
Altaf Hussain¹, Babar Shah², Tariq Hussain³*, Farman Ali⁴, and Daehan Kwak⁵

Abstract
A novel ad-hoc network called a flying ad-hoc network (FANET) has recently emerged, in which the flying nodes are referred to as unmanned aerial vehicles (UAVs) that are operated remotely live from a distance or using some determined approach in perspective of algorithms. Due to their high degree of mobility and flying nature with dynamic topology, the nodes in this network may discontinue their transmission because of transmission loss and unstable links among them. A relay node serves as an intermediary to reduce the distance of the nodes from each other as well as to boost the performance of communication. In this paper, Delay and Link Stability Aware (DLSA) and Cooperative Delay and Link Stability Aware (Co-DLSA) have been proposed as relay strategy routing schemes. Co-DLSA is an extension of the DLSA routing scheme in which the relay strategy has been introduced for cooperative routing with fair-relay-strategy (FRS) and red-black (R-B) routing tree to increase the performance of the network. The main focus is to minimize the delay while minimizing transmission loss and lowering the network stability count in terms of discontinuous nodes. Through the simulation results, it has been concluded that the proposed routing protocol performs efficiently in terms of network lifetime, network delay, network packet drops, network throughput, and transmission loss compared to the existing routing protocols in this network. The average results of the simulations recorded a network stability for Co-DLSA of 18, average transmission loss was recorded as 67.72, average network delay was recorded as 23.28, average network throughput was recorded as 95.85, and network packet drop was recorded as 20.85, showing outstanding performance in comparison with all other routing protocols.

Keywords
FANET, UAV, Cooperative Routing, Relay Strategy, DLSA, Co-DLSA

1. Introduction

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A flying ad hoc network (FANET) is a state-of-the-art ad hoc network in which the communicating nodes known as unmanned aerial vehicles (UAVs)/nodes [1] are automatic flying objects which have no human personnel. These nodes have fixed on-board [2] actuators for operating or can be controlled from a distance using some remote procedure. The group of flying nodes in this network are multi-UAVs which communicate with each other and maintain [3] distance by using algorithms that have the ability to calculate distance and speed. Networks such as these are used by the military in various situations like monitoring volcanoes and earthquakes, or by civilians for purposes and tasks which involve risk and danger [4]. These nodes have been shown to perform such tasks effectively [5]. These nodes are also known as drones, quadcopters, or planes; some have fixed wings and cannot hover in the air due to their need for continuous movement while some have propellers that can easily hover in the air. Improving the Quality of Service (QoS) [6] involves highly accurate work, because the nodes of this network have a high degree of mobility, due to which the network’s topology constantly remains dynamic. This feature creates more challenges in this network due to disconnected nodes [7], loss of transmission, increase of delay as well as the stability time of the network [8].

It is expected that these flying nodes will be the eyes of humans operating in the sky and will be required to function for a long period of time to monitor events and activities [9]. From this perspective, signal efficiency is the key factor in this network for the cooperation of nodes by keeping them utilized as much as possible for events and other missions [10]. It is also obligatory to deliver a data transmission ratio with high throughput and lowest transmission loss ratio and lowest packet loss ratio while avoiding transmission impairments. In other words, the nodes of this network have limited capacity, and consume the signal power in flying and transmitting tasks. Regarding the working of the network layer, the issue of routing is key, as routing and energy is the main challenge in this network [10]. Current work has focused on routing protocol with a cooperating mechanism with the help of relay nodes to be embedded on the relay layer, which works as an intermediary to boost and amplify the signal. To avoid packet loss as well as transmission loss, the nodes must work in cooperation with relay nodes, which only send and receive signals for the purpose of amplification. During the flight, the nodes face difficulties with increasing distance as well as the occurrence of unstable links, which ultimately reduces the number of nodes in operating scenarios and may cause route failure.

Routing with a cooperative approach has the potential to gather data more frequently, in which the loss of the least amount of data can be expected. Noise and other transmission impairments can affect the signal quality, which ultimately degrades the performance of the network [11]. The data received at the destination side can be gathered in signals for which some traditional approaches of combining can be used like selection combining (SC), maximal ratio combining (MRC) or fixed ratio combining (FRC) to stabilize the links and to avoid transmission loss [12]. For the proposed work, the FRS has been introduced in which the calculation of the signal strength as well as the efficient routing of data from source node to destination node via relay path tasks is performed [13]. This is described as cooperative routing, as it is the multi-path gathered transmission to be obtained. Cooperative routing is a robust and reliable approach which focuses on avoiding transmission loss during the transmission of data by using multiple relays. This technique can be accomplished in diverse manners, without the need for multiple antennas [14]. A mathematical model of the proposed work is also introduced, in which the three-layered approach is designated where (N, M, and K) with FRS are applied via relay (K) for ground (N) and aerial (M).

This article aims to do the following:
- Present a survey of the related literature and existing state of the art solutions for FANET.
- Design and propose a robust approach to specifying the problem.
- Organize the detected problem statement and arrange a suitable solution.
- Identify and formulate the existing problem and then organize and combine a strategy from the perspective of cooperative routing.
- Introduce a network partitioning algorithm in which the three operating units operate at the same time.
• Design a novel approach based on relay strategy for the proposed Cooperative Delay and Link Stability Aware (Co-DLSA), an extension of the Delay and Link Stability Aware (DLSA) routing scheme [15].

• Analyze and compare the proposed work with existing routing protocols LEPR [16] and DPTR [3] in terms of network throughput, network stability, network delay, network packet drop, and transmission loss.

The rest of the article is organized as follows. In Section 2, related works on FANET are examined. In Section 3, the proposed methodology is discussed. In Section 4, the results derived through simulations are analyzed and considered. Finally, Section 5 concludes the paper.

2. Literature Review and Formulation of Research Model

A number of state-of-the-art solutions have been formulated previously and will be discussed in this section. De Rango et al. [1] proposed a novel approach for routing which is inspired by nature to operate multiple nodes. They have fundamentally originated this proposed work for the proper utilization of agriculture-based tasks. The basic motive was to design a smart agriculture approach based on FANET which employs sensors and other technological devices. They used drones for the inspection by utilizing the on-board cameras in the nodes. In [17], the authors addressed a novel approach to routing in FANET named Q-FANET. Their main focus was on minimizing the network delay and maximizing packet throughput, especially in those scenarios in which mobility matters. In [18], the authors proposed a routing scheme based on fuzzy logic for the sake of network improvement in FANET. The proposed scheme was based on Q-learning in which the scheme uses an alternative approach to determining a specific route from source to destination by using the minimum hop counts. Mariyappan et al. [19] introduced an approach which focused on the network layers of the OSI to improve the performance of the FANET, particularly from a routing perspective. In [20], authors introduced a routing protocol named partial backwards routing protocol (PBRP) with three strategies using an integration-based partial algorithm for forwarding, information of road traffic and a recovery strategy of backward with the working principle for the information of the VANET. The main proposed protocols are EGyTAR and GyTAR. The results have shown that their work have improved the throughput up to 50% and reduced the delay up to 75% in the considered scenarios. Darabkh et al. [21] proposed a routing protocol that has awareness of mobility and data rate during transmission, which they named Multi-Data Rate Mobility Aware (MDRMA). This protocol has been considered as a successor to another scheme named Mobility-Aware Dual-Phase Ad hoc On-demand Distance Vector with Adaptive Hello Message (MA-DP-AODV-AHM). Mah et al. [22] suggested an approach to improve security on the flight path and transmission power of the UAV relay. Souza et al. [23] proposed a routing scheme which focused on improving QoS and QoE. These two were taken as the performance metrics to evaluate and analyze properly by using the simulator NS-2. Abualola et al. [24] proposed a relay selection for stability in optimized state link routing (OLSR) protocol in scenarios with the presence of the UAVs of urban environment with the use of Internet of Vehicles (IoVs). In [25], the authors introduced a novel scheme in which the primary focus was to save energy by using the energy efficient Hello (EE-Hello) approach as a proposed work. Anand et al. [26] introduced an approach in which the primary focus was to design a system to improve the quality of the network and to use an interference management scheme in MAC state for the evaluation of nearby nodes and with power transmission adjustment in the given geography. Tropea et al. [27] focused on the accurate use of FANET in multiple applications with no involvement of human personnel.

Hussain et al. [15] proposed a novel hybrid routing scheme named DLSA that is completely focused on link stability. The authors’ main contribution was to stabilize the link between the ground nodes and aerial nodes. Aissa et al. [28] proposed an algorithm based on a clustering mechanism to support the safe distance and fast mobility of the UAV network, while extending lifetime of network and stable communication. In [29], the authors proposed a comparative-based study of AODV and DSDV routing
schemes for FANET. The authors primarily focused on the energy level, as energy is the key and primary challenge in this network due to the flying nature of nodes in this network.

Khan et al. [30] presented an approach of a routing scheme for FANET that uses a modified version of AntHocNet (AHN), a technique of ACO. They focused on energy level to improve the energy use and to introduce a network that can consume less energy. Namdev et al. [31] introduced an optimization algorithm called whale optimization algorithm (WOA) based on OLSR. The authors have focused on optimal routing as well as stabilizing the energy efficiency in FANET. Park and Lee [32] proposed a less weighty measurable approach to FANET, in which alternate features exist that were not present with other approaches. In this regard, the authors were focused on security in FANET since it is a wireless technology and thus vulnerable to perpetrators. Radley et al. [33] presented a routing scheme named Multi-Information Amount Movement Aware (MIAMA) with a new routing to control the movements of the nodes in the network.

The proposed work is different from the existing literature in terms of methodology, contribution, and results. In previous research, a majority of the authors have focused on link stability, energy efficiency, improving QoS, and security in FANET, all of which are critical topics (Table 1). However, none of the existing work focused on the relay strategy for simultaneously operating units of FANET works together in the form of network partitioning.

Table 1. Literature summary and objectives of the existing work

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Objectives and methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>De Rango et al. [1]</td>
<td>2019</td>
<td>Proposed a protocol for agriculture applications in which the UAVs operate for the surveillance of agriculture</td>
</tr>
<tr>
<td>da Costa et al. [17]</td>
<td>2021</td>
<td>Improved QoS optimization</td>
</tr>
<tr>
<td>De Francesco et al. [18]</td>
<td>2018</td>
<td>Solved interference problem</td>
</tr>
<tr>
<td>Mariyappan et al. [19]</td>
<td>2021</td>
<td>Improved energy of UAVs</td>
</tr>
<tr>
<td>Nebou et al. [20]</td>
<td>2019</td>
<td>Improved energy in ground node network</td>
</tr>
<tr>
<td>Darabkh et al. [21]</td>
<td>2019</td>
<td>Improved mobility awareness models</td>
</tr>
<tr>
<td>Mah et al. [22]</td>
<td>2020</td>
<td>Improved security and privacy</td>
</tr>
<tr>
<td>Souza et al. [23]</td>
<td>2019</td>
<td>Improved the QoS in FANET</td>
</tr>
<tr>
<td>Abualola et al. [24]</td>
<td>2021</td>
<td>Improved stability of UAVs</td>
</tr>
<tr>
<td>Mahmud et al. [25]</td>
<td>2019</td>
<td>Improved PDR and decreased overhead problem</td>
</tr>
<tr>
<td>Anand et al. [26]</td>
<td>2020</td>
<td>Improved energy utilization</td>
</tr>
<tr>
<td>Tropea et al. [27]</td>
<td>2020</td>
<td>Improved dynamic topology connectivity</td>
</tr>
<tr>
<td>Hussain et al. [15]</td>
<td>2021</td>
<td>Improved PDR, link stability and decreased delay</td>
</tr>
<tr>
<td>Garcia-Santiago et al. [29]</td>
<td>2021</td>
<td>Compared AODV and DSDV protocols for future FANET</td>
</tr>
<tr>
<td>Khan et al. [30]</td>
<td>2020</td>
<td>Improved energy efficiency in FANET</td>
</tr>
<tr>
<td>Namdev et al. [31]</td>
<td>2021</td>
<td>Improved energy efficiency and security</td>
</tr>
<tr>
<td>Park and Lee [32]</td>
<td>2020</td>
<td>Improved security</td>
</tr>
<tr>
<td>Radley et al. [33]</td>
<td>2020</td>
<td>Improved movement awareness models</td>
</tr>
</tbody>
</table>

3. Research Methodology

The proposed DLSA and Co-DLSA protocols have been designed in the given sections. In this methodology, we deal with the practical implementation of the protocol by proposing mathematical models. The DLSA and Co-DLSA protocols assume numerous kinds of mathematics are involved in the design strategy, which has been designed with multiple steps given in the below mentioned mathematical equations. The proposed research methodology is shown in Fig. 1.

3.1 DLSA: The First Proposed Protocol
In this section, a routing protocol DLSA [15] has been proposed which has the feature of link stability. Considering the perspective of routing under link stability, the network lifetime is improved by minimizing delay and transmission loss of the nodes. For performance evaluation, the proposed DLSA routing scheme has been evaluated with other LEPR and DPTR routing protocols. In the given subsections, a detailed explanation of the mathematical model for the proposed work is provided.

Fig. 1. Proposed framework of research methodology.
3.1.1 System model for DLSA

The challenging task is to design a routing protocol with simultaneously operating ad-hoc units that are aerial and ground. In this regard, the core task is to design an approach which formulates the network corridor (NC) for both aerial and ground operating units. In DLSA, three terms have been introduced: K indicates an intermediary layer, M indicates the aerial layer and N indicates the ground layer identification [3]. In this approach, the K layer has only introduced normal nodes for the communicating scenario, whereas in Co-DLSA the K layers have been introduced for cooperative routing with an FRS approach [15].

Two-way data forwarding: For collaboration, the NC terminology used which divides the corridors for aerial and ground ultimately makes 2 NCs. The given expression indicates the NC for ground, for which the term G is used. The condition indicates that if the NC is in true mode, then the NC can be started from initial up to the last of the NC during the communication scenario, but divides by 2 at last for M and K [3, 34].

\[
\text{Collaborative}_{\text{node}} = \text{True} \quad (1)
\]

\[
G_s = \{NC_1, \ldots, NC_{\frac{s}{2}}\} \quad (2)
\]

where,

\[
NC_i = \max \{\mathcal{C}_1, \ldots, \mathcal{C}_{\frac{s}{2}}\}, 1 \leq i \leq \frac{s}{2} \quad (3)
\]

Route discovery estimation: With the help of the neighbor nodes, this mechanism can take place in which route discovery is performed to estimate the best one. By doing this, it can predict the disconnected and connected nodes in the network

\[
t_e = (t' + t'') \quad (4)
\]

In Equation (4), different terminologies are introduced, in which \( t_e \) is used for the formation of the initial route. For switching of nodes through communicating with one node then starting a link with another node, Equations (5) and (6) are given

\[
\frac{n (n - 1)}{2} \quad (5)
\]

whereas for aerial nodes,

\[
\frac{m (m - 1)}{2} \quad (6)
\]

The estimation of route discovery is given in Equation (7), in which \( t_g \) indicates ground and \( t_a \) aerial nodes.

\[
t_g = t_e \frac{n (n - 1)}{2} \quad (7)
\]

\[
t_a = t_e \frac{m (m - 1)}{2} \quad (8)
\]

Hereinafter, the minimum and shortest path of route for discovery is indicated by \( D_{\text{min}} \) and can be calculated using Equation (9) [3].

\[
D_{\text{min}} = \max (t_a, t_e) \quad (9)
\]

Equations (10) and (11) are introduced for top-down and bottom-up transmission to route the generated data [3].
\[ t_{a-d} = \max (t_a + t_c, t_g) \]  
\[ t_{b-u} = \max (t_a, t_g + t_c) \]  

where,

\[ t_c = k_c \times L_g \times t_{lg} \]  

In Equation (12), \( t_{lg} \) indicates time to maintain log, \( L_g \) indicates collaboration layer logs that are maintained, and \( k_c \) represents the connected neurons in amount [3].

**Formation of a tree:** Formation of a tree is achieved with the simultaneous operating of the aerial and ground units of the ad hoc network with a neural structure which works as an intermediary between them [3]. Time slot \( t \) in a network has three calculating units for aerial M, ground N and neural K as an intermediary is shown in Equations (13), (14), and (15).

\[
\text{Avg rate} (g) = \sum_{i=1}^{N} x_i - N_{ini} \quad (13)
\]

\[
\text{Avg rate} (n) = \sum_{i=1}^{K} x_i - K_{ini} \quad (14)
\]

\[
\text{Avg rate} (a) = \sum_{i=1}^{M} x_i - M_{ini} \quad (15)
\]

**Link stability estimation with threshold metric:** The best stability metric has the ability to be aware of the link stability and instability as well as to effectively represent the quality of the communication link. The metric should also be aware when the network topology changes, especially in scenarios of FANET [15, 16]. As discussed earlier, the stability metric has restrictions in which the threshold is defined which place a condition to be applied. As shown in Equations (16) and (17), for DLSA a threshold metric has been set in which the three restrictions or conditions have been placed with the values of 0.33, 0.33, and 0.34 for \( \lambda_1 \), \( \lambda_2 \), and \( \lambda_3 \), which sum up to 1. This 1 value indicates that the link between communicating UAVs is stable. If the value decreases from 1 then the link is defined as lacking stability, and transmission loss and network instability occur [15]:

\[
D_{ij} = \lambda_1 LQ_{ij} + \lambda_2 Y_{ij} + \lambda_3 S_{ij} \quad (16)
\]

\[
\lambda_1 + \lambda_2 + \lambda_3 = 1 \quad (17)
\]

When the value of the metric exceeds 1 then the speed of the UAV is also increased, which can cause instability and discontinuity of the network. The proposed 1 value is the combination of the LQ, Y, and S, mentioned in Equation (16), whose values are 0.33, 0.33, and 0.34. The other terms in Equation (16) indicate the safety of link, the prediction of mobility, and degree of quality for stability. Equation (18) expresses a reverse and forward ratio for delivery in which the link quality can be calculated using

\[
LQ_{ij} = \gamma^f \ast \gamma^r \quad (18)
\]

In the given mathematical Equations (19) and (20), the same approach has been introduced for stability in which the major two terms are used, which are 1 and 0. The 1 indicates a stable link whereas the 0 indicates no stable link. If data are received by using 1 then a direct transfer path can be followed, but if not then the path of stability can be followed in which the stability procedure takes place.

From Equation (18) the \( \gamma^f \) or \( \gamma^r \) indicates the ratio of reverse and forward, and can be calculated as
\[
\begin{align*}
\gamma_n &= \alpha \cdot \gamma_{n-1} - (1 - \alpha) \cdot h_n \\
\gamma_0 &= 0
\end{align*}
\]  
(19)

whereas,
\[
h_n = \begin{cases} 
1, & \text{if the } n^{th} \text{ hello message is received} \\
0, & \text{else}
\end{cases}
\]
(20)

Calculation of the Euclidean Distance is given in Equation (22) since the link stability also deals with the speed and distance of the UAVs. For safety of the link quality and degree, Equation (21) is introduced.

\[ Y_{ij} = \frac{R - dt}{R} \]
(21)

In Equation (21), the R indicates radius, which can be calculated using Equation (22) and is shown as

\[
d_t = \sqrt{[X_j(t) - X_i(t)]^2 + [Y_j(t) - Y_i(t)]^2 + [Z_j(t) - Z_i(t)]^2}
\]
(22)

As the UAVs of FANET possess high mobility, instability occurs due to the dynamic topology, and the speed can vary and change rapidly, compromising the link with another UAV. The time interval shows the control approach in which the node does not have to speed up or become too slow. This time interval has the ability to maintain a control scenario among the UAVs [15]. These are expressed in Equation 23. For the two nodes i and j which are in communication range, their time interval is shown as

\[
V_{re} = \frac{d_t - d_{t-\Delta t}}{\Delta t}
\]
(23)

In Equation (23), the term \( V_{re} \) shows the threshold value of received message, the terms \( t - \Delta t \) and \( t \) indicate the interval of time for Hello messages during the route discovery process, whereas to match the space among nodes i and j, the terms \( d_{t-\Delta t} \) and \( d_t \) are used. If the two connected UAVs are moving in an opposing path at high speed, the term used is \( V_{max} - V_{re} \) whereas \( 2V_{max} \) shows the highest speed of link stability. Now, if the same UAVs are moving towards each other with equal speed then the term will be kept in negative \( -2V_{max} \), in which the speed needs to be controlled. This prediction has been introduced with the factor of mobility \( S_{ij} \) and can be calculated using

\[
S_{ij} = e^{\frac{V_{re}}{2V_{max}}}
\]
(24)

If a path is not active for communication, then all the other coming nodes near that will also disconnect. To stabilize and solve this factor, Equation (25) is introduced which can be calculated using

\[
P = \min_{i,j \in \text{path}} D_{ij}
\]
(25)

From the given Equation (25), a high P value indicates effective and reliable stability for the route, and it is best to be transferred the data packets via it [16].

**Discovery of route:** For the calculation and measurement of the route to discover, the DLSA routing protocol used the RREQ and RREP messages to the nearby nodes in which the RERR messages also include a route error [15, 16]. The DLAS scheme is shown in Algorithm 1.

**Algorithm 1.** DLSA proposed scheme algorithm

1. **Start**
2. **System Initialization**
3. **Deployment**
4. **Partitioning of network**
   
   If
   
   5. **Collaborative mode = true**
   
   6. **Design R-B routing tree for priority**
      
      Else
      
      Repeat the phase of initialization in step 2
      
      End if;
      
    7. **Select highest priority nodes based on R-B selected priority**
       
       If
       
       8. **The node with highest priority is designated**
       
       9. **Check the link stability**
          
          Else
          
          repeat the phase of node highest priority in step 8
          
          End if;
          
        11. **The value of link for stability is less than or equal to the proposed threshold metric**
        
        12. **Direct transfer of the data**
        
        Else
        
        13. **Use the path of route discovery to estimate the link stability**
        
        End if;
        
        14. **Use the highest threshold metric for stability of link**
        
        15. **Forward the data in collaborative move for both sender and receiver**
        
        16. **End**

### 3.2 Co-DLSA: The Second Proposed Protocol

In the proposed routing scheme Co-DLSA, a relay strategy has been used as a cooperative routing in which a three-layered approach of a ground, aerial and relay layer has been introduced, and these layers are represented with N, M, and K. For direct communication the ground and aerial have been selected, whereas for multi-UAV communication the relay layer has been selected. Using cooperation, the relay nodes have the ability to transfer data from one node to another using the highest priority order and to maintain the fairness in nodes. For the analysis of the Co-DLSA, the network delay, network throughput, network stability, network packet drops, and transmission loss evaluation parameters have been used.

#### 3.2.1 System model for Co-DLSA

**Network layout:** The methodology shows a relay strategy has been introduced for Co-DLSA for the purpose of cooperative routing. In DLSA, the ground and aerial nodes are utilized by directly linking two nodes (ground and aerial), although in Co-DLSA, the nodes of relay strategy are utilized for a cooperative routing mechanism in which the source node is selected to utilize more than one link at a time.

**Basic assumptions:** The Co-DLSA routing scheme is based on relay strategy in which the relay nodes work through cooperative routing. The FRS has been proposed in this protocol in which the three operating units simultaneously communicate with each other (ground, aerial and relay works as intermediary nodes between ground and aerial). The normal nodes in FANET have the permission to route packets between other cooperating nodes in every round of the simulation. The outgoing and incoming data transmission of every node within the network must be at an equal level by using the fairness and priority order. The cooperating and normal nodes have a link for communication which has high capacity for the packet’s transmission because every generating data node forwards its own data along with the data of neighbor nodes.

**Phase of initialization:** The initialization phase shows the starting of the simulation when the setup is prepared, and simulation starts. This phase is the same as the DLSA routing scheme, but with some additional tasks performed.
Phase of routing and cooperation: Routing is a procedure through which an appropriate and best route must be discovered to transfer the data packet from one node to another and vice versa. Cooperative routing is a procedure which functions as an aid between the communication bodies. In this phase, the best and most suitable route must be found from the source node \((s)\) to the destination node \((d)\) with a suitability and fairness strategy. A method for choosing the highest priority among the nodes for forwarding data with efficient manner has been given in Equations (26) and (27). In the given Equation (26), the term \(S_k\) is the reliable state in which the nodes have completely gained the data from other nodes successfully. For decisions among the nodes, the term \(U_k\) represents this activity in which reliable and effective transmission takes place. In this regard, the +1 indicated the second step whereas in step 1 the \(S_k\) consumes 0\[35\].

\[ S_k + 1 = S_k \cup U_k \]  \hspace{1cm} (26)

The core task of the given Equation (27) to find the alternative \(S_k\) or the best sequence \(U_k\) along with the decreasing of the transmitted power \(P_t\) after dealing with the relay nodes is given as [35].

\[ P_t = \sum_k LC(S_k,U_k) = \sum_k LC(S_k,S_{k+1} - S_k) \]  \hspace{1cm} (27)

Selection of relay for cooperation: To deal with the relay strategy for cooperative routing, one must also deal with the energy of the nodes because the relay nodes work as boosters to enhance the signal and strength of the network, as shown in Fig. 2. As discussed earlier, Co-DLSA deals with a relay strategy for a cooperation mechanism with three layers introduced in which different operating ad hoc networks work at the same time. To balance the fairness communication in nodes and to minimize the delay and transmission loss as well as network stability, the Co-DLSA routing scheme selects relay nodes in every round of the simulation as compared with the DLSA scheme nodes. In Equation (28), the three terms \(N\), \(M\), and \(K\) are used to denote the ground, aerial and relay approach, respectively. In this regard, it checks if the transmission is efficient, and energy and fairness are utilized, then directly transfers the data or follows the relay path.

\[ M(i) \begin{cases} P_{tr}(N) > E_{re}(K), \text{Direct Transfer Link} \\ P_{tr}(N) \leq E_{re}(K), \text{Follow Relay Path} \end{cases} \]  \hspace{1cm} (28)

Equation (28) reveals that if the relay path is followed for communication, it will directly transfer the data in order to maximize the throughput and minimize delay and network stability, as well as transmission loss.

Relay strategy with fair mechanism: As discussed earlier, in the relay mechanism with fair strategy the highest priority approach will be followed. In Equation (29), \(RS\) denotes the relay strategy with source \((s)\) and destination \((d)\). The FRS approach has been introduced in which not only cooperation but maintaining the energy level of the relay have been utilized. This terminology can be calculated using Equation (29).

\[ RS(S_i) = \arg \max_{RS \in D(S_i)} \left\{ P'_{RS_j} |h_j,BS|)^2 \right\} \]  \hspace{1cm} (29)

\[ P'_{RS_j} = P_{RS_j} - \Delta P_{RS_j} \]  \hspace{1cm} (30)

For user \(S_i\) in the given expression, the selected RS is the relay strategy. The power of the relay and already consumed power of the relay is denoted by \(RS_j\) and \(P_{RS_j}\) before the selection approach of the
relay. $|h_{j,BS}|^2$ illustrates the quality of the communication channel between the relay node strategy (RS) and base node strategy (BS), respectively [36].

**Combining and collaborative strategy:** This phase is measured as the final phase of the simulation in which different data sources are gathered and checked in conditional state. This is done to combine and collaborate aggregated data for final transmission to generate the final output in the proposed algorithm. The cooperative routing implementation in FANET is shown in the Fig. 1, in which three layered approaches have been introduced with N, M, and K expressions. The signal coming from N and K, M could implement a diversion route approach. In Co-DLSA, the FRS Combining has been proposed, which has high performance compared to other approaches that are equal ratio combining (ERC), signal-to-noise ratio combining (SNRC) and MRC. In the FRS, not only the additions of the incoming signal but the weights are also selected with a constant ratio. Due to interference and other impairments, this indicated ratio reflects the average quality and executes on channels. There are multiple relays proposed in Co-DLSA that will be utilized. If a single relay has to take place for communication in FRS, then it can be illustrated as:

$$y_d = w_1 y_{nm} + w_2 y_{km}$$

(31)

In the given Equation (31), the term $y_d$ illustrates the signal that has been combined from the output at aerial (M) whereas $w_1$ and $w_2$ are the introduced weights of the link between them. The given expression is extendable and can also be varied if any kind of a relay node must be selected. The illustrated weights are the distance of function for which its ratio can be explained as [37]. The Proposed Co-DLAS scheme is shown in Algorithm 2.

$$\frac{w_1}{w_2} = \frac{d_1}{d_2}$$

(32)

**Algorithm 2. Co-DLSA**

1. **Start**
2. System configuration and initialization
3. Cooperation phase
   4. Deployment of relay strategy
   5. Selection phase for high criteria of nodes as relay
      If
   6. Satisfy the highest criteria for selection
      End if;
   7. Go to routing phase
   Else
   8. Repeat step 5
      If
   9. Node with maximum priority is selected as relay
   10. Use the direct path transfer
   Else
   11. Use path of relay strategy for cooperative routing
      End if;
   12. Select the relay nodes for transfer
   13. Node selected as relay
   14. Proceed to stability of link phase
   15. Use the threshold value for stability
      If
   16. Value is less than or equal to the proposed metric
   17. Direct path for transfer
   Else
4. Data Analysis and Results

In this section, the results from simulations are analyzed and discussed to check the performance of the proposed Co-DLSA routing scheme in contrast with the other existing routing schemes. Based on the performance evaluation metrics, the proposed work is compared with the state of the art. The chosen performance metrics for evaluation of the proposed work are given as follows.

- **Network stability**: This is a measure of the total time in which the network is working without any disruption caused by any unstable link or other disconnected node. In this sense, it can be measured as the total number of disconnected nodes.

- **Transmission loss**: This can be defined as the loss of the signal during the propagation that travels from one node to another. In this regard, it can be measured in decibel-milliwatts (dBm).

- **Network delay**: This can be defined as the delay of the network from starting of the communication to reaching to the other side. It is also known as latency of the network. The total time taken by a packet to go from sender to receiver; here, a long time taken by a packet is known as delay. The delay of the network should be minimized as much as possible. It can be measured in seconds or milliseconds (ms).

- **Network throughput**: This can be defined as the total data packets that have been sent from the sender and the total number of packets that have been received by the destination. It can be measured either as a percentage or as the ratio of total sent to total received packets.

- **Network packet drop**: This can be defined as the dropping of network packets; here, the source sends packets, and the destination receives fewer packets. It can be measured in packets by counting the number of dropped packets.

The simulations are carried out to compare the performance of the proposed work with the existing approaches of LEPR, DPTR, and DLSA. The key and major aim of this simulation is to evaluate and observe the impact of the proposed FRS with cooperating technique for proposed work in comparison with the non-cooperating based DLSA routing protocol. The simulations are executed with a running time of 1,400 seconds in total.

4.1 Analysis of Network Stability

Fig. 2 shows a graphical representation of the four routing protocols, in which the Co-DLSA is compared with other protocols. The stability of the network can be evaluated and analyzed using Fig. 2. The total simulation has run for 1,400 seconds. During the first 200 seconds of the simulation, the stability level of all routing protocols is (Nil), indicating that all protocols are performing well and no disconnecting nodes or unstable nodes that are not maintaining communication with others have been spotted. Similarly, in the second round of the simulation at the time of 400 seconds, all the protocols still performed well, with no unstable or disconnected nodes. During the 3rd round of simulation at 600 seconds, LEPR has one disconnected node, DPTR has four disconnected nodes and DLSA has three disconnected nodes; while Co-DLSA has no unstable nodes, meaning that Co-DLSA has performed better than all others. Up to the 4th round at the time of 800 seconds, the Co-DLSA has 0 unstable nodes; whereas LEPR has six, DPTR has eight, and DLSA has three disconnected nodes. These unstable or
disconnected nodes are no longer in communication with the other nodes, indicating the poor performance of the protocol. The lower the number of disconnected nodes, the greater the network lifetime will be, and the network will be considered efficient with best performance. With the passage of simulation time all the protocols have performed comparably well, but the total number of disconnected nodes for Co-DLSA was 18, whereas for LEPR it was 30, for DPTR 36 and for DLSA 25. From all discussion, it has been concluded that the proposed Co-DLSA routing protocol has performed well in each simulation time as well as in comparison with the other routing protocols. The key and major reason why Co-DLSA achieved higher performance is its proper utilization of the FRS for cooperation, in which it calculates the distance as well as the stability of the nodes. The average stability of the LEPR is measured as 4.28, DPTR is 5.14, and DLSA is 3.57; whereas for Co-DLSA it is calculated as 2.57 which indicates that the Co-DLSA is the best among all of them.

4.2 Analysis of Transmission Loss

The term transmission loss (TL) deals with the strength of the signals; if loss occurs during the transmission of data, it is defined as TL. Such loss can occur due to many reasons, with the major reason being that the strength of the signal becomes weak and cannot propagate from one UAV to another in a FANET scenario. Due to loss of transmission, instability and disconnected nodes can arise in the network. To efficiently and effectively transmit data, the transmission loss must be kept as low as possible, because the lower the transmission loss the greater the communication will be. Fig. 3 indicates the analysis of the transmission loss for four routing protocols. The simulations were executed for 1,400 seconds, with each 200-second segment illustrated in graphical representation with different TL values. The initial time indicates the initialization stage, which is 0 for all protocols. After 200 seconds of simulation time, each protocol has achieved high performance, in which LEPR has a TL of 180, DPTR has a TL of 431, and DLSA has a TL of 380, while Co-DLSA has a TL value of 160, which is much better than the other protocols. This illustrates that Co-DLSA has the lowest value of TL in dBm, placing it in the high-performance category compared with the other protocols. After 400 seconds of the simulation, again LEPR has a TL of 180, DPTR has a TL of 271, and DLSA has a TL of 376; whereas Co-DLSA has a TL of 107, which is much lower than the first round of 160 as well as lower than the other protocols.

Similarly, after 1,400 seconds of simulation, the TL of all protocols measured in dBm is 0. From this discussion and evaluation, the average TL calculated of LEPR is 93.14, of DPTR is 247.14, and of DLSA is 199.71; whereas the average calculated TL of Co-DLSA measured in dBm is 67.71. This illustrates that the proposed Co-DLSA has achieved outstanding performance in terms of TL compared with the other routing protocols. The Co-DLSA has achieved the lowest TL in dBm, which means that communication
in this protocol has performed well because of non-discontinuous nodes. The FRS for cooperative routing is the key reason why the Co-DLSA has achieved the lowest value of TL in dBm, from which it is illustrated that this protocol has performed well. Using the relay strategy for cooperation makes it possible to maintain minimum distance as well as to propagate the signal with full efficiency. From this approach, the proposed routing protocol Co-DLSA has achieved outstanding results in terms of TL.

Fig. 3. Transmission loss w.r.t time (in second).

4.3 Analysis of Network Delay

Delay of a network indicates latency from one node to another; for example, if it is expected to deliver a packet in 50 ms but that packet is delivered in 1 second, then clearly a delay has occurred. Keeping the minimum delay in a network will ultimately improve its reliability and performance. Fig. 4 illustrates the network delay of the four routing protocols in terms of milliseconds in considered scenarios. The total execution time of the simulation conducted is 1,400 seconds, which is graphically illustrated in seven different rounds of 200 seconds. The initial stage has been placed at 0 for all protocols which also indicates the initialization stage. After the first round of simulation time of 200 seconds, the delay of LEPR has been measured as 50 ms, while for DPTR delay is 45 ms, for DLSA it is 50 ms whereas Co-DLSA has been measured as having delay of 52 ms in the scenario. This illustrates that the lowest delay was measured with DPTR at 45 ms, which is the best compared with the others. Similarly, in the second round of simulation with 400 seconds of time, LEPR has measured delay of 50 ms, DPTR 33 ms, and DLSA 33 ms, while Co-DLSA measured a delay of 40 ms. With the passage of simulation time of 800 seconds, the proposed Co-DLSA achieved outstanding performance in terms of delay, which was measured as 15 ms while LEPR has delay of 40 ms, DPTR 23 ms, and DLSA 40 ms. With additional simulation time, the Co-DLSA has achieved delay of 12 ms at 1,000 seconds, then 10 at 1,200 seconds and finally at 1,400 seconds of simulation time achieved delay of 4 ms. From this discussion and analysis, the proposed Co-DLSA has achieved the best performance in terms of delay due to having the shortest distance as well as utilizing relay nodes which avoid high delay and overhead. The average network delay of LEPR has been measured as 36.42 ms, for DPTR has been measured as 25.28 ms, and for DLSA has been measured as 30 ms whereas Co-DLSA has achieved a network delay of just 23.28 ms.

This shows that the proposed Co-DLSA routing protocol, which is an extension of DLSA, has achieved outstanding performance compared to all other routing protocols. The key factor is the proper utilization of FRS for cooperative routing to maintain fairness among all the nodes operated in the network. The proposed Co-DLSA uses the positive features of DLSA due to which it used the link stability mechanism as well as its own relay mechanism for cooperative routing.
4.4 Analysis of Network Throughput

The throughput of a network can be measured either as a percentage or the amount of sent packets versus the amount of actually received packets at the destination. Keeping the throughput ratio of a network as high as possible will definitely make an impact on the performance of the network to efficiently deliver the packets without dropping or losing any. Fig. 5 illustrates the network throughput as a percentage for the four routing protocols in our simulation. The total simulations were executed for 1,400 seconds for analysis and evaluation of the proposed work with the existing work. The initial time has been set as 0 for all protocols which is the initialization of the simulation execution. These simulations were separately placed in a total of seven rounds, in which each round has a period of 200 seconds. During the first round of simulation time of 200 seconds, LEPR achieved 95% throughput, DPTR achieved 92%, and DLSA 90%; whereas the proposed protocol Co-DLSA achieved 100% network throughput, an outstanding performance. Similarly, in the 2nd round of simulations with a time of 400 seconds, LEPR and DPTR achieved 70% throughput, DLSA achieved 94% throughput and Co-DLSA achieved 91% throughput. Likewise, in all simulation times, the proposed Co-DLSA achieved 100% network throughput three times, a feat that was not achieved by any of the other routing protocols. From this viewpoint, the total average network throughput of LEPR was 85.71%, for DPTR was 83.0%, and for DLSA was 86.57%, whereas the proposed relay strategy with the cooperative routing protocol Co-DLSA achieved 95.85% network throughput. Network throughput can go up and down depending on the situation and environment of the simulation. Due to the dynamic topology of FANET, these conditions are at risk and difficult to maintain. For this reason, in Co-DLSA the number of nodes has been increased to support the cooperative routing relay strategy. In this sense, 50 nodes have been added and selected to function as a relay in the network by placing them in the relay layer.
4.5 Analysis of Network Packet Drop

Packet drop in a network can be measured by comparing the total number of sent packets with the total number of received packets. If there are a total of 10 sent packets and a total of 8 received packets, then the packet drop is 2 (i.e., 2 packets were dropped). From this viewpoint, the total simulation time has been set as 1,400 seconds for the evaluation and analysis of the packet drop ratio of the four routing protocols shown in Fig. 6. At first, the initial value is set to 0, which is the initialization stage for the simulations. Total simulations have been placed in seven rounds with each round being 200 seconds, and based on these, the performance has been evaluated to check the efficiency and robustness of the Co-DLSA relay strategy routing protocol. During the first simulation round of 200 seconds, the packet drop of LEPR was 50, of DPTR was 55, and of DLSA was 40, while the packet drop of Co-DLSA was measured as 60 packets. Thus, all the other protocols performed better here than Co-DLSA, which dropped more packets than others. It is not necessary for the proposed protocol to perform well in every given scenario. The simulation environment may sometimes give high results and sometimes give poor results, but the main aim is to focus on the average ratio of the packet drop, and which protocol has the highest and lowest packet drop ratio. After the first 200 seconds, beginning within the 400 seconds Co-DLSA has the lowest packet drop ratio up to the last round of 1,400 seconds. Drop ratio of Co-DLSA at 600 seconds is measured as 20, at 800 seconds of simulation time is measured as 12, at 1,000 seconds is measured as 9, at 1,200 seconds is measured as 10, and finally at 1,400 seconds is measured as 5. The highest ratio of packet drop was achieved by DPTR, which dropped a total of 486 packets during the entire simulation. LEPR dropped a total of 373 packets during the entire simulation run time, and DLSA dropped a total of 211 packets in the whole run time of the simulation. The proposed Co-DLSA routing protocol dropped a total of 146 network packets, which is the lowest of all the routing protocols tested. Thus, the DLSA is a close second in performance in terms of packet drop, but Co-DLSA has achieved outstanding performance by maintaining the lowest packet drop ratio. As this data shows, the proposed Co-DLSA has outperformed in each scenario as well as in each simulation time period.

![Network Packet Drop](image)

**Fig. 6.** Network packet drop w.r.t time (in second).

In terms of network delay, network packet drop, network throughput, network stability, and transmission loss, it was found that the proposed Co-DLSA routing protocol performed well in comparison with the existing approaches as well as with DLSA. Co-DLSA is an extension of DLSA, which combines its positive features with a novel approach of a relay strategy for the sake of cooperative routing. The given evaluation metrics are illustrated with average values of each in which the Co-DLSA has been considered the best routing algorithm. A comparison of the proposed work (Co-DLSA) with the existing approaches is provided in Table 2.
Table 2. Comparative evaluation of proposed work (Co-DLSA) with existing works

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Average network stability (total number of disconnected nodes)</th>
<th>Average transmission loss (dBm)</th>
<th>Average network delay (ms)</th>
<th>Average network throughput (%)</th>
<th>Average network packet drop (packets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEPR [16]</td>
<td>30</td>
<td>93.14</td>
<td>36.42</td>
<td>85.71</td>
<td>53.28</td>
</tr>
<tr>
<td>DPTR [3]</td>
<td>36</td>
<td>247.14</td>
<td>25.28</td>
<td>83.00</td>
<td>69.42</td>
</tr>
<tr>
<td>DLSA [15]</td>
<td>25</td>
<td>199.71</td>
<td>30.00</td>
<td>86.57</td>
<td>31.57</td>
</tr>
<tr>
<td>Co-DLSA</td>
<td>18</td>
<td>67.71</td>
<td>23.28</td>
<td>95.85</td>
<td>20.85</td>
</tr>
</tbody>
</table>

After successful simulations, the proposed work has been compared with the existing approaches for validation and efficiency to be checked properly with proper justification. Fig. 7(a)–7(e) are graphs derived from Table 2. The average evaluation is portrayed in each figure for a clear understanding as well as for ease of analysis to compare the proposed work with the existing protocols. Fig. 7(a) illustrates the average network stability of each protocol, Fig. 7(b) illustrates the average transmission loss, Fig. 7(c) illustrates the average network delay, Fig. 7(d) illustrates the average network throughput, and Fig. 7(e) illustrates the average network packet drop.

![Graphs](image)

**Fig. 7.** Average results of the proposed work with comparison with the state-of-the-art: (a) average network stability, (b) average transmission loss, (c) average network delay, (d) average network throughput, and (e) average network packet drop.

### 5. Conclusion
In this paper, Co-DLSA, an extension of the DLSA routing scheme, is introduced as a novel routing scheme. Unlike existing schemes, the proposed Co-DLSA has achieved higher throughput, minimum delay, the lowest packet drop ratio, the lowest TL and the lowest network instability rate. Through simulations, it has been observed that the proposed routing scheme has the ability to work in a cooperative environment due to its use of a relay strategy for a cooperative mechanism. The FRS has been introduced for selection of the best and most suitable route with optimal efficiency. The simulations were carried out by setting 1,400 seconds as the duration of simulations. As shown in the results, higher performance was achieved by the proposed protocol. In summary, each protocol has given output with different percentage levels, but their performance was poor compared to the proposed work. Cooperative routing has been achieved by using this relay strategy by placing the relay nodes in the network in a partitioned manner, in which a three-layered approach of a ground, aerial and relay strategy was introduced to work as an intermediate node between them in order to minimize the measure of the network stability; here, the lowest value is considered the best because it means that the lowest amount of discontinuations has occurred. Similarly, the lowest transmission loss also indicates the best performance. Minimum delay indicates the best performance and less packet drop also shows best performance as compared to others. Co-DLSA aced all of these evaluation metrics and was the best of all protocols.

With advances and efficiency improvements in FANET, its application is increasing very rapidly. The main challenges here are the ease of usage and deployment of FANE in the environment. There may be risks or dangers, for which protocols must be specifically designed to effectively solve the issues. The needs of FANET will continue to increase day by day, requiring robust routing algorithms from a perspective of security, QoS optimization, and node and geographic scalability for both aerial and ground nodes.

Author’s Contributions

Conceptualization, AH, TH. Funding acquisition, BS, DK. Investigation and methodology, AH, TH, FA. Project administration, DK. Resources, AH, TH, FA. Supervision, DK, FA, BS. Writing of the original draft, AH, FA. Writing of the review and editing, AH, TH, FA. Software, AH, TH. Validation, TH, DK. Formal analysis, BS, DK. Visualization, AH.

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Competing Interests

The authors declare that they have no competing interests.

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