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3D Location Oriented Routing in Flying Ad-Hoc Networks for Information Dissemination

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ABSTRACT: A Flying Ad-hoc Networks (FANETs) is an autonomous technology that creates a self-organized wireless network via Unmanned Arial Vehicles (UAVs). In this network, all UAVs can communicate within a restricted range of wireless communication in the absence of fixed infrastructure. As a result of high mobility, the limited energy, and the communication range of UAVs, network forming, and deformation between them are very frequent that causes packet delivery failure. Therefore, a stable route is always needed to ensure effective data dissemination between source and destination in FANETs. Since it has drastically changing network topology, therefore, to maintain the stable route during packet transmission, there is a need for a suitable routing protocol. This paper proposes an Optimized Location-Aided Routing (O-LAR) protocol which is the modified version of Location-Aided Routing (LAR) protocol. Our protocol's novelty comes from the fact that it established an optimal route between UAVs for information dissemination towards their respective destination UAV by considering weight function. A weighted function is used to decide the best next-hop node selection based on the parameters like residual energy, distance, and UAV movement direction. The performance of the O-LAR is evaluated mathematically and simulated through the NS-2 simulator. The empirical results attest that O-LAR improves the link duration, network lifetime, packet delivery ratio, and average throughput compared with the state-of-the-art protocols: LEPR, D-LAR, and LAR. Further, the proposed scheme reduces the number of next-hops, routing overhead and end-to-end delay compared to the state-of-the-art protocols.

INDEX TERMS: Flying ad hoc networks; Link duration; Residual energy; Movement direction; Weight function.

I. INTRODUCTION

A UAV, commonly known as the flying vehicle or drone, is a highly portable and miniature pilotless aircraft, which can fly in the sky and be controlled remotely [1], [2]. Recently, with the fast advancement in the electronics and communication technologies industry, UAVs have been extensively engaged in military, civil, and commercial sectors [3], [4]. The global UAV market is valued at USD 19.3 billion in 2019 and is expected to reach USD 45.8 billion by 2025, at a CAGR of 15.5percent from 2019 to 2025 [5]. The use of military UAVs by defence forces is the main factor projected to drive UAV market growth. A wide range of utilization of UAVs in various applications such as health planning, product delivery, media and entertainment industry, remote sensing, pandemic detection, monitoring, and so forth is adding to the development of the UAV market. Further, UAVs can offer high quality of service for

the Internet of Things (IoT) with supportive communication and relay technologies. Besides, UAVs have many unique features, such as portability, autonomous fly capability, re-programmability during on-board, and the ability to sense everything from everywhere [6]. Therefore, UAVs technology becomes an essential part of IoT infrastructure and the field of next-generation networks. The fusion of UAVs and IoT technology can utilize in precision agriculture [7], emergency services [8], and crowd surveillance [9]. UAVs are dispatched to disseminate information to a vast number of distributed wireless devices in many critical areas.

Moreover, the growing use of Mobile Ad-hoc Networks (MANETs) or Vehicular Ad-hoc Networks (VANETs) has led them to leverage new growth areas such as FANETs [10]. Recently, FANETs have attracted so much attention from academia and industry as a large group of advantages for

sparing time, reducing costs, better outcomes, and upgraded safety. Fundamentally, FANETs conquer the constraints where the past traditional networks are not legitimate utilitarian in some essential regions, for example, military, mountains, ocean, hazardous situation, and so forth or may be damaged due to any disasters like earthquake, tsunami, hurricanes, and so on. In such critical conditions, FANETs becomes a promising solution involving UAVs for search, monitoring, and rescue operation to save human lives [11]. Recently, the next-generation VANET is another area of the domain where FANETs can play an important role. In VANETs, frequent route failures, frequent topology change, and network traffic density may affect data transmission reliability between the vehicles. To address these problems [12]-[14], vehicles can cooperate in an ad-hoc approach with existing smart UAVs. This kind of fusion provides reliable routing paths and facilitates data dissemination in vehicular environments where the communication infrastructures are not accessible. In FANETs, a group of UAVs can connect by establishing an ad-hoc network for acquisition, processing, and analyzing the real-time data to enhance the work efficiently for different applications scenarios [15]. Also, the FANETs enabled UAVs, also called smart vehicles. These are fitted with the appropriate hardware configured with a digital map, high-resolution camera, micro-embedded computers, sensors, computing devices, GPS, and other advance processing tools. These smart vehicles improve the technical effectiveness of FANETs for work in a highly complex environment with flexible manners. According to any mission carried out by UAVs in a FANET architecture (Fig. 1), two networking modes must be enabled: first, UAV-to-UAV (U2U) communication, also known as ad-hoc communication, in which all UAVs may connect via other UAVs and second, UAV-to-Infrastructure (U2I) communication also known as cellular mode communication, either individually or more UAVs can connect to the infrastructure such as ground station, UAV-control centre, satellite, etc.) [16], [17].
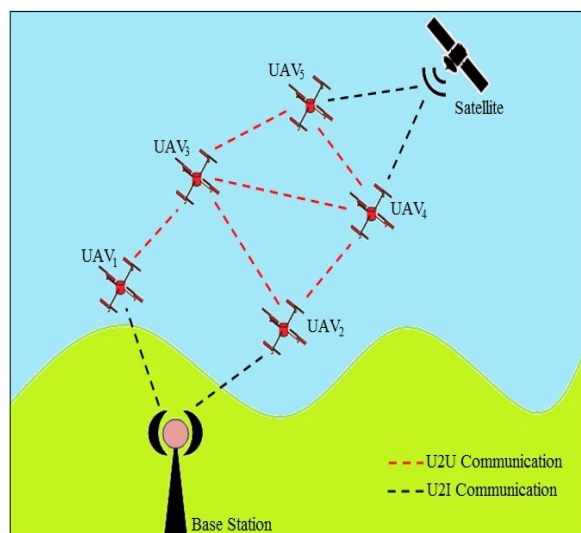

FIGURE 1. FANETs architecture

However, these communications have faced many challenges for transmitting or receiving data about performing various operations due to the unique characteristics of FANETs, such as the high mobility degree of UAVs, the frequent topology variation of a network, and the energy restrictions of UAVs, etc. The UAVs high dynamic movement in 3D can trigger many communication failures among these constraints. This makes the development of an efficient routing scheme increasingly complex [18].

Moreover, routing is a crucial challenge for every ad-hoc network to keep all their applications and services stable and active. Routing in FANETs is a procedure to finding an efficient route between UAVs, sending a data packet from a source UAV to another UAV until the information comes to the target UAV. Another side, efficient routing is still a major explore region to investigate communication in FANET due to the flexible nature of UAVs [19]. To establish the communication between UAVs in FANETs, the routing protocols are divided into two sections: topology-based and location-based scheme. However, topology-based schemes are not worked well when there is a dynamic change in the network topology and extensive use of memory to store routing tables and bandwidth for the flooding process [20]. Therefore, for the highly dynamic nature of the network like FANET, since few decades, many researchers focus on location-based (or geographical-based) routing protocols that include the local information and real-location of the moving nodes as UAVs via the Global Positioning System (GPS). Besides, the location-based schemes significantly reduce the necessities of topology capacity and provide appropriate and adaptable conditions to the dynamic behaviour of FANETs [21]. Also, the location-based protocols concern with the selection of the best next-hop node. Therefore, the topology changes impose little impact on the location-based schemes. However, the highly vibrant nature of the FANETs, the established link between the UAVs can easily disconnect and affecting the network performance. Consequently, it is very difficult to set up a stable route as well as along-lasting connection between the UAVs. With these all circumstances, designing a stable routing protocol is quite challenging in FANETs.

Motivated by these facts, in this paper, we have proposed a novel Optimized Location Aided Routing (O-LAR) protocol, which is a modified version of the existing Location-Aided Routing (LAR) protocol. The proposed scheme uses the concepts of greedy geographical positioning-based routing for the FANETs. The primary goal of the proposed O-LAR protocol is to improve the routing procedure to select the best route between source and destination UAV by considering some important factors. The proposed scheme utilizes residual energy, distance, and movement direction of the neighbouring UAVs placed around the border area of forwarding UAV. O-LAR select the best next-hop UAV based on the maximum weighted function for further information dissemination. Our proposed scheme is based on a greedy forwarding approach. In this

scheme, the border UAVs, which are always the forward direction of the destination and closer to the destination, will be selected as a next-hop node for further packet transmission in the network. Therefore, O-LAR minimizes the hop count between the source and destination. If such greedy forwarding is not possible in the border area of forwarding UAV, the proposed scheme employs the existing LAR forwarding strategy (flooding to all).

This paper presents the following significant contributions:

1) A novel optimized location-aided routing scheme has been proposed to improve the route discovery process for link stability between the UAVs using a weighted function.

2) Each UAV selects the best next-hop UAV in the forward direction of destination UAV based on the weighted function concerning three key parameters as: residual energy ratio, distance, and movement direction, respectively.

3) A Mathematical model of the proposed work has been done for the parameters like residual energy of UAVs, expected next-hop UAV distance (one-hop distance), and expected direction of UAV movement. We have validated the proposed scheme using the cost function in terms of complexity.

4) Further, a mathematical formulation is presented to calculate the expected link duration between the UAVs, and the average number of hops between source and destination UAVs.

5) Finally, O-LAR is simulated through the NS-2 simulator, results thoroughly analyzed and compared with the state-of-the-art protocols; LEPR, D-LAR, and LAR. The simulation results signify that O-LAR has higher link durability, higher network lifetime, better throughput and packet delivery ratio. On the other hand, as per results, O-LAR minimizes the number of hops, delay, and routing overhead compared to the existing state-of-the-art routing protocols.

The remainder of this article is structured as follows: Section 2 presented the background and literature survey about the work. The details discretion of the proposed O-LAR scheme is presented in section 3. The mathematical analysis of the proposed work has been investigated in Section 4. Section 5discusses the implementation and analysis of simulation results and finally, the conclusion and future scopes are presented in section 6.

II. BACKGROUND AND RELATED WORKS

FANET is considered as a sub-class of VANET and an application of MANET. Therefore, some common characteristics and strategies could be the same for data delivery. However, high mobility, drastically changing network topology, and energy restriction of UAVs make existing MANET and VANET routing protocols unfeasible in FANETs environment. Therefore, a significant number of enhancements and customizations are needed in existing location-based routing protocols to make them more efficient and suitable for FANETs. In this section, authors provide a review of some current location-based routing solutions in FANETs through Table 1.

The survey has given some of those protocols which have considered the routing metrics such as link duration, route discovery, energy efficiency, network lifetime, and a number of hops. Besides, the authors present in-depth existing work about the location-based routing protocol named LAR because the authors have to be optimized this protocol and make it more suitable for FANETs environment. Such categories are considered to be the most appropriate for shaping our proposed scheme. The energy of the node is one of the major issues for FANETs environment, which is limiting the optimized use of the UAVs. Although different types of mechanisms are proposed to resolve the energy constraints of UAVs, such as CBLADR [22], IMRL [23], and EALC [24], these schemes fail to meet the link stability requirements due to the vibrant nature of UAVs. Furthermore, due to the high speed of UAVs, connectivity is also the main issue between the nodes; therefore, the authors proposed [25] route discovery mechanism based on the connectivity factor between the UAVs, but the protocol fails to deal with sudden link breakage that occurs in the route. There is a necessity to improve link stability between UAVs, especially for a highly dynamic scenario. Therefore, the work introduced in [26] aims to calculate various stable link-disjoint paths. Further, the link stability metric is determined through the source UAV to choose the most stable route among the different routes. On account of connection breakage, the most stable cached route is selected for the data transmission. But if the network is dense in FANET, then the energy will be the main issue for UAVs.

TABLE 1. Features comparison between routing schemes

Features	Link stability	Route discovery	Energy efficiency	Network lifetime	Hop count
CBLADR [22]		√	√		
IMRL [23]			√	√	
EALC [24]			√		
UVAR [25]	√	√			√
LEPR [26]	√	√			
D-LAR [29]		√			√
LAR [32]		√			√
Proposed protocol	√	√	√		√

Besides, the Location-Aided Routing (LAR) protocol [27] is the most accepted and extensively used by MANET and in VANET as well, but the other side it is less utilized in FANETs. LAR is essentially on-demand location-based scheme, which utilizes GPS to acquire the topographical information of every versatile mobile node. This routing scheme divides the network into two zones; the expected zone (EZ) and the request zone (RZ). EZ could be considered

as a territory where the destination node is available, as appearing in Fig. 2.
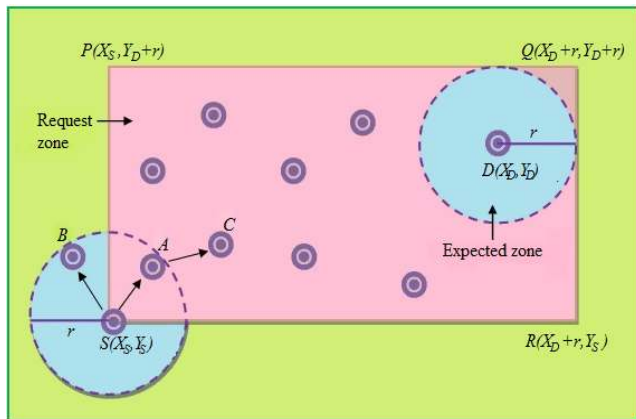

FIGURE 1. A working scenario of LAR protocol.

All nodes within the RZ, participate in data packet forwarding toward the destination node. When the RZ is set up, the source node broadcasts an *RREQ* message to all its neighbouring nodes within the communication range. The *RREQ* message got simply by those nodes which are in RZ otherwise, outside neighbours will dispose of the *RREQ*. Thus, the neighbouring nodes inside the RZ can forward the request for further processing and LAR control flooding and overhead by restricting other nodes in the network [28].The authors introduced [29], [30]Directional LAR (D-LAR) protocol with the combined advantages of the DIR and LAR concepts. The authors utilized the LAR scheme's main concept, such as restrict the flooding through RZ in the network area, and the DIR scheme selects the best next-hop node as a forwarding node having direction closest to the straight-line SD drawn between source and destination. Basically, the D-LAR protocol is based on a greedy approach to select the most suitable next-hop node for the high dynamic nature of the network. Further, with the addition of some features [31], the authors demonstrate the stateless geographic packet routing protocols like LAR, GFG, PAB3D,and so on, which are adjusted to the 3-D network climate, for example, FANETs. In [32] authors proposed an opportunistic routing scheme named OD-LAR for VANETs environment. The proposed OD-LAR combined the concepts of geographical location, link quality, and angular deviation, which helps select the next-hop forwarder node for routing process. But this scheme not performs very well in FANETs due to the energy restriction of UAVs. The stable route is a prime concern for transmitting the data between the nodes; therefore authors [33] introduced the multi-hop routing such as the LAMHR scheme based on the inter-vehicle distance VANETs environment to enhance the vehicle's connectivity. The proposed scheme performs well in terms of the path vanish, node broadcasting time, packet delivery ratio, and throughput compared to existing FLDLR, DLAR, and LAR. In reference [34], authors explained the basic architecture of LAR protocol in FANETs scenario and also comparatively evaluated the performance of conventional AODV scheme

with LAR for two different flying traffic scenarios: variable velocity and variable density of UAVs through simulation. The outcomes show that the LAR performs very well for the profoundly unique nature of FANETs as compared to the AODV scheme. However, because of UAVs' energy constraint and abundance flooding in LAR, some vital upgrades are needed to make LAR more reasonable for FANETs.

As per the above conversation and tabular analysis (Table 1), we note that numerous realistic characteristics, such as energy, link durability, and the network lifetime, have been neglected in their protocol evaluations, which are essential parameters FANETs. Although the existing LAR protocol is more suitable for MANET and after some extensive improvement, it has been used in VANETs, which is highly dynamic compared to MANET. In FANET, UAVs (flying nodes) are moving fast compared to VANET, but have some similar characteristics, therefore, in FANET; LAR cannot directly address the requirements of FANET, as the FANET is adaptive to high link duration, needs a smaller number of hops, and reduced routing overhead to find a stable path between source and destination UAVs.

In our proposed work, we have considered the above routing issues, introduce a range of features, and offered an O-LAR protocol. The O-LAR works better in the flying traffic environment of FANET. In this paper, we present not only joint study of essential parameters such as packet delivery ratio, average throughput, end-to-end delay, normalize routing overhead, but also worked on improving network lifetime, link duration, and minimizing the number of hops through efficient utilization of energy concept.

III. PROPOSED OPTIMIZED LAR PROTOCOL

As with VANET, FANET also has unique characteristics such as the very high mobility of UAVs and frequently changing its network topology. Somewhere it is different from VANET as the nodes (UAVs) move in the sky at a very high speed. These unique features of FANETs make it challenging to use location-based traditional LAR protocol. Therefore, some improvement in LAR is required that take advantage of the unique feature of FANETs. In the following subsections, we have presented the proposed O-LAR protocol for FANETs in detail.

A. SYSTEM MODEL

A communication network in FANETs environment can be represented with the popular terminology such as a graph $G = (V, E)$ where V is the different vertices called a set of UAVs and E is the various edges that represent the links between the UAVs. As with VANET, in FANET if two UAVs do not share a direct link, then they will use other intermediate UAVs between them to establish a connection [35]. In this proposed work, all smart UAVs randomly and uniformly deployed in a specific area for creating FANETs environment. We assume that each UAV like U_i is aware of its three-dimensional location (X_i, Y_i, Z_i)through GPS and

some other positioning system and its neighbour's UAV locations by sending *HELLO* control messages periodically in the networks. The links between the UAVs are considered to be bidirectional, and all UAVs initially have equal energy and the same transmission range. Furthermore, since every UAV will exchange its location and all other required information to its all neighbouring UAVs through *HELLO* packet (UAV_ID, UAV_Loc, UAV_Dir, UAV_ResE, Timestamp)therefore, this information can be used to find the best next-hop UAV that can be used in routing decision. Additionally, all UAVs at any given time are able to calculate their residual energy, the distance between themselves and their neighbouring UAVs, and movement direction to computing its link stability between themselves and their neighbouring UAVs. The fundamental notations utilized in this study are summarized in Table 2:

TABLE 2. Mathematical notation

Notation	Meaning
U_S	Source UAV
U_D	Destination UAV
U_B	Boarder UAV
N	Neighbour UAVs in border area
(X_i, Y_i, Z_i)	Coordinate value of UAV node U_i
CFU	Current Forwarding UAV
WF	Weight Function
SBU	Selected Border UAV
NHU	Next Hop UAV
NU	Neighbouring UAVs of CFU
$RREQ$	Route request
$RREP$	Route reply
E_i	Initial energy
E_c	Consumed energy
E_{re}	Residual energy of a UAV
R	UAVs communication range *(0-150m)*
R	UAVs communication range *(0-250m)*
ρ	Residual energy ratio
ρ_B	Residual energy ratio of UAV node U_B
D	Distance between two UAVs.
D_{SB}	Distance between source UAV U_S and border UAV U_B
$E(x)$	Expected distance between CFU and SBU
θ	UAV movement direction
$E_{threshold}$	*60J*
$D_{threshold}$	*(150-250)m*
$\theta_{threshold}$	*45°*
$E(\theta_{min})$	Expected movement direction with minimum angle
$F(x)$	Cumulative Density Function (CDF) of x
$f(x)$	Probability Density Function (PDF) of x
$F_{\theta min}(\theta)$	CDF of θ_{min}
$f_{\theta min}(\theta)$	PDF of θ_{min}

B. WEIGHT FUNCTION FOR SELECTING NEXT-HOP UAV

In this subsection, a thorough description of the mathematical weight function is givenwhich is based on three different system parameters: (a) Residue energy ratio, which indicates the energy level of UAV; (b) Distance, which shows the distance between forwarding UAVs and neighbouring UAVs in border areas; (c) Movement direction, which indicates the angle of moving UAVs from the baseline draw from the forwarding UAV to destination UAV. Further, in this proposed scheme the neighbouring UAV with a minimum value of weight function *(WF)* is selected as a next-hop UAV to further transmit the data packets. The *WF* can be defined as the neighbour UAV has minimum residue energy ratio (ρ), the maximum distance from the forwarding UAV (*D),* and minimum angle (θ) from the baseline drawn from the forwarding UAV to the destination UAV in order to select the best next-hop UAV. Firstly, the WF evaluates the performance of each candidate next-hop UAV and then selects the best-next hop UAV. The *WF* can be determined as:

$$WF = \alpha(1 - \rho) + \beta(1/D) + \gamma\theta \qquad (1)$$

Where α, β, and γ represents the corresponding tunable weight factors for ρ, D, and θ, respectively. The solution of Eq. (1) is strongly depending on the chosen weighting factors and therefore, these weight factors combined together and satisfying the condition $\alpha + \beta + \gamma = 1$, where $\alpha, \beta, \gamma \in (0,1)$. These factors should be made with a dynamic tuning of different weights. Based on many simulation experiments, we have computed the values for these three weight factors as follows: $\alpha = 0.4, \beta = 0.3, \gamma = 0.3$.

C. NEXT-HOP UAV SELECTION

In this subsection, we have presented the proposed O-LAR algorithm and a detailed description of the working process with a flow chart for selecting the best next-hop UAV among the neighbouring UAVs in the border area, which has the minimum *WF* to routing data packets towards the desire destination UAV. The selection algorithm for the next-hop UAV is given below.

Next-Hop UAV Selection Algorithm

Input: FANETs components and entire system model like N, ρ, D, θ etc.

Output: Next-hop UAV

Steps

1. **Start** (next hop election among neighbouring UAVs)
2. Set $CFU = U_S$
3. The CFU node broadcast the "*HELLO* packet" to all neighbouring UAVs for required information in the network
4. CFU node also updates the neighbour UAV table
5. **if** the destination UAV U_D is within the transmission range R of the CFU **then** CFU transmits the data packet directly to the U_D

6. **else**

7. Set $WF_{min} = 1$

8. **for**(*i = 1 to NU*)

   Compute the weight function WF_i of the border UAVs through calculating the values of ρ, D and θ. Furthermore, the values of the weight factors such as α, β, and γ select according to different cases from 1 to 6.

9. **end if**

10. **end for**

11. **end if**

12. Set $NHU = SBU$

13. Set $CFU = SBU$

14. Repeat **step 2** to **13** until the data packet reached at U_D.

15. **Stop**

Also, in the past few years, the number of routing algorithms has been proposed without considering the computational complexity of the existing problem. The proposed O-LAR protocol is a loop-free scheme. Since there is only a finite number of the neighbouring UAVs present within the communication range of every UAV U_i. It selects the unique UAV with minimum WF and moves towards the desired destination UAV for transmitting the data. Therefore, no UAVs are repeated consequently, as it is loop-free scheme. Further, in the route discovery process, every UAV can communicate to maximum n-1 numbers of neighbouring UAVs in its communication range for exchanging the message *RREQ* (except U_D) in the forward direction of destination UAV. We have considered the computational complexity of the proposed routing algorithm. In this case, the network complexity is $O(n)$. If we believe the whole network as a single system model, then the complexity will be $O(n^2)$.

Moreover, when a source UAV wishes to send the data to the destination UAV, it may involve multiple next-hop UAVs when the destination is out of the source coverage area. In this context, the source UAV first establishes a route to the destination UAV by transmitting the *RREQ* message to all neighbouring UAVs. This process repeats until the data packet is received by the destination UAV. Fig 3 shows how the *RREQ* is broadcasted in the route discovery process. When the *RREQ* is initiated, the source UAV U_S which is called *CFU*, broadcasts an *RREQ* message with coordinate values of the four corners of the rectangular area to all its neighbours' UAVs in the request zone like U_A, U_B, and U_C. The *CFU* node U_S select the U_B as the next-hop UAV (*NHU*) with minimum weight function (*WF_{min}*) as determined through Eq. (1) to Eq. (21) for different cases (1) to (6). As shown in Fig 3, once the *NHU* node U_B receives the *RREQ* from the U_S, the U_B becomes the *CFU* and follows the same forwarding method for further transmission before the request reaches the destination U_D. Once the *RREQ* message received at destination U_D via intermediate UAVs ($U_B \rightarrow U_E \rightarrow U_F \rightarrow U_G \rightarrow U_H \rightarrow U_D$), and then the U_D uses a unicasting scheme to send the *RREP* to the source U_S. The detailed data flow processing in the proposed O-LAR has been shown in Fig. 3.

FIGURE 3. Next-hop node selection in O-LAR scheme.

Further, as explained above, the UAV with the minimum value of the *WF* is selected as the best next-hop UAV. The minimum value of the *WF* to select the next-hop UAV depends on the system parameters such as ρ, D, and θ. WF also depends on the values of the weight factors such as α, β and γ. The values of the weight factors are selected according to the different FANETs scenario. Therefore, we have considered all possible scenarios (Case 1 to 6) for the selection of the best next-hop node, which are considered as follows:

Case 1: If only a single neighbour is available in transmission range R for forwarding UAV. Simply forward the *RREQ* without any calculation.

Case 2: If more than one neighbouring UAVs are there in RZ with equal E_{re}, and equal distance D from forwarding UAV within the transmission range R. Then the forwarding UAV select the next-hop UAV which has minimum movement direction θ_{min} as computed by Eq. (13) to Eq. (21) and then calculated *WF* through Eq. (1), where $\alpha=0$, $\beta=0$, and $\gamma=1$.

Case 3: If more than one neighbouring UAVs are there in RZ with equal E_{re}, and the same value of θ_{min} from forwarding UAV within transmission range R. Then select the next-hop UAV which has maximum distance D from forwarding UAV in the border area as computed by Eq. (8) to Eq. (12) and then calculated the *WF* through Eq. (1), where $\alpha=0$, $\beta=1$, and $\gamma=0$.

Case 4: If more than one neighbouring UAVs are there in RZ with equal distance and same value of θ_{min} from forwarding UAV within transmission range R, then, it selects the next-hop UAV which has maximum E_{re} as computed by the Eq. (2) to Eq. (7) and calculated the *WF* through Eq. (1), where $\alpha=1$, $\beta=0$, and $\gamma=0$.

Case 5: If there are more than one neighbouring UAVs with equal E_{re}, equal distance, and same direction (θ_{min}) from forwarding UAV within transmission range R. Then, in this condition, any of one UAV will be selected as a next-hop

UAV and calculates WF through Eq. (1), where $\alpha=0.4$, $\beta=0.3$, and $\gamma=0.3$.

Case 6: If there is more than one neighbouring UAVs with following values:

- Equal E_{re} but different distance D and different direction, θ_{min} from forwarding UAV or
- Equal distance D but different E_{re} and θ_{min} from forwarding UAV or
- Same direction, θ_{min} but different E_{re} and distance D from forwarding UAV.

Then, in this condition, the next-hop UAV will be selected as per the computed value of a weighted function, WF_{min} in Eq. (1), where $\alpha = 0.4$, $\beta = 0.3$, and $\gamma = 0.3$.

As depicted in Fig. 3 and described above through the next-hop UAV selection algorithm along with different cases of a selection of next-hop UAV, we have simplified the selection procedure and represented it using a data flow diagram as shown in Fig. 4.
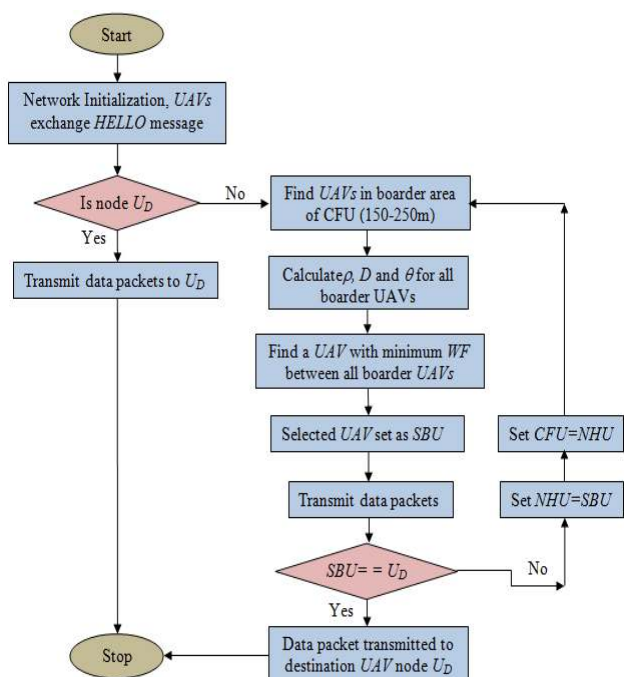
FIGURE 4. Flowchart of selecting best next-hop UAV

IV. MATHEMATICAL ANALYSIS OF PROPOSED O-LAR PROTOCOL

This subsection has discussed the detailed mathematical analysis of the proposed scheme for FANETs using some routing parameters. These parameters determine the performance of the route and help to determine the best next-hop UAV for further packet transmission. In a highly dynamic network, a stable route depends on the stability of the link or link lifetime and other factors such as hop count and power or energy level of nodes.

A. RESIDUAL ENERGY

A UAV energy level determines how much UAV is capable of handling all essential networking tasks and how long it can function properly. One of the most significant factors in enhancing route stability is the residual energy of UAV and also plays a vital role in choosing stable and quailed next-hop UAV. The current energy value in a UAV after receiving or transmitting routing packets is called residual energy. A UAV loses a particular amount of energy in the network for each value transmitted, and each packet received or performing network operations [36]. If the residual energy of any UAV is less than the $E_{threshold}$, UAV cannot participate in the routing process; hence that UAV will be dead. The greater the residue energy, the longer the node communication link, therefore network topology will remain active and used for further routing. To select the next-hop UAV for further communication, every UAV knows its residual energy and neighbour's UAV residual energy via exchanging Hello packet within specific time duration. Therefore, the neighbours closer to border or on the border with higher residual energy will be selected as the best next-hop UAV in the network.

1) MATHEMATICAL ANALYSIS

Let $E_i^B(t)$ as the initial energy of any intermediate UAV node U_B at the time t, generally a fixed value and the residual energy (Fig. 5) $E_{re}^B(t + \tau)$ of UAV U_B at the period of time τ is calculated as follow.

$$E_{re}^B(t + \tau) = E_i^B(t) - E_c^B(t + \tau) \qquad (2)$$

where $E_c^B(t + \tau)$ denotes the energy consumption (during transmission, receiving, exchanging information, and internal operations) by U_B for a period of τ.
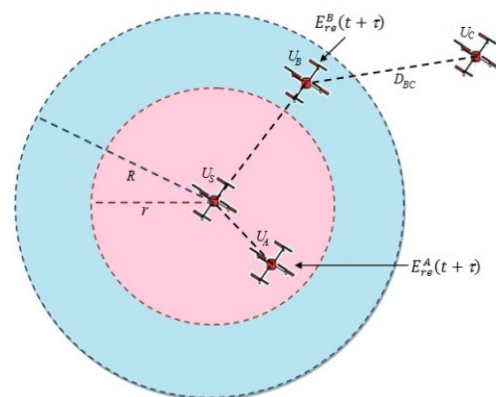

FIGURE 5. Residual energy of UAVs

Furthermore,

$$E_r^B(t + \tau) = l \times E_{elec} \qquad (3)$$

$$E_t^B(t + \tau) = l \times E_{elec} + l \times D_{BC}^2 \times E_{amp} \qquad (4)$$

where $E_r^B(t + \tau)$ and $E_t^B(t + \tau)$ represents the energy consumed by receiving l bit data, sending l bit data to U_C at

the distance D_{BC} respectively as well as E_{elec} and E_{amp} correspond to the energy consumed the circuit and the power amplifier, respectively.

In addition, all UAVs often consume energy when performing internal operation such as linking, capturing, computing, managing, and updating the database at the time of τ period, which is expressed by $E_O^B(t + \tau)$.

$$E_c^B(t + \tau) = E_r^B(t + \tau) + E_t^B(t + \tau) + E_o^B(t + \tau) \quad (5)$$

Finally, by Eq. (2) the residual energy of U_B updated at time τ is calculated as:

$$E_{re}^B(t + \tau) = E_i^B(t) -$$

$$[E_r^B(t + \tau) + E_t^B(t + \tau) + E_o^B(t + \tau)] \quad (6)$$

Therefore, the energy residual ratio ρ_B for U_B in the network can be expressed as:

$$\rho_B = \frac{E_{re}^B}{E_i^B} \quad (7)$$

Furthermore, $1 - \rho_B$ represents the energy consumption rate of U_B and calculated by the formula $\frac{E_i^B - E_{re}^B}{E_i^B}$.

B. EXPECTED DISTANCE OF UAV

The selection of next-hop UAV also depends on the distance between the current forwarding UAV and neighbour UAVs. The distance can be obtained using the position information obtained through *HELLO* packet of the forwarding UAV, neighbour UAV, and destination UAV. The selection of next-hop UAV at the maximum distance from the forwarding UAV used to reduce the number of hops between source and destination UAV causes minimized end-to-end delay. Thus, reduced hop count or minimized distance between forwarding UAV and next-hop UAV affect the routing and network performance as minimized end-to-end delay improves the network efficiency and throughput. Furthermore, the proposed strategy assigns priority to those neighbour UAVs, which are nearer to the border area ($D_{threshold}$). The border UAV in the forward direction of destination UAV is always closer to the destination and it may reduce the number of hops between the source and destination. If in case, such greedy forwarding fails, O-LAR engages existing LAR forwarding strategy to forward the packet successfully to the destination.

1) MATHEMATICAL ANALYSIS

VANET is different from other networks due to its unique The proposed O-LAR is based on a location-based routing strategy; therefore, the forwarding UAV can utilize the coordinate values of its every border neighbouring UAVs within the threshold region of the communication range. Let the coordinate value of source UAV U_S is (X_S, Y_S, Z_S) and U_B is (X_B, Y_B, Z_B), then the distance from U_S to U_B is simply

calculated [37] by the mathematical formula in Eq. (8) as given below:

$$D_{SB} = \sqrt{(X_S - X_B)^2 + (Y_S - Y_B)^2 + (Z_S - Z_B)^2} \quad (8)$$

Since all UAVs are distributed randomly as assumed, it is therefore very difficult to calculate the exact maximum distance of UAVs from the forwarding UAV at the border area. Therefore, we have calculated the expected distance of UAV, which is the distance from the source UAV to neighbour UAVs in the border area of the communication range R. Assume a source U_S has n neighbour UAVs towards the destination U_D in border area as shown in Fig. 6. Let U_B is the farthest UAV of the source U_S within the transmission range R of U_S. Furthermore, let D_{SA}, D_{SB}, $D_{SC} \ldots \ldots \ldots D_{Sn}$ denotes the distances between source UAV and its neighbour UAVs and x is the distance between U_S and its farthest UAV node U_B, i.e.

$$x = Max_{i=A}^n D_{Si} \quad (9)$$

Then we can calculate the expected distance $E(x)$ from forwarding UAV to farthest boarder UAV with the help of CDF and PDF. Let $F(x)$ is CDF of x as well as $f(x)$ is the PDF of x, then,

$$F(x) = P[D_{SA} \leq x, D_{SB} \leq x, , D_{SC} \leq x, \ldots \ldots D_{Sn} \leq x]$$

$$F(x) = \prod_{i=A}^n P[D_i \leq x]$$

$$F(x) = \left(\frac{x}{R}\right)^n \quad (10)$$

Similarly,

$$f(x) = \frac{d}{dx} F(x) \Rightarrow \frac{d}{dx} \left(\frac{x}{R}\right)^n$$
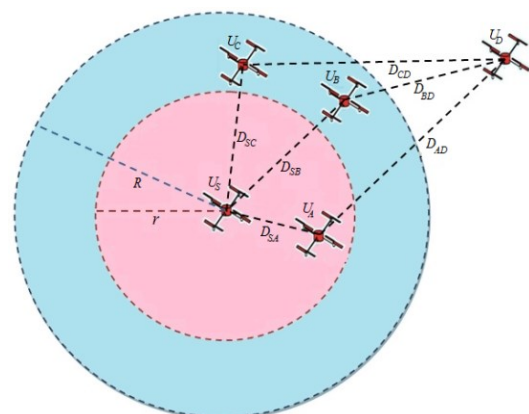
$$f(x) = \frac{n}{R^n} x^{n-1} \quad (11)$$

FIGURE 6. Distance calculation from UAV U_S to farthest UAV U_B

Therefore, expected distance of the boarder UAV is:

$$E(x) = \int_{r}^{R} x \cdot f(x)dx$$

$$\Rightarrow \frac{n}{R^n} \int_{r}^{R} x \cdot x^{n-1} dx \Rightarrow \frac{n}{R^n} \int_{r}^{R} x^n \, dx$$

$$\Rightarrow \frac{n}{R^n} \left[\frac{x^{n+1}}{n+1} \right]_{r}^{R} \Rightarrow \frac{n}{R^n} \left[\frac{R^{n+1}}{n+1} - \frac{r^{n+1}}{n+1} \right]$$

$$E(x) = \frac{n}{n+1} \left[R - \frac{r^{n+1}}{R^n} \right] \tag{12}$$

C. EXPECTED DIRECTION OF UAV MOVEMENT

The third factor for the proposed O-LAR model is the UAV movement direction, which is considered for selecting the UAV as the next-hop has a minimum $(\theta_{threshold})$ angle from the baseline draw from the source to destination UAV. If the border UAV comes closer to the baseline, the hop counts between source and destination will decrease automatically. Therefore, the source UAV takes very little time to deliver the data packets to the desired location, which causes the increase of the packet delivery ratio.

1) MATHEMATICAL ANALYSIS

As shown in Fig. 7, let U_A, U_B, and U_C are neighbouring UAVs of the source U_S and also these all UAVs lie in the converge area (0-250m) of U_S. Moreover, let U_B and U_C move in the forwarding zone at the border area of the transmission range of the U_S. Now, U_S computes an angle θ for each border UAV such as θ_B and θ_C through Eq. (13) with the information received by *HELLO* packet. UAVs U_B and U_C are also assumed to have sufficient ρ required to cooperate. Let θ_B is an angle formed between neighbour UAV U_B, sender U_S, and destination U_D and it is obtained by the following equation:

$$\theta_B = arccos\left(\frac{(D_{SD})^2 + (D_{SB})^2 - (D_{BD})^2}{2D_{SB} \cdot D_{SD}} \right) \tag{13}$$

The distance between the UAVs such as D_{SD}, D_{SB} and D_{BD} can be calculated through the following equations.

$$D_{SD} = \sqrt{(X_S - X_D)^2 + (Y_S - Y_D)^2 + (Z_S - Z_D)^2} \tag{14}$$

$$D_{SB} = \sqrt{(X_S - X_B)^2 + (Y_S - Y_B)^2 + (Z_S - Z_B)^2} \tag{15}$$

$$D_{BD} = \sqrt{(X_B - X_D)^2 + (Y_B - Y_D)^2 + (Z_B - Z_D)^2} \tag{16}$$

Where, (X_S, Y_S, Z_S), (X_B, Y_B, Z_B), and (X_D, Y_D, Z_D) are the current coordinates of U_S, U_B, and U_D.
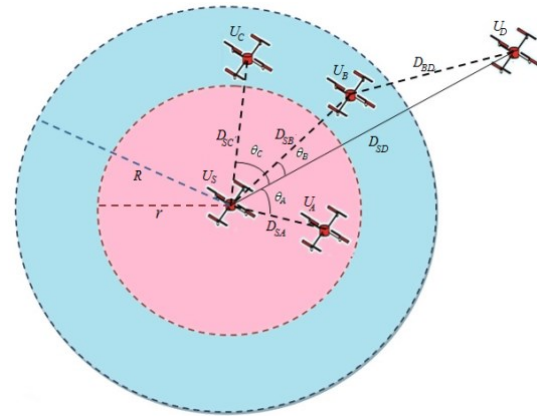

FIGURE 6. Angle calculation between a border UAV U_B, sender U_S and destination U_D

Since we have considered a highly dynamic nature of the network in which all UAVs are randomly distributed, the UAV is hard to determine. Therefore, this movement direction, such as angle, can be viewed as a random variable, and its expected value can be calculated. The expected direction of UAV on movement is an angle between the lines of the border, sender, and destination UAVs. Let θ_B is an angle of U_B^{th} UAV node at the border area. Furthermore, if the total number of UAVs in the border area is n, then the minimum angle θ_{min} will be calculated as:

$$\theta_{min} = min(\theta_A, \theta_B, \theta_C, \dots \dots \theta_n) \tag{17}$$

Fig 7 shows that the source UAV U_S selects the next-hop UAV U_B as $\theta_B \leq \theta_C \leq \theta_C$. The selected UAV U_B will follow the same procedure until reach to destination UAV U_D. Now, suppose $F_{\theta min}(\theta)$ and $f_{\theta min}(\theta)$ are CDF and PDF of θ_{min} respectively. Then,

$$F_{\theta min}(\theta) = P(\theta_{min} < \theta) = 1 - P(\theta_{\theta min} \geq \theta)$$

$$\Rightarrow 1 - P(\theta_A \geq \theta, \theta_B \geq \theta, \theta_C \geq \theta, \dots \dots \theta_n \geq \theta)$$

$$F_{\theta min}(\theta) = 1 - P(\theta_A \geq \theta)P(\theta_B \geq \theta) \\ P(\theta_C \geq \theta), P(\theta_n \geq \theta) \tag{18}$$

The angle θ will be uniformly distributed over 0 to $\pi/2$. Therefore, CDF of θ_{min} is evaluated as:

$$F_{\theta min}(\theta) = 1 - \left(1 - \frac{\theta}{\frac{\pi}{2}} \right)^n$$

$$F_{\theta min}(\theta) = 1 - \left(1 - \frac{2\theta}{\pi} \right)^n \tag{19}$$

Similarly, the PDF of θ_{min} is:

$$f_{\theta min}(\theta) = \frac{d}{d\theta}(F_{\theta min}(\theta)) = \frac{d}{d\theta}\left(1 - \left(1 - \frac{2\theta}{\pi} \right)^n \right)$$

$$f_{\theta min}(\theta) = \frac{2n}{\pi}\left(1 - \frac{2\theta}{\pi}\right)^{n-1} \qquad (20)$$

Therefore, the expected angular deviation is computed as:

$$E(\theta_{min}) = \int_0^{\frac{\pi}{2}} \theta \cdot f_{\theta min(\theta)} d\theta$$

$$E(\theta_{min}) = \int_0^{\frac{\pi}{2}} \theta \cdot \frac{2n}{\pi} \cdot \left(1 - \frac{2\theta}{\pi}\right)^{n-1} d\theta$$

$$E(\theta_{min}) = \frac{\pi}{2(n+1)} \qquad (21)$$

D. EXPECTED LINK DURATION

As we know that a link is established between two UAVs when one UAV enters the other UAVs transmission range R. Therefore, the time during which the connection between the UAVs within R remains active is referred to as the link duration. In our proposed O-LAR, all UAVs are randomly distributed; therefore, the expected link duration of the UAVs can be calculated as:

$$E(Link_D) = \frac{E(D_{AB})}{E(V_{AB})} \qquad (22)$$

Here $E(D_{AB})$ is the expected distance from source UAV U_A to border UAV U_B, which is calculated by Eq. (12) and $E(V_{AB})$ is the expected relative velocity between the U_A and U_B. We can acquire the relative velocity V_{AB} through the law of parallelogram and calculated as:

$$V_{AB} = \sqrt{(V_A)^2 + (V_B)^2 - 2V_A V_B \cos\theta} \qquad (23)$$

In the proposed O-LAR scheme, let us assume that all UAVs move with the same speed in FANETs environment. Therefore, the velocity: $V_A = V_B = V$. Now, the relative velocity is:

$$V_{AB} = V\sqrt{2(1 - \cos\theta)} \qquad (24)$$

Also, we assumed that all the UAVs move toward the destination UAV, such that angular direction varies from 0 to $\pi/2$. Consequently, the $E(V_{AB})$ can be obtained as follows:

$$E(V_{AB}) = V\int_0^{\frac{\pi}{2}} \sqrt{2(1 - \cos\theta)} \, d\theta \qquad (25)$$

Simplified as: $\quad E(V_{AB}) = 2\sqrt{2} \cdot V \qquad (26)$

Finally, by Eq. (12) and Eq. (26), the expected link duration of UAVs is:

$$E(Link_D) = \frac{E(D_{AB})}{E(V_{AB})} \Rightarrow \frac{\frac{n}{n+1}\left[R - \frac{r^{n+1}}{R^n}\right]}{2\sqrt{2} \cdot V}$$

$$E(Link_D) = \frac{n}{2\sqrt{2}(n+1)V}\left[R - \frac{r^{n+1}}{R^n}\right] \qquad (27)$$

D. AVERAGE NUMBER OF NEXT-HOPS

In any wireless network, the hop count refers to the total number of intermediate nodes through which a data packet will travel between source and destination. The average hop count analysis in FANETs is very important and challenging because it can provide design and network establishment information. Moreover, the average hop count is a key parameter for performance analysis of the networks using analytical methods. Therefore, a minimum number of hop counts increase the network's performance because within a short time span, the data packet reaches at the destination UAV. The average number of hop count can be calculated for the proposed protocol in the FANETs as follows:

$$A(H_{count})$$
$$= \frac{Distance\ between\ source\ to\ destination}{Expected\ distance\ of\ the\ next\ hop} \qquad (28)$$

Therefore,

$$A(H_{count}) = \frac{D_{SD}}{E(x)} \Rightarrow \frac{D_{SD}}{\frac{n}{n+1}\left[R - \frac{r^{n+1}}{R^n}\right]}$$

$$A(H_{count}) = \frac{(n+1)D_{SD}}{n\left(R - \frac{r^{n+1}}{R^n}\right)} \qquad (29)$$

V. SIMULATION SETUP AND RESULTS DISCUSSION

This section evaluated the performance of our proposed O-LAR mechanism against the existing LAR, D-LAR, and LEPR schemes using simulated experiments. The simulations of the proposed and existing routing protocols were conducted for different scenarios with varying number of UAVs and their speed through the NS-2.35 simulator [38-45].At the beginning of FANET scenario, all UAVs (05-25) are randomly distributed in the area of 1×1km^2 with a transmission range of each UAV is maximum as 250m and used IEEE 802.11g as a mac layer wireless standard. The speed of each UAV is varying from 20 to 100m/sec. The initial energy of every UAV is 150J. The simulation time is 200sec. with 512bytes packet size and traffic type is CBR. The other parameters for the simulator are summarized in Table 3.

TABLE 3. Simulation parameters

Parameters	Values
Channel type	Channel/Wireless channel
Simulation area	1×1km²
Simulation time	200sec.
UAVs	05-25
Packet size	512bytes
Routing protocol	O-LAR, LEPR, D-LAR and LAR
Antenna model	Omni
Interface queue type	Drop tail/Priority queue, CMU priQueue
Interface queue length	50
Mac layer protocol	802.11g
Maximum transmission range	250m
Traffic type	CBR
Initial energy of UAV	150J
Weight factors	α=0.4, β=0.3 and γ=0.3
UAVs speed	20-100m/sec.

The performance of the proposed O-LAR protocol is evaluated and compared with the existing protocols by using the parameters like link duration, expected hop counts, packet delivery ratio, network lifetime, normalized routing overhead, average throughput, and end-to-end delay in FANETs environment. The taxonomy of the parameters mentioned above used for the analysis is as follows:

A. EXPECTED LINK DURATION

If the link duration between the UAVs is high, more data packets can be transmitted by UAVs in the network that causes an increase in the network's performance. The link duration between the UAVs depends on the communication range of the UAVs. Fig. 8 shows that the maximum communication range achieves the highest expected link duration (ELD) since UAVs remain in contact with each other for longer periods. We notice that, as per the simulation set up, the number of border UAVs is 05, and they travel at the same speed as 60m/s. As shown in Fig 8, the ELD between the UAVs is higher than the state-of-the-art protocols. Therefore, O-LAR gives better performance than others.
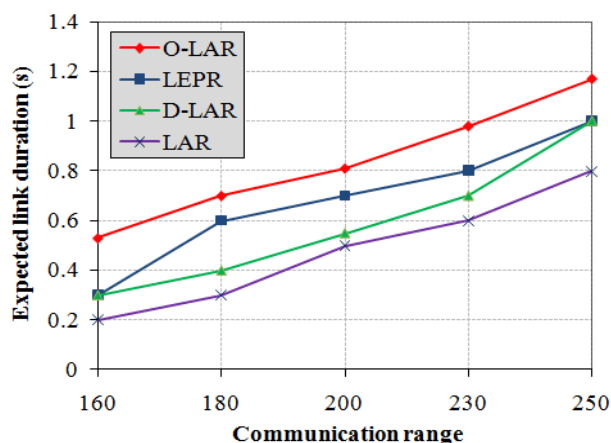

FIGURE 8. Expected link duration versus Communication range.

Further, Fig. 9 shows the impact of ELD on proposed O-LAR and LEPR, D-LAR, and LAR protocols with a varying speed of UAVs from 20m/s to 100m/s and fixed transmission range such as 250m. As shown in Fig 9, it is observed that the ELD between the UAVs decreases as the speed of UAVs increases because it causes a higher probability of link failure. The ELD of O-LAR is greater as compare to the LEPR, D-LAR, and LAR protocols due to residual energy and link duration time between the UAVs. Similarly, Fig. 10 shows the impact of ELD over border UAVs with fixed speed 60m/s. To higher the link duration, O-LAR gives better results. This is due to the large number of border UAVs where; link is maintained quickly as depicted. Therefore, the result reveals that the proposed O-LAR protocol prolongs the ELD compared to LEPR, D-LAR, and LAR protocols.
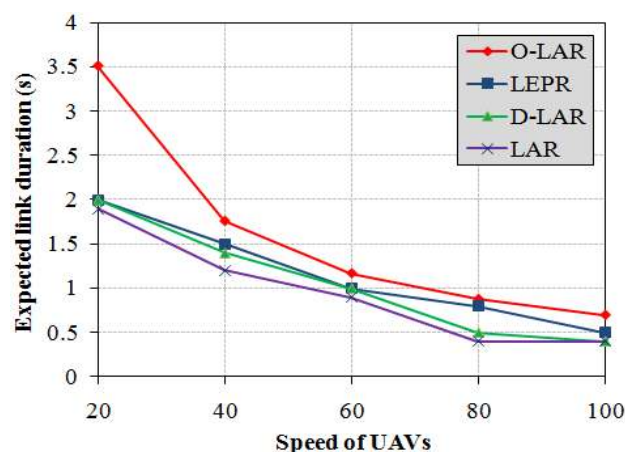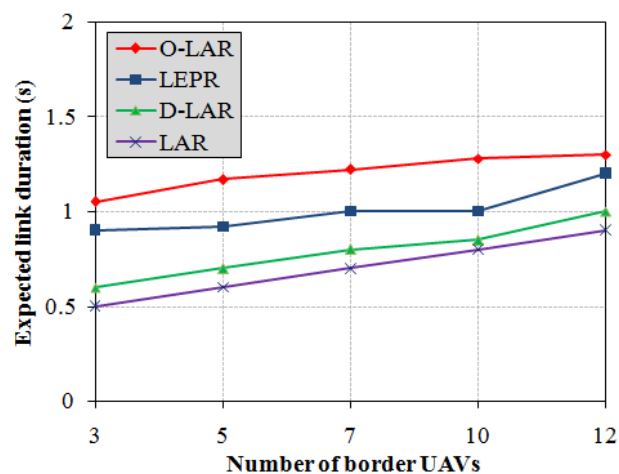

FIGURE 9. Expected link duration versus UAVs speed.

FIGURE 10. Expected link duration versus Number of border UAVs (speed 60m/sec.)

B. AVERAGE NUMBER OF NEXT-HOPS

Fig. 11 shows the comparison of the number of hops between source and destination UAV (distance =1000m). If the number of border UAVs increases, the average number of

hop counts decreases. Hence, it causes an increasing possibility of the selection of the best next-hop UAV. Thus, a minimum hop count takes less time to deliver data packets at the destination UAV. As shown in Fig. 11, the proposed O-LAR performs well as compared to the state-of-the-art protocols. For the other protocol such as D-LAR, and LAR the packet hop counts are high due to flooding concepts in RZ.As shown in the figure, LEPR has a maximum number of next-hops as the next forwarder node selects the nearest neighbour node for further packet transmission, resulting in an increase number of next-hops compared to O-LAR.
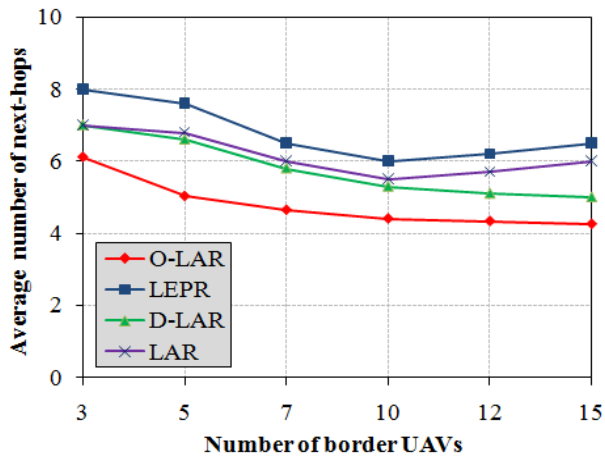
FIGURE 11. Average number of next-hops versus Number of border UAVs (speed 60m/sec.)

C. PACKET DELIVERY RATIO

The packet delivery ratio (PDR) is simply the ratio of the number of delivered data packets from source UAV to destination UAV in FANETs. It can be calculated as:

$$PDR = \frac{\sum_{i=1}^{n} P_R}{\sum_{i=1}^{n} P_S} \times 100 \qquad (30)$$

Where, P_R is packets received by the destination UAV and P_S is packets generated by the source UAV. Fig. 12 represents the variation in PDR with varying numbers of UAVs. Here, the horizontal axis shows the different number of UAVs, and the vertical axis represents the PDR in the network. The higher number of UAVs maximize the probability of finding the best next-hop UAVs in the area that forwards the packets to the destination UAV. Also, the concept of the link durability and network lifetime in terms of the residual energy can offer long-life routing paths for sending more data packets. Therefore, as shown in the figure, the PDR in the proposed O-LAR is higher, and the count of UAVs increases compared to the other existing protocols.

Further, it can be seen from Fig 13, if the speed of UAVs is high, the PDR of all routing protocols decreases automatically. Because the high mobility of UAVs causes frequent changes in network topology therefore data packet being transmitted to be unable to find the proper next-hop UAV, then, the packet is discarded. However, O-LAR has

been evaluated through residual energy and link duration parameters therefore; it has the advantage over LEPR, D-LAR, and LAR protocols. It improves the UAV's connectivity and PDR as well. Besides this, LEPR, D-LAR, and LAR suffers from packet loss and less PDR due to UAVs' insufficient energy level to continue the data transmission.
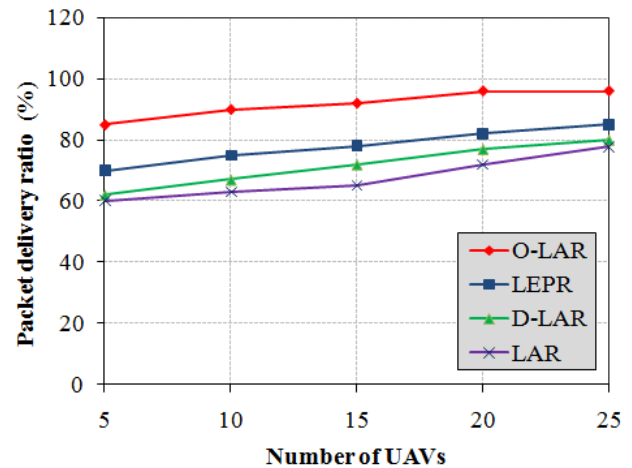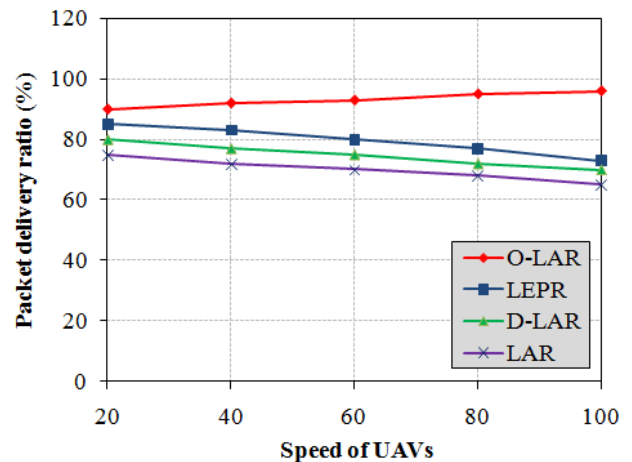

FIGURE 12. PDR versus Number of UAVs (speed 60m/sec.).

FIGURE 13. Packet delivery ratio versus UAVs speed.

C. NETWORK LIFETIME

Since the UAVs in the FANETs use battery power which is the efficient utilization of the energy that ameliorates the network lifetime. Thus, the network lifetime can be defined as the time from the commandment of the simulation until the first UAV node in the FANETs runs out of energy. Fig 14 shows the impact of network lifetime with the number of UAVs considered as 5, 10, 15, 20, and 25 and the fixed speed of each UAV as 60m/s. We observe that our proposed O-LAR scheme performs significantly better than the other four existing protocols. Obviously, that O-LAR scheme has superior performance, like 14.2%, 25.0%, and 28.50% improvement is achieved in network lifetime over LEPR, D-

LAR, and LAR. Moreover, farthest next-hop UAVs with less energy consumption is selected to pursue data forwarding; as a result, O-LAR outperforms as compared to state-of-the-art protocols.
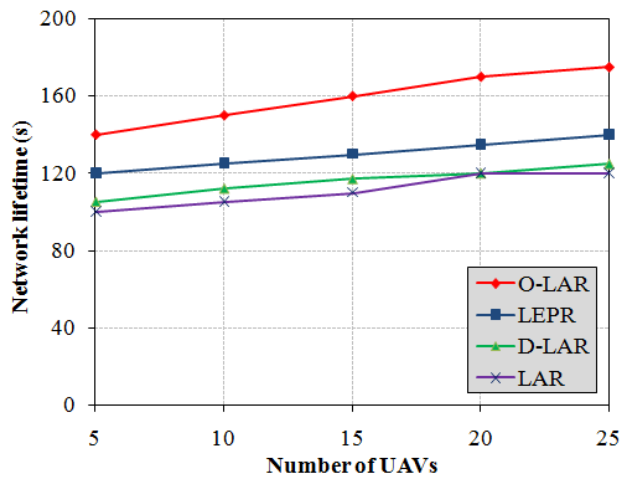

FIGURE 14. Flow Network lifetime versus Number of UAVs (speed 60m/sec.)
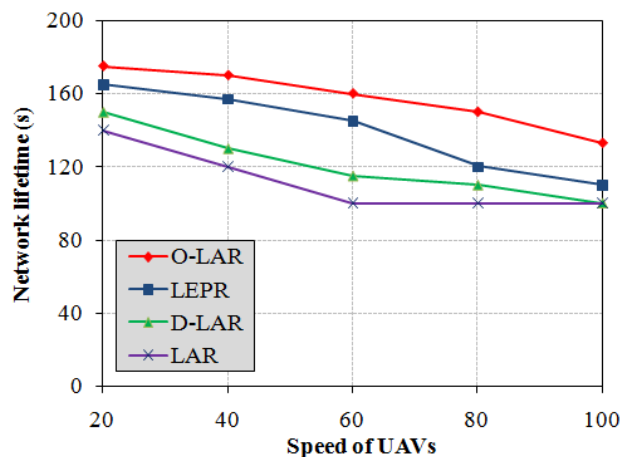

FIGURE 15. Network lifetime versus UAVs speed.

Further, Fig. 15 shows the comparison of the performance of the proposed scheme with existing state-of-the-art protocols for network lifetime, and varying speeds of UAVs. In this case, the density of UAV sets as 10 and speed varies from 20 to 100 m/s. As shown in Fig. 15, when the speed of UAVs increases, the network lifetime is decreased accordingly. Therefore, it is observed that O-LAR performs better as compare to LEPR, D-LAR, and LAR because it has adopted the residual energy thresholds to avoid the participation of lower residual energy of UAVs. On the other hands, since UAV moving towards the destination in a limited area of RZ therefore, it is having more residual energy for further communication. In such a situation, the proposed O-LAR gives better performance. Thus, the result reveals that the proposed scheme outperforms as compared to state-of-the-art protocols.

D. NORMALIZED NETWORK OVERHEAD

The normalized routing overhead (NRO) can be calculated as the ratio of the total number of control packets propagated by the nodes to all delivered data packets during the simulation. Fig. 16 shows the impact of overhead with different UAV numbers and fixed values of speed as 60m/s in the network. As shown in the figure, the proposed O-LAR protocol has been compared with existing state-of-the-art protocols. O-LAR has lower NRO as compared to LEPR, D-LAR, and LAR protocols. The movement direction of the UAV is used to determine the net-hop UAV in the forward direction of the destination UAV, which decreases the undesirable control messages in the network to discover the route. Therefore, the NRO can be minimized by maximizing the link durability and high residual energy paths. In this case, the route re-discovery process will be minimized, resulting in less NRO.
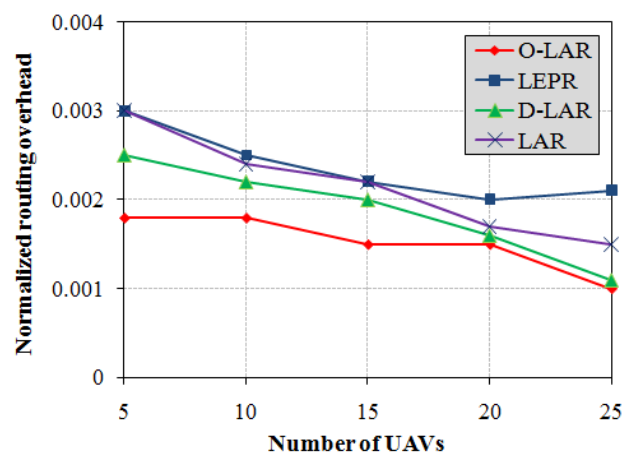

FIGURE 16. NRO versus Number of UAVs (speed 60m/sec.)
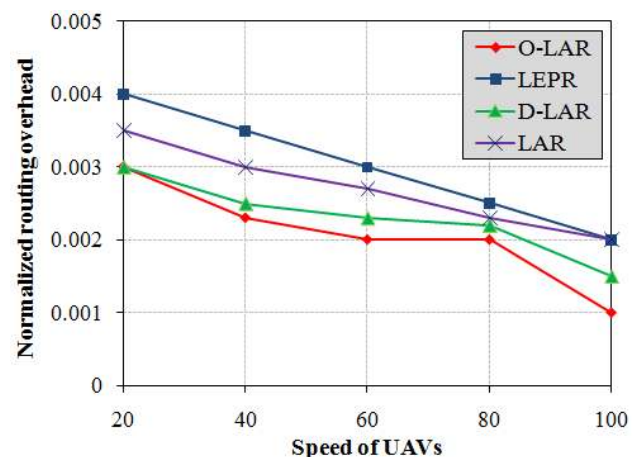

FIGURE 17. NRO versus UAVs speed.

Furthermore, Fig. 17 depicts the impact of NRO with varying speeds of UAVs. As the speed of UAVs increases, the rate of recurrence of route breakage increases, consequently increasing the routing overhead to find new paths. From Fig.

17, we can say that the proposed O-LAR protocol gives a lower NRO than LEPR, D-LAR, and LAR protocols, especially in the case of the higher speed of the UAVs. This is possible because of the reduction of the number of route requests by limiting the route discovery. Further, since D-LAR and LAR protocols are not based on residual energy of the UAVs therefore, it makes the network more vulnerable to sudden disconnections, resulting in more control overhead. Consequently, it is concluded that O-LAR outperforms as compare to state-of-the-art schemes.

E. NAVERAGE THROUGHPUT

Throughput is one of the significant parameters for accessing the scalability of any routing technique. A comparison of average throughput metric for proposed O-LAR and the existing state-of-the-art protocols are shown in Figs. 18 and 19 for the number of UAVs and varying speed of UAVs, respectively. The horizontal axis shows the speed of UAVs, and the vertical axis represents the average throughput. From Fig. 18, it is clear that the average throughput of the proposed O-LAR protocol is better than that of the existing protocols, since the drop rate of the packet is much lower in proposed scheme due to link stability based on energy principle between source and destination UAVs.
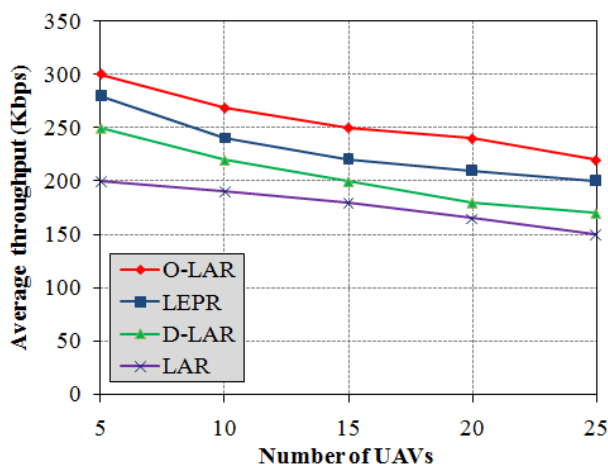

FIGURE 18. Average throughput versus Number of UAVs (speed 60m/sec.).

Further, average throughput comparisons for the proposed O-LAR and the existing protocols have been given in Fig 19. We observed a significant improvement in throughput of proposed O-LAR with a varying speed of ten numbers of UAV compared to LEPR, D-LAR, and LAR protocols. Moreover, the proposed protocol shows a more stable throughput with 250kbps compared to the 225kbps, 210kbps, and 190kbps of the existing protocols. The higher average throughput of O-LAR restricted the flooding through the request zone which minimizes the network load and improves the average throughput compared to LEPR. Because of more residual energy and improved link duration time, O-LAR performs well as compared to D-LAR and LAR protocols.
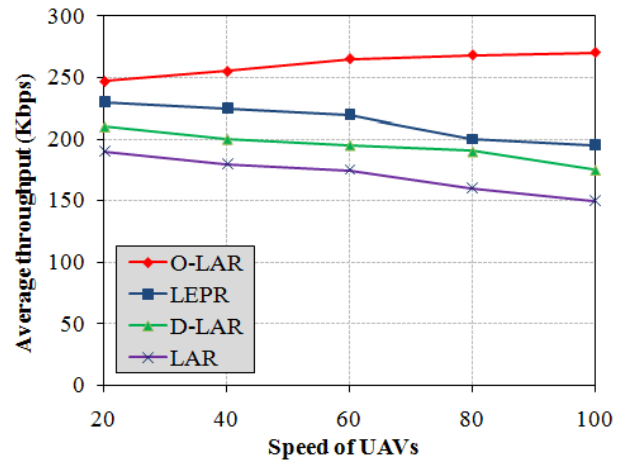

FIGURE 19. Average throughput versus UAVs speed.

F. END-to-END DELAY

A comparison of end-to-end delay (E2ED)is depicted on proposed O-LAR and the state-of-the-art protocols for varying numbers of UAVs and fixed speed as shown in Fig20 and Fig. 21, respectively. Fig. 20 exhibits that the E2ED for O-LAR is minimal compared to the LEPR, D-LAR, and LAR protocols. The E2ED increases as the number of UAVs increases. The large number of UAVs in the route holds data packets, leading to higher E2ED. As shown in Fig. 20, the proposed O-LAR shows lower E2ED than the other existing protocols such as LEPR, D-LAR, and LAR. This is because the usage of the packet holding time is based on the residual energy concept.
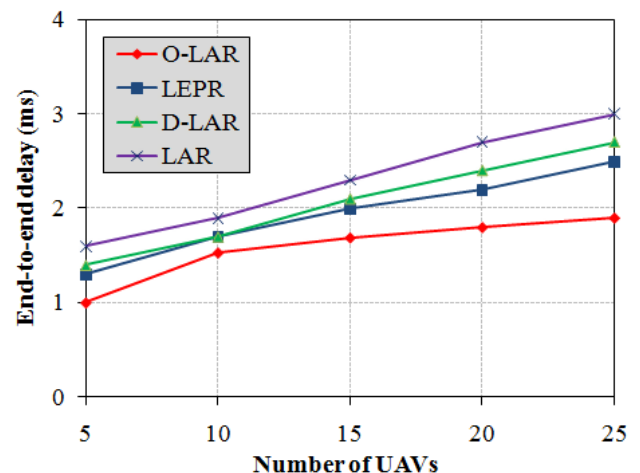

FIGURE 20. End-to-end delay versus Number of UAVs (speed 60m/sec).

Further, Fig. 21shows the impact of E2ED with a varying speed of ten numbers of UAVs. In general, the E2ED is turned for all protocols when the UAV speed increases because once the UAV speed goes up the link duration between the UAVs is reduced. Thus, the short period of the communication allows the UAVs to share a few data packets over the wireless connections. Moreover, if the source-

destination pairs are relatively closer to each other then, as consequence, the E2ED declines for O-LAR. Overall, O-LAR possesses a fairly good E2ED other than the state-of-the-art protocols.
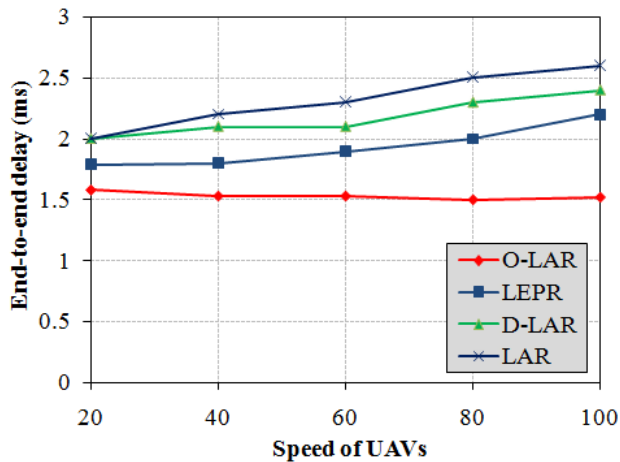

FIGURE 21. End-to-end delay versus UAVs speed

VI. CONCLUSION AND FUTURE SCOPES

FANETs are widely used in the modern era for military, civil and commercial applications. However, different issues can be faced for information dissemination between the UAVs in this network, such as the high mobility of the UAVs, the limited transmission range, the restricted residual energy, and the frequent breakdown of the link. To overcome these challenges in FANETs, we have successfully proposed and implemented an O-LAR protocol, which exploits the discovery phase to selects remarkable next-hop UAVs towards the destination UAV. The proposed O-LAR helps to establish a stable path for the highly dynamic nature of the network with some important metrics such as residual energy, distance, and the movement direction of UAVs. We have explained and evaluated the proposed O-LAR protocol mathematically. The proposed O-LAR protocol minimizes the average number of next-hop UAVs, improves the link duration between UAVs in the network. It is also reliable for information dissemination even in highly dynamic scenarios of UAVs such as 100m/sec. The simulation results proved the effectiveness of O-LAR over the existing protocols in terms of the routing metrics like expected link duration, average hop count, network lifetime, packet delivery ratio, routing overhead, average throughput, and end-to-end delay, respectively.

Although our simulation results are promising, still there is a great deal of work to be done in the highly dynamic mode of FANETs. Due to the high mobility of UAVs, sometimes localization in 3D space becomes more challenging and difficult for information dissemination between the nodes. Further, the size of the RZ in the proposed scheme can impact the performance of the network; for example, if the destination UAV is farthest away from the source UAV, the size of RZ increases, and hence it causes the maximizing of the routing overhead. Therefore, in future, more works are

required for the modification of RZ in O-LAR and the quality of data dissemination strategies for FANETs, especially in position-based routing fields.

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