 3.1 System Model

It is a challenging task to formulate and design a routing scheme for a network that is composed of two different kinds of ad-hoc units i.e. ground and aerial. The key functionality of a routing protocol is to distinguish and decide the intercommunicating nodes in both the routing units that will create a network corridor (NC) to permits the routing in diverse modes. The DLSA proposed protocol in this research has the capabilities of the R-B tree i.e. it has extended the positive features of that tree for the formation of two different operating units along with some changes and modifications of the tree. It suits possible for having two nodes operating with each other. So, for the solution of the partitioning of network the proposed DLSA protocol acts in the given three parts:

- Ground nodes Identification (N)
- Aerial Nodes Identification (M), and
- Using neural structure for Interfacing (relay nodes K)

The terms N, M, and K are the symbols that represent the Ground, Aerial and Neural Structure of the Network. The routing scheme operates the neural interface/structure for its operating environment and senses the formation of the tree from a routing table arising from both ground and aerial nodes [8].

### 3.1.1 Collaborative (Two-Way) Data Forwarding

For efficient and robust routing, the hierarchy of the network is self-included bound along with having the formation of multiple topological maps and the decision from end to end analysis. It is need-based that a protocol ought to have the capabilities enough for two ways collaborative data transfer of the information. For effective networking, the self-included parameter is a hierarchy of the network, but to have multiple topology-map formations and head-to-head decision analysis, the protocol must be capable enough to collaboratively transfer the data. In this mode, the amount of the network corridors may be more than single and utilizes the excessive level of the channel for transferring i.e.:

$$\text{if collaborative}_{\text{mode}} = \text{True} \tag{1}$$

$$G_s = \left\{ \text{NC}1, \ldots, \text{NC}\frac{s}{2} \right\} \tag{2}$$

where

$$\text{NC}i = \max \left\{ C1, \ldots, C\frac{s}{2} \right\}, 1 \le i \le \frac{s}{2} \tag{3}$$

where NC shows the network corridor and NC$i$ shows the initials of the corridor. $\frac{s}{2}$ shows the session of the network divided into 2 for ground and aerial with the multiplication of NC [8].

### 3.1.2 Route Discovery Estimation

This procedure is performed out by utilizing pre-existing operations of the network known as the discovery of the links via neighbor nodes. This allows the identification of the active and connected nodes, and additionally permits estimation of the connectivity times of nodes and examines the design of a randomly oriented graph for data transmission. Henceforth, the discovery time of route may be introduced as it is the lowest time in which every edge of the network is recognized that leads to the connectivity of two nodes or it is the shortest time interval for forming the routing table created by every active node [9]. For this technique, let's assume that $m$ is the number of aerial nodes, $n$ is the number of ground nodes, $k$ is the number of neural interface's nodes in the layer of the collaborative network, $t'$ reveals the exchange of time beacons within two nodes and $t''$ expressed the time for updating the table of routing like:

$$t_e = \left( t' + t'' \right) \tag{4}$$

While for bottom–up transmission', It can be expressed as:

$$t_{b-u} = \max\left( ta, tg + tc \right) \tag{5}$$

where

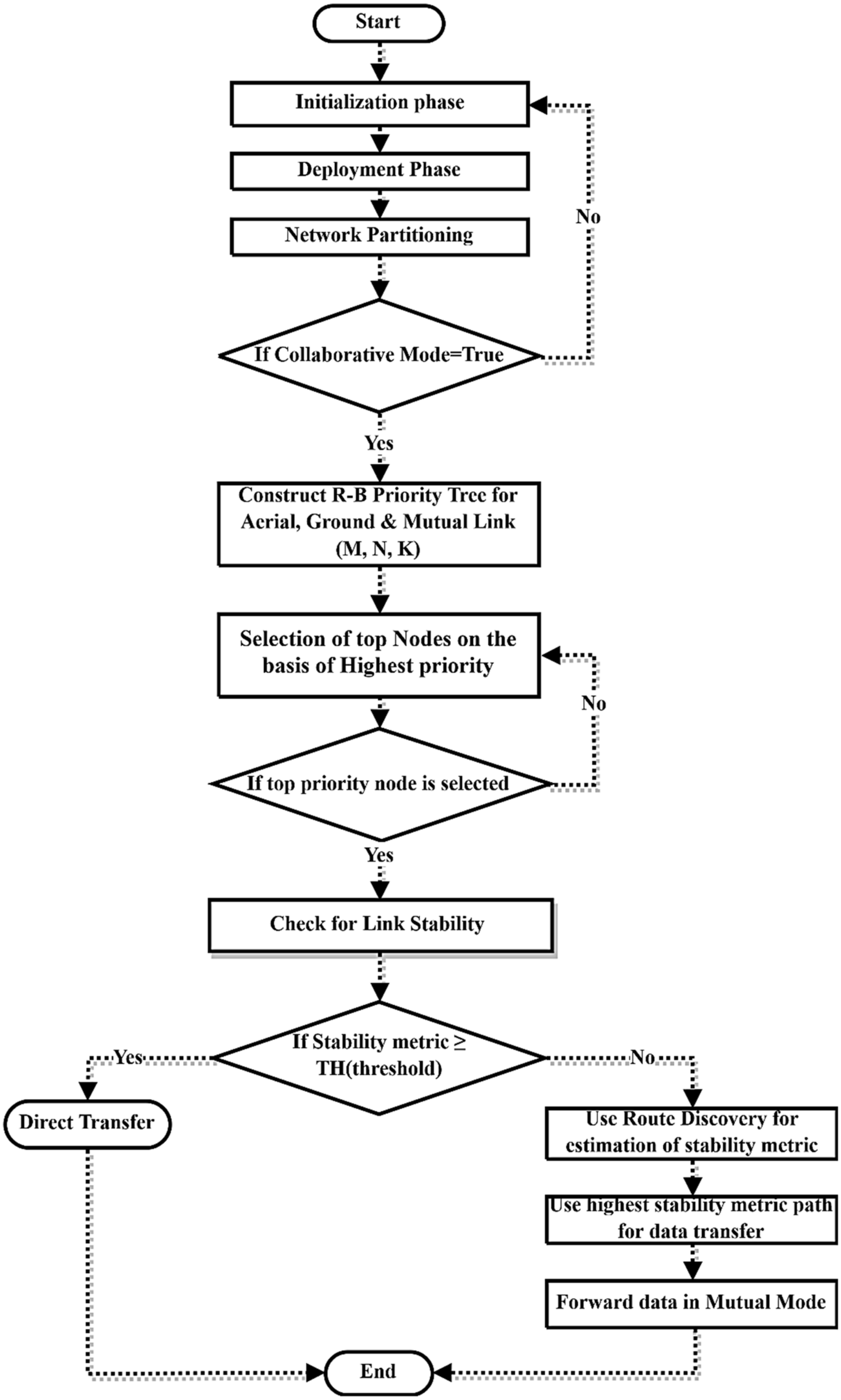

**Fig. 1** Proposed Flow Chart of the research

**Table 1** General simulation parameters

| Parameter | Value |
|---|---|
| Simulator | MATLAB 18a |
| Network volume | 500 m × 500 m × 500 m |
| Number of nodes | 100 (Divided between Ground and Aerial) |
| Ground node maximum speed | 25 m/sec |
| Aerial node maximum speed | 200 m/sec |
| Transmission range/Node | 350 m |
| Channel type | Wireless IEEE 802.11 s |
| Network | FANET |
| The proposed scheme | DLSA |
| Compared schemes | DPTR and LEPR |
| Packet size | 256 bytes |
| Simulation time | 1000 (seconds) |

$$tc = kc \times Lg \times tlg \tag{6}$$

In this scenario of formulation, $kc$ shows several neurons connected, $L_g$ shows the maintained logs at the collaborative layer and $t_{lg}$ indicates the time for maintaining logs [8].

### 3.1.3 Tree Formation for Aerial, Ground and Neural Set

The probability-based tree creation and formulation permit the revealing of the nodes along with the slots of time in a difficult manner in the network, i.e. it indicates and introduces the nodes in the network that may cause the highest and lowest modifications at the time of operation of the network in a routing tree. Apart from this, it also delivers and helps for maintaining the logs of the nodes of the network. A network that has time slot $t$ for operating units are given as, average rate $\text{Avg}_{\text{rate}}\ (g)$, $\text{Avg}_{\text{rate}}\ (a)$ and $\text{Avg}_{\text{rate}}\ (n)$ for ground, aerial and mutual network are formulated as:

$$\text{Avg}_{\text{rate}}(g) = \sum_{i=1}^{N} xi - N_{ini} \tag{7}$$

$$\text{Avg}_{\text{rate}}(a) = \sum_{i=1}^{M} xi - M_{ini} \tag{8}$$

$$\text{Avg}_{\text{rate}}(n) = \sum_{i=1}^{K} xi - K_{ini} \tag{9}$$

where $N$, $M$, and $K$ are symbols that represent three different operating ad hoc networks. Whereas, $N_{ini}$, $M_{ini}$, *and* $K_{ini}$ are the initial number of nodes in ground, aerial and neural ad hoc networks, accordingly [22].

### 3.1.4 Link Stability Estimation and Mathematical Terms

First, it is a very significant and mandatory part to have such a reliable and robust routing maintenance scheme for FANET. For this purpose, the key idea of the proposed DLSA scheme is to formulate and calculate many stable dis-joint routes by utilizing the proposed link stability metric (threshold) scheme for finding suitable and best paths for switching the current link with that if the link is about to break soon. This is remarkably proposed and designed for FANET in which the connectivity of the network via links is the mandatory and major part during transmission of data. The proposed DLSA is designed based on DPTR and LEPR schemes. In the current section, the new stability link procedure has been proposed and then formulated with mathematical models accordingly [9].

### 3.1.5 Estimation of the Link Stability Metric

The best metric (threshold value) is not to only efficiently representing the quality of the links but also should be active and aware when the topology of the network changes particularly in FANET scenarios. For meeting the desired needs as mentioned procedures, it is particularly being specific to introduce and comprehensive and robust scheme having the features of link stability metric along with the knowledge and awareness of the current, past, and future status of the link. Also, especially, this novel metric contains having three parts that are quality of the link, degree of safety, and prediction factor of mobility, in response these all relate to a single sequence of the status. Consider their existing two nodes indicated by $i$ and $j$ and these are in the communication range to each other. The term $D_{ij}$ indicate the stability of the link between $i$ and $j$ that can be mathematically expressed as the mixture of the link quality $LQ_{ij}$, safety degree $Y_{ij}$ and prediction factor of mobility $S_{ij}$ as shown in Eq. 16:

$$Dij = \lambda 1 LQij + \lambda 2 Yij + \lambda 3 Sij \tag{10}$$

where, $\lambda 1, \lambda 2 and \lambda 3$ are the weighting coefficients controlled by the given state.

$$\lambda 1 + \lambda 2 + \lambda 3 = 1 \tag{11}$$

This is worth predicting that every of the aforementioned three costs is controlled to a cost unit. By the circumstance, the value of $D_{ij}$ is restricted from 1 to 0 ranges. So forward and reverse ratios of delivery have to measure the quality of the link that can be indicated as:

$$LQij = \gamma^f * \gamma^r \tag{12}$$

where, $\gamma^f$ is the forwarder ratio of delivery, such that the possibility in which node j becomes able to receive a packet from node $i$. Similarly, $\gamma^r$ is the ratio of delivery in reverse mode, if there is a packet that received successfully from reverse and forwarder direction, then the value of quality is equal to 1. The ratio of delivery, either $\gamma^f$ or $\gamma^r$ can be indicated mathematically as:

$$\begin{cases} \gamma n = \alpha * \gamma n - 1 - (1 - \alpha) * hn \\ \gamma 0 = 0 \end{cases} \tag{13}$$

where,

$$hn = \begin{cases} 1, & \text{if the } n\text{th hellow } e \text{ is received} \\ 0, & \text{otherwise} \end{cases} \tag{14}$$

The restricted value of parameter $\alpha$ redirects the time relationship, changing in the ranges (1, 0). When $\alpha$ equivalent to 0, the ratio of delivery just is dependent on the existing link quality, so the scheme will respond quicker. By increasing the value of $\alpha$, the additional estimation of stability and average is depicted. To allocate the GPS directions through the network, there will be added field-loc to the Hello packet.

Consider $(\mathcal{X}i, \mathcal{Y}i, \mathcal{Z}i)$ be the coordinates of UAV $i$. The degree of safety $Y_{ij}$ signifies the nearness of the UAV $i$ and $j$ based on their space presently as shown:

$$Yij = \frac{R - dt}{R} \tag{15}$$

The term $R$ is the radius of communication of a UAV, and Euclidean Distance $d_t$ is indicated of two nodes as:

$$dt = \sqrt{\left[Xj(t) - Xi(t)\right]^{2} + \left[Yj(t) - Yi(t)\right]^{2} + \left[Zj(t) - Zi(t)\right]^{2}} \tag{16}$$

When the values of $Y_{ij}$ are greater than the two nodes become in the movement to stay close with one another. There will be a long time interval taken when a communication link between UAVs becomes no longer i.e. becomes a break. The comings are the mobility prediction factor $S_{ij}$ that are discussed. In the scenario of the real world, a UAV can't move in unsorted propagation due to dynamic and kinetic restrictions. So, for this, it must formulate and measure the sudden and fast speed between the UAV $i$ and $j$ to evaluate their trends of moving within the upcoming time interval for the next connection with another UAV.

The rapid speed of UAVs between $i$ and $j$ is shown as:

$$Vre = \frac{dt - dt - \Delta t}{\Delta t} \tag{17}$$

where $t$ and $t - \Delta t$ show the time interval to the Hello messages incoming of the last and second to last the time of the last and second to last Hello messages arriving. $D_t$ and $dt - \Delta t$ are the matching spaces between UAV $i$ and $j$. Even, if the existing two UAVs travel separately near the contrary path at extreme speed $V_{\max}$. $V_{re}$ is up to the highest rate $2V$max. Despite this, if these UAVs are near to one another at the highest speed, $V_{re}$ had to reach the lowest value $-2V$max.

Thus, it has introduced the prediction factor of mobility $S_{ij}$ such as:

$$Sij = e^{1 - \frac{Vre}{2V\max}} \tag{18}$$

$S_{ij}$ is controlled to a cost unit cost in Eq. 18. The lowest the value of $V_{re}$ is the highest $S_{ij}$ generates, and the further stability of the link leads to the path of metric of stability relies on the lowest link stability threshold values starting this route. The basics of this path are that if there disconnect a stand-alone path, and then the overall links will have to be disconnected. Henceforth, the route stability is expressed as:

$$P = \min_{ij \in \text{path}} Dij \tag{19}$$

The highest value of $P$ shows that the route has better and efficient stability, ideal for transmission of data packet [9].

### 3.1.6 Route Discovery

DLSA transforms the base scheme LEPR mechanism of route discovery to measure and calculate many link dis-joint routes utilizing the above stability metric of link. These two link dis-jointness and node dis-jointness may create every route fail autonomously indebted to the feature of having not any common link. By comparison with the link, dis-jointness is an excessive and extra limited alteration characterized by not possessing any similar link. However, it can affect lesser changes to the paths to be generated, particularly the environment of sparse. This procedure makes UAV dis-jointness effective with less quality. This scheme uses the RREQ and RREP procedure for route discovery to find an alternative and suitable route for the existing link with the current communication scenario when an anticipated route is about to break. So, it has to introduce and design a link dis-joint route in this research [9].

### 3.1.7 Semi-Proactive Route Maintenance

Since several retransmission time-outs are mandatory to expire early before a connection is assumed broken then the detecting of cost for link failure may be high. Also, this failure of the early route due to the motion of a node affects the diverse route. To deliver a service of unbroken connection as probable, it has to evaluate periodically the primary path of communication quality and its response in advance to the early breaking of the connectivity. That is the reason this scheme has the features via which it is designated as semi-proactive. Once identifying a link in connection is probable to break early, the semi-proactive route preservation approach originates a recovery action by detecting the maximum quality route to switch the early route. This different route may fit one of the reserve routes of a novel gained from the process of route discovery [9].

## 4 Simulations Result

This section shows the simulated results along with a discussion of each concerned evaluation parameter. The results are collected from many simulation parameters are evaluated and debated. The simulations were carried out in MATLAB by taking the network volume of 500 m × 500 m × 500 m. In FANET, diverse kinds of nodes are used, like ground nodes, aerial nods, and cluster heads and for the mutual link of these nodes, intermediary nodes are used known as relay nodes that work on the principle of taking the message from one node and pass it to another node. In short, they work as a third party in the formation of FANET.

### 4.1 Performance Evaluation

The parameters designated for performance evaluation are End-to-End Delay, Packet Delivery Ratio, Network Lifetime, and Transmission Loss.

### 4.1.1 End to End Delay

The term End-to-End delay indicates the complete delay from source to destination within a specific interval of time. The delay consists of the transmission delay, the propagation delay of the signal, the processing delay of the data, and the queuing delay in the entire network. From sender to destination, when a signal travels and carries data, which undergoes these mentioned delays, is counted as the end-to-end delay of the network [8, 23].

This metric can be calculated using Eq. 20.

$$d_{\text{end - end}} = N\left(d_{\text{trans}} + d_{\text{prop}} + d_{\text{proc}} + d_{\text{queue}}\right) \tag{20}$$

where

$d_{\text{end-end}}$ = End–to–End Delay
$d_{\text{prop}}$ = Propagation Delay
$d_{\text{proc}}$ = Processing Delay
$d_{\text{queue}}$ = Queuing Dela
$N$ = Number of connection

### 4.1.2 Packet Delivery Ratio (PDR)

The term PDR indicates the number of packets that have been sent from sender to receiver and the number of packets that have been acknowledged back i.e. the number of packets acknowledged divided by several packets sent multiply by a hundred [24]. This metric can be calculated using Eq. 21

$$\text{PDR} = \frac{\text{Number of packets acknowledged}}{\text{Number of packets sent}} \times 100 \tag{21}$$

### 4.1.3 Network Lifetime

The term network lifetime describes the total operational time of the network in the given intervals of simulations. In other words, ‘‘break of the time in which from the beginning of the network until the death of the first node. It expresses that for how long the existing network is/was stable’’. The lifetime of the network is measured in seconds or rounds. The lifetime of the network can also be expressed in terms of connected and disconnected nodes i.e. active and non-active nodes. When the node is dead, we can say the network is not stable, also when that node is no longer in communication with another node then it also expresses that the network is not stable, because the network completely depends upon the nodes that can be in the communication range with another node [25, 25].

The lifetime of a network can be calculated using Eq. 22,

$$N_{\text{Lifetime}} = \begin{cases} \dfrac{1}{\sum_{i=1}^{n} wi} (\text{If } n \geqslant 1) \\ 1 \quad (\text{If } n = 0) \end{cases} \tag{22}$$

$W_i$ = Weight of every weak module
Lifetime = Lifetime of Network
$n$ = Amount of weak modules

### 4.1.4 Transmission Loss

The term transmission loss indicates the reduction in power that happens throughout transmission from one point to another i.e. from source to destination or from one node to another node [13].

Transmission loss (TL) is generally measured in dBm (decibels milliwatt), as shown in Eq. 23.

$$\mathrm{TL} = 10\log_{10}\left|\frac{W_i}{W_t}\right|\mathrm{dBm} \tag{23}$$

where: $\boldsymbol{W}_i$ is the power of incident signal coming towards a defined area i.e. destination? $\boldsymbol{W}_t$ is the power of the transmitted signal going away from the defined area i.e. destination?

Analysis of the performance evaluation parameters for DLSA, DPTR, and LEPR is discussed and depicted in the following Graphs.

## 4.2 Analysis of End to End Delay (Milliseconds)

End-to-end delays w.r.t three schemes are portrayed in Fig. 2 that characterizes an assessment between the average E2ED of DPTR, LEPR, and DLSA. The results are achieved from the simulation. Assessment has shown that E2ED in DLSA is less than DPTR and LEPR due to minimum distances between the nodes by using relay nodes. In DLSA, the average E2ED is 0.457 as compared to DPTR, which is 1.492, and LEPR that is 1.006. The results were taken for 1000 (seconds) as shown in Fig. 4. The X-axis displays simulation time in seconds while the Y-axis displays End end delay in milliseconds. As depicted from Fig. 4, E2ED of DLSA, DPTR, and LEPR is calculated and the results have presented that the value of DLSA is 0.675 after hundred seconds, while the value of DPTR is 8.658 and LEPR is 4.625. After two hundred seconds, the E2ED of DLSA is 0.675, while DPTR is 2.340 and LEPR is 3.847. After four hundred seconds, the E2ED of DLSA is 0.549, while

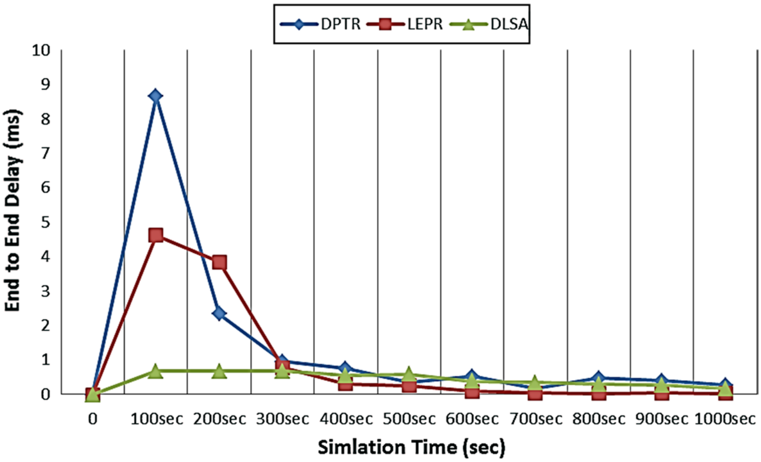

**Fig. 2** End to End Delay (ms)

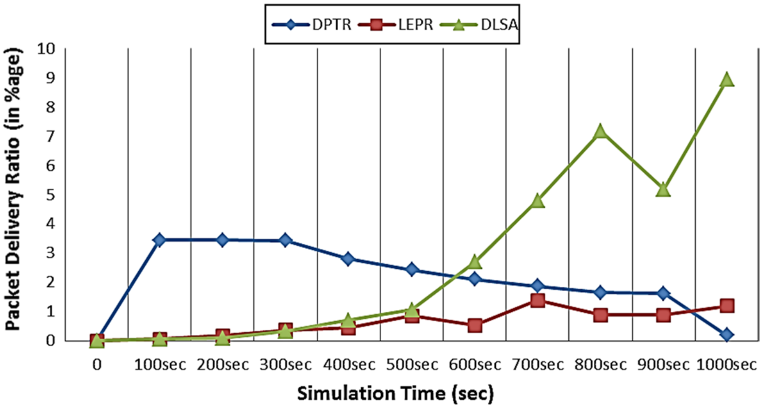

**Fig. 3** Packet delivery ratio

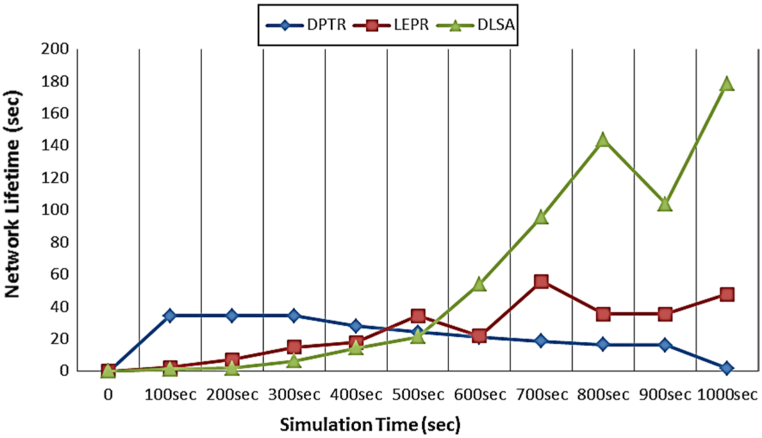

**Fig. 4** Network lifetime (sec)

DPTR is 0.751 and LEPR is 0.309. After eight hundred seconds, the E2ED of DLSA is 0.294, while DPTR is 0.493 and LEPR is 0.030. After thousand seconds, the E2ED of DLSA is 0.168, while DPTR is 0.274 and LEPR is 0.031. The overall E2ED in the percentage of DLSA is calculated and measured less than DPTR and LEPR routing protocols.

## 4.3 Analysis of Packet Delivery Ratio (Percentage)

PDR is the percentage of the sent packets from source to destination in a given interval of time. When the packet arrival time is lesser, higher traffic is sent from source nodes. This rises packet accident tends to a lesser PDR. DLSA scheme increases the likelihood of getting packets effectively by forwarding packets on alternative routes and joining at the destination. It is clear from Fig. 3 that DLSA has achieved higher PDR than DPTR and LEPR. During the early periods of the simulation PDR of DLSA is not much high as compared to other schemes. But using the collaborative and choosing high threshold value from source to destination, it has clearly shown that the PDR of DLSA has drastically increased. Comparison has shown that PDR in DLSA is higher than DPTR and LEPR due to minimum distances between the nodes by using relay nodes that possess clear LOS. In DLSA, the average PDR in percentage is 3.106 as compared to DPTR, which is 2.303, and LEPR that is 0.682. The results were taken for 1000 (seconds) in 10 intervals as shown in Fig. 3. The X-axis shows simulation time in seconds while the Y-axis shows PDR in percentage w.r.t simulation time.

### 4.4 Analysis of Network Lifetime (Seconds)

It illustrates the total execution time of the protocol. This metric shows the duration of the network that for how long the existing network has performed until the death of the first node has occurred. DLSA is not dealing with the energy of the nodes, but lifetime also indicates the link stability of the current nodes. The network lifetime for DLSA, DPTR, and LEPR is shown in Fig. 4. The lifetime of DLSA is much greater than DPTR and LEPR routing protocols. Increased network lifetime of DLSA comparative to DPTR and LEPR is because of non-continuous data transmission and flooding mechanism. Data is transmitted only if there exists some active node within the network with having the highest threshold value. Hence, DLSA shows much better results in comparison with the DPTR and LEPR routing protocols. By calculating the overall network lifetime, it has been concluded that the lifetime of DLSA is much higher in comparison with DPTR and LEPR. The average network lifetime of DLSA is 62.141 s as comparison with the DPTR whose lifetime shows 27.298 s and LEPR shows 23.036 s. DLSA shows a much greater improvement overall protocols as depicted in Fig. 6.

Figure 5 shows the transmission loss investigation of DLSA with different FANETs protocols DPTR and LEPR. Proposed DLSA decreases the transmission loss because of the way that a high stability metric value is taken and figured and based on this multi jump transmission pursues various ways to diminish transmission loss. DPTR scheme demonstrates an improvement over LEPR protocols by decreasing the estimation of transmission loss from 5 dBm to 1.148 dBm, while LEPR estimation of transmission

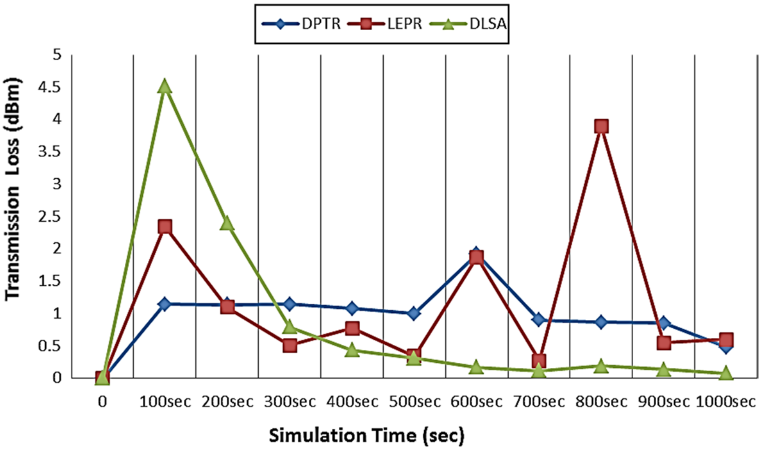

**Fig. 5** Transmission loss (dBm)

**Table 2** Comparison of DLSA with DPTR and LEPR

| Protocol Name | Average E2ED (ms) | Average PDR (%) | Average network Lifetime (sec) | Average transmission loss (dBm) |
|---|---|---|---|---|
| DPTR | 1.492 | 2.303 | 23.036 | 1.053 |
| LEPR | 1.006 | 0.682 | 27.298 | 1.227 |
| DLSA | 0.457 | 3.106 | 62.141 | 0.975 |

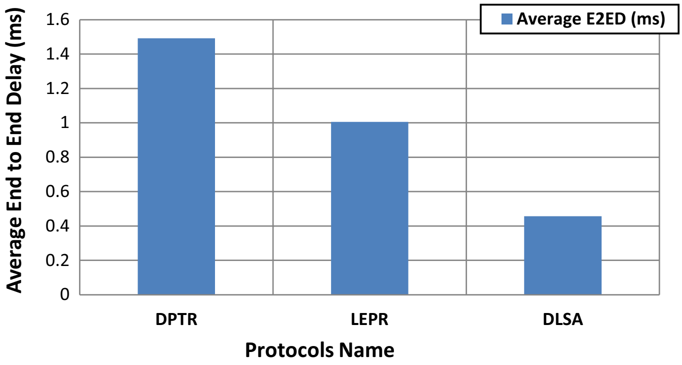

**Fig. 6** The comparison of protocols for average End to End Delay

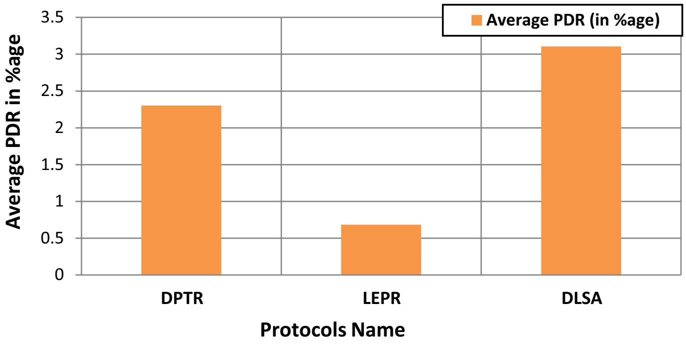

**Fig. 7** The comparison of protocols for average PDR

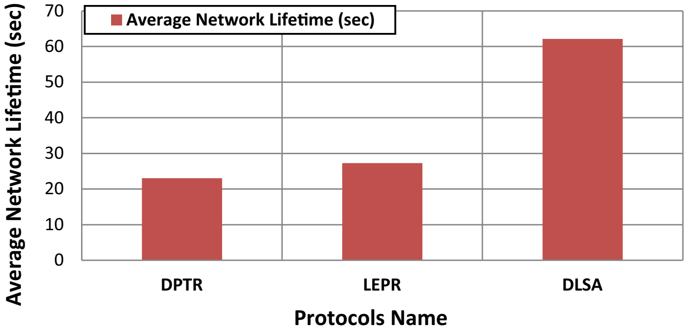

**Fig. 8** The comparison of protocols for average network lifetime

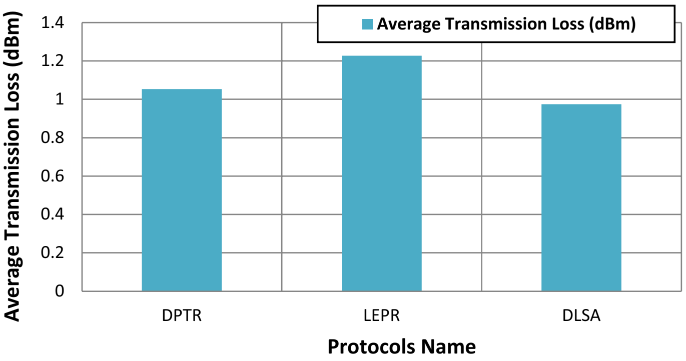

**Fig. 9** The comparison of protocols for average transmission loss (dBm)

loss is diminished from 5dBm to 2.353. By demonstrating the most reduced estimation of transmission loss in DLSA, it has reasoned that DLSA is fundamentally improved the productivity in examination with DPTR and LEPR. Since, when the transmission loss value is radically going down then it is by all accounts the ideal execution of the scheme. The proposed scheme DLSA demonstrates a sensational enhancement for them two by dropping the transmission loss to 0.975 dBm as appeared in Fig. 5 which is an extensive improvement over every one of the two under-thought FANETs protocols. Due to the link stability mechanism by taking the lowest value of threshold which reduces overhead and avoids high transmission loss, the positive features of DPTR and LEPR are taken; thus, DLSA has shown the lowest average transmission loss ratio which is considered efficient.

### 4.5 Comparison of DLSA with DPTR, LEPR protocols

The simulation results of DLSA routing protocol is evaluated and compared with DPTR and LEPR protocols of FANET based on the following performance evaluation parameters End to End Delay, PDR, Network Lifetime, and Transmission Loss as depicted in Table 2 depicts the overall average of PDR, E2ED, Network Lifetime and Transmission Loss of three routing protocols DPTR, LEPR and DLSA. Figures 6, 7, 8, 9 are derived from Table 2. These Figures shows different kinds of values w.r.t their desired evaluation parameters. Each Figure shows separate values in Average perspectives like Fig. 6 shows the overall average E2ED of DPTR, LEPR and DLSA routing protocols. Also it shows that which one is giving better result in contrast to each other's.

In Fig. 7 that shows the overall average PDR of each protocol i.e. DPTR, LEPR and DLSA and shows that which one is efficient and gives much better result. From Table 2, the given four parameters E2ED, PDR, Network Lifetime and Transmission Loss are depicted here in separate graphs; each graph shows the desired value of each protocol. The key factor of DLSA for showing the best result in each graph is that DLSA has the ability to keep minimum delay with high PDR along with high network lifetime and low transmission loss as possible. It has been clearly seen that DLSA routing protocol have given magnificent and drastic results in terms of each scenario accordingly. The key factor is that it uses the positive features of the DPTR and LEPR routing protocols for the proposed mechanism. And it also uses different threshold values that keep the link stable which gives high PDR and uses R-B priority tree which keeps low E2E delay.

In addition, each graph gives different results w.r.t the required value. In this scenario, the DLSA routing protocol the proposed one has given much better results in contrast to the existing ones based on End to End Delay, Packet Delivery Ratio, Network Lifetime, and Transmission Loss. By using the R-B priority and introducing the link stability metric (a threshold value) for the DLSA routing protocol. This procedure has done made it possible that DLSA has outperformed well in comparison to the existing routing protocols by taking their positive features and merging them. It allows DLSA to keep minimum end-to-end delay and keep PDR increased in all scenarios for FANET.

## 5 Conclusion

In this paper, the comparison of a hybrid protocol named DLSA has been evaluated and examined with the existing ones. The main motive of DLSA was to minimize end-to-end delay and maximize the packet delivery ratio. In addition, a stability metric value for DLSA has been taken that aims to minimize End-to-end delay and reduces the broken paths thus enhance the lifetime of the network. After the simulation results, the DLSA routing protocol is compared with the existing DPTR and LEPR routing protocols for FANETs. After successful simulations, it has been observed that the DLSA routing protocol outperformed the existing FANETs routing protocols in all parameters. The DLSA routing protocol gives much better results by using the link stability mechanism along with network partitioning by using the R-B priority tree that takes the highest priority node among others for the communication channel to create a network corridor. Through MATLAB simulations, it has been proved that DLSA routing protocol provides significant improvement in E2ED, PDR, Network Lifetime and Transmission Loss over existing FANETs routing protocols i.e. DPTR and LEPR, by using the positive features of the existing protocols that have the highest mathematical terms and equations that were potential to simulate because the tool used for simulation supports highly mathematics.

## 6 Future Work

In this research, the concerned study was conducted to check the performance and efficiency of different evaluation parameters for DLSA in comparison with DPTR and LEPR. To minimize end-to-end delay and increasing PDR based on the performance evaluation parameters End to End Delay, PDR, Network Lifetime, and Transmission Loss by taking the positive features of DPTR and LEPR protocols. It is suggested that link stability awareness with a minimum delay has presented better results. Henceforth in the future, some other issues arise in this network that needs to be estimated first and then properly solved. These issues include congestion control that can be utilized along with these parameters and tested under new conditions. Additionally, the nodes and geographical scalability of the network can also be analyzed by increasing or decreasing the number of nodes and results can be obtained through experimental simulations. This research also gives directions for upcoming challenges and issues to be solved.

In the future, these protocols can also be evaluated under different evaluation parameters along with different mobility models in FANETs. Also, jitter, path loss, network stability period, total energy consumption, etc. can be used as performance evaluation parameters to generate the best and alternative results in comparison with the existing state-of-the-art solutions. NS-2, NS-3, OPNET, OMNET++, etc. can also be used as simulation tools for the concerned study.

Research work on FANETs is still in its infancy and it offers many issues and challenges that need effective results and solutions. Numerous new technologies relative to UAV software, hardware, and routing schemes are developing and some of them may be easily adjustable to FANETs. Incorporating these new technologies with the existing ones is the main research challenge. FANETs need to be open-ended and should be capable to accommodate any new technology. Nevertheless, FANET still needs robust and reliable routing algorithms that solve the vulnerability issue to protect the UAV network from perpetrators.

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**Authors contributions** Altaf Hussain and Tariq Hussain contributed equally and are co-first authors. All the authors contributed to this research.

### Declarations

**Conflict of Interest** The authors declared no conflict of interest.

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