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A Distributed Anticipatory Life-Enhancing Recovery Approach for Unmanned Aerial Vehicular Networks

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Abstract—Rapidly growing research in the field of Unmanned Aerial Vehicles (UAVs) has redrawn the application map for UAVs that now incorporates personal to public side applications apart from having just military domain within its boundary. Despite numerous practical advantages, UAVs systems are not utilized up to their full potential owing to the characteristics of higher mobility and limited lifetime of on-board batteries. In multi-hop real-time systems, abrupt movement or early depletion of energy resources for some overloaded UAVs may result in the creation of a network hole or even in a breakdown of the whole network. In this article, a new Life-Enhancing recovery Approach for a Multi-UAVs (LEAMU) network is proposed that not only provides a routing solution but also serves as a fail-safe method. The crux of the LEAMU is the identification of the best recovering UAV since the selection of an unhealthy UAV will result in more recovery requests afterward. In LEAMU, network hole creation is avoided beforehand through a distributed election of a suitable candidate keeping distance, remaining energy, neighborhood density, and traffic load factors into consideration. The proposed strategy is simulated and has shown to have a promising future for its integration into the existing UAV systems.

Index Terms—UAVs, UAVs routing, connectivity recovery, Energy efficiency, Multi-hop routing, Fail-safe method

I. INTRODUCTION

The ability of Unmanned Aerial Vehicles (UAVs) to fly over inaccessible and dangerous areas with great maneuvering skills has become the reason for providing highly feasible and economical solutions compared to their helicopter counterpart. Due to technological advancements, UAVs have developed into a mature technology, with its applications in several domains including but not limited to personal, defense, monitoring, disaster management, and rescue operations [1]. One of the use cases of UAVs is during natural disaster situations wherein these are usually deployed for rescue operation as well as for the temporary provision of network connectivity [2]. Spraying over different areas during the current pandemic of COVID-19 is the recent use case of UAVs wherein the social distancing rule is respected [3].

Despite the several advantages and expansion of its applications in several domains, UAVs having inherent limitations are still not utilized up to their full potential [4]. Inadequate

energy resources and short communication range of UAVs are among the major drawbacks that restrict the operational time and coverage area, respectively. The size constraints of a UAV itself restricts the maximum weight a UAV can carry that eventually results in shorter flight time [5].

In UAVs, maneuvering operation has the highest impact on energy consumption, leaving behind the communication part in second place [4]. Communication energy becomes the decisive factor considering all UAVs have a flight map with almost the same distance to cover. The communication load on any UAV largely depends upon the transmission distance and overhead generated due to the underlying MAC and routing protocols. The more is the transmission distance, the more will be the required transmitting power. Sometimes, a UAV close to a BS has to transmit its own data packets while at the same time acting as a relay for far away nodes that results in more energy consumption as compared to other UAVs.

Nowadays, the paradigm of using single UAV has been shifting to a swarm of UAVs that solve problems more efficiently [6]. Swarm of UAVs is more scalable and robust in comparison to single UAV offering limited coverage area with limited operational lifetime. UAVs in a collaborative manner, transmit packets hop by hop manner and are proven to be more energy-efficient due to a small distance between transmitting and receiving nodes. On the other hand, single UAV based networks are supposed to transmit at longer distances, which results in higher energy consumption.

The development of robust energy-efficient communication or routing protocol is inevitable due to the unique characteristics (e.g., high mobility and limited energy resources) imposed by UAVs. During any ongoing operation, there is no guarantee for all UAVs to be depleted in energy at the same time. For example, in a scenario where a UAV, being a part of an active path, suddenly leaves the network. The leaving reason could be either the fall of energy below the threshold level or sudden failure of the UAV. A routing protocol, like AODV [7], generates a router error message and based on the availability of an alternate UAV, the broken path is recovered. A routing protocol fails to tackle a path breakage scenario when a UAV

linking two parts of a network, called a cut-vertex UAV, dies out. In this situation, called network hole creation, a routing protocol remains unable to repair the damaged path due to the non-availability of nearby alternate UAVs. So, depending on the network topology, the removal of one or several more UAVs may blackout the entire network.

In this article, a new Life-Enhancing recovery Approach for Multi-UAVs (LEAMU) based networks is presented. LEAMU is a proactive routing approach that anticipates a network hole creation and takes necessary measures beforehand to prevent the system from a downfall. A cut-vertex UAV falling in its energy threshold level, called Leaving UAV (L-UAV), initiates a recovery request. A UAV responds to this request by broadcasting a Willingness Message (WM) in the entire network. This message contains distance (D) to L-UAV and its calculated Candidature Value (CV). While calculating CVs, each UAV keeps into consideration its remaining energy after joining L-UAV, neighborhood density, and data traffic load factors. The distance between L-UAV and its nearest candidate plus one transmission range distance defines a new election range. A UAV having the highest CV within this range qualifies for the replacement. Depending on the availability of nearby candidates, this election procedure is restricted to one-hop neighbors only. Direct one-hop neighbors take responsibility for the initiation of a recovery request during a sudden failure of UAV.

The remaining paper is organized as follows. Section II presents the related work in this field. Section III presents the core functionality of the proposed strategy. In Section IV, the LEAMU scheme is evaluated. The paper is concluded in Section V.

II. RELATED WORK

The first part presents classical routing protocols for UAV networks that are followed by state-of-the-art related to network connectivity repairing techniques.

On-demand Distance Vector (AODV) [7] is a classical reactive routing protocol designed for mobile ad-hoc networks. Path formation is on-demand and accomplished through the flooding of the route request message (RREQ). In a unicast manner, the reply to RREQ is made by an intermediate or destination node, and state maintenance is carried out using periodic hello messages. Sometimes, a higher number of RREQs in AODV may result in the overloading of a network with leaving no bandwidth even for themselves.

Predictive-OLSR (P-OLSR) [8] is an extension of the OLSR protocol [9] that takes advantage of GPS coordinates to predict the link quality. Hello message in the original OLSR is modified to share geographical position information among neighbors. Link quality information is included in the Topology Control (TC) messages that are distributed in the entire network. Unlike in OLSR, P-OLSR uses the direction and speed of the neighboring node along with the hop count factor in the route selection process. P-OLSR is suitable for rapidly changing topology and provides better multi-hop communication compared to OLSR.

Boids of Reynolds-AODV (BR-AODV) [10] is AODV based reactive routing protocol designed for UAV networks. In BR-AODV, AODV plays its part in route formation, while Boids of Reynolds is used to ensure connectivity among all the UAVs along the path. This connectivity is maintained until a path is needed, after which UAVs are allowed to follow their predefined map. BR-AODV is designed for dynamically changing networks and avoids generation of repetitive route discovery requests in the network.

Link-quality and Traffic-load Aware Optimized Link-State Routing (LTA-OLSR) [11] is a protocol for UAV ad hoc networks that takes into account link quality as well as traffic load. This scheme differentiates between the link qualities of a node with its different neighboring nodes. This link quality is estimated using a received signal strength indicator. Besides link quality, the load factor is also considered while finding an optimal path from a source node to a destination node. Buffer occupancy and channel contention information are used for the estimation of a traffic load.

In [12], the authors present a new fault-tolerant scheme for ad hoc robotic networks. As robotic movement is controllable so this inherent feature is utilized to move a subset of robots to have a reliable fault-tolerant topology. This technique tries to reduce the effect of cut-vertices through the creation of new edges by utilizing a movement control algorithm. To ensure a biconnected graph, leaf nodes are moved to cut-vertices that result in an overall increase in connectivity and an entire network's degree of fault-tolerance.

A simple Proactive Routing scheme with Multiple ground Base Stations deployment (PRMBS) [13] is a simple routing approach for UAV networks. Periodic Hello messages are broadcast from the BS and flooded in the entire network. Data packets take the reverse of a path taken by the hello message to reach the respective BS. This scheme is applicable work for any number of BSs, however, the overhead in the network will increase with the increase in the number of BSs hello message. In PRMBS, fault tolerance is provided by having connectivity with multiple BSs at the same time. This approach requires a massive initial investment to deploy multiple BSs.

In [14], a Connectivity Recovery algorithm for UAV Networks (C^3 RUN) is presented. C^3 RUN is based on Cooperative Communication (CC) to allow a quick repair of connectivity for UAV networks. In CC, neighboring nodes are the helping nodes that send analogous packets to the destination so that a destination can decode them by combing partial signals. In C^3 RUN, with the use of CC, long-distance communication links are established between different separated parts of the network. The use of CC not only makes it possible to have a quick recovery but also allows nodes to move to better places for the establishment of better CC links.

Most of the classical protocols like AODV and OLSR lack node failure recovery feature specifically during cut-vertex node failure or entire network breakdown scenarios. Some literature study is available on failure recovery for UAV networks, with most of them, like C^3 RUN, consider only distance-to-move parameter which can lead to the selection of

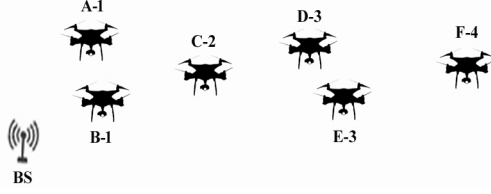


Fig. 1. Hop no. representation in a UAV network

low energy UAVs. These unwise selections of recovery nodes will result in more recovery requests later. To avoid frequent recovery requests, LEAMU makes a robust decision by considering the most influential factors like energy, neighborhood density, and traffic load factor besides having a distance-to-move factor only.

III. PROPOSED WORK

A highly dynamic UAV network imposes tough challenges for the designing of routing protocols. In this paper, we propose LEAMU that aims to maintain connectivity by replacing the failing UAVs. LEAMU distinguishes between the sudden failures from the announced departures of UAVs (low battery, etc.). A sudden UAV failure separates the network into two parts that result in the selection of two replacing UAVs. Announced departures, on the other hand, will determine only one best replacing candidate among other UAVs from the entire connected network.

A. Illustration of the Problem

In this subsection, we illustrate the problem we addressed in the paper through an example. In Fig. 1, a multi-UAV network with ground BS is considered. UAV C-2, at two hops away from BS, is a cut-vertex node. Any failure of this node will lead to the break down of the whole network. UAV C-2 can affect the network in two ways i.e., (i) occurrence of sudden physical (electronics or mechanical) failure, or (ii) announced departure. LEAMU keeps an eye on the link status of a cut-vertex UAVs, and tries to resolve any existing or forthcoming failure with the replacement of a suitable candidate.

B. Proactive Routing Strategy

In the proposed LEAMU scheme, soon after the network deployment, BS starts to broadcast periodic Heart Beat (HB) messages. These HB messages are similar to hello messages found in most of the routing protocols but flooded in the entire network with BS as a root. In LEAMU, at each UAV, Neighbors Table maintains the state of each direct neighbor. Table I presents the fields of Neighbors Table along with their respective definitions. Heart beat message transmission phase is explained in Algorithm 1. In this algorithm, \mathcal{F} is a boolean variable having true value if the immediate sender of the HB message is already available in Table I of the receiving UAV, and false otherwise. The second boolean variable \mathcal{S} is true when a new sequence number HB message is received at the receiving UAV, and false otherwise. HB message \mathcal{P} contains

Algorithm 1 Heart Beat Message Transmission

Input:

1: $\mathcal{F}, \mathcal{S}, \mathcal{P}, Hopno$

Output: $Broadcast(\mathcal{P})$: Broadcast this packet \mathcal{P} among one hop neighbors

2: **if** $\mathcal{F} = true$ **then**

3: Update neighbor entry in Table I

4: **else**

5: Insert new neighbor entry in Table I

6: **end if**

7: **if** $\mathcal{S} = true$ **then**

8: Update my own $Hopno$

9: Update packet fields and $Broadcast(\mathcal{P})$

10: **end if**

the immediate sender's address, GPS coordinates, and the hop number information. For any UAV, $Hopno$ variable keeps the number of hops value to reach BS.

BS sets its $Hopno$ to "0" and broadcasts \mathcal{P} among its one hop neighbors. Any UAV receiving this message updates Nbr_ID , Hop_No , $Link_Status$, $Link_Expire_Time$, and $Nbr_Position$ fields in the Neighbors Table for the immediate sender of this message. If the sequence number of the received message matches with the already received HB message, no further action is taken. However, after the reception of HB message with a new sequence number, $Hopno$ is updated with a value one higher than the received one and the HB message is rebroadcast among its one hop neighbors while updating its fields. This advancement is continued until HB message is received by every UAV in the network. At the end of each HB message transmission phase, each UAV gets updated about its neighbors. The hop number assigned to each UAV by this process is presented in Fig. 1 as an example.

C. Anticipatory Recovery Algorithm

Let U be the set of all UAVs in a network. We define a function h that returns, for each UAV u_n ($1 \leq n \leq N$), its hop number, wherein n is a UAV identity and N is the total number of UAVs in a network. We also define Z_n as a set of neighbor UAVs which belong to the u_n 's Table I entries. A node u_n is in the set of cut-vertex nodes B if its failure may result in a permanent disconnection, for at least one UAV, from the BS.

Any UAV u_n initiates a Recovery Message (RM) if $u_n \in B$

TABLE I
FIELDS OF NEIGHBORS TABLE

Field	Definition
Nbr_ID	The unique address of Neighbor
Hop_No	Hop number of neighbor with address Nbr_ID
$Link_Status$	A flag, having value 1 if $Link_Expire_Time$ field is not expired yet, 0 otherwise
$Link_Expire_Time$	Expire time of link with neighbor (Nbr_ID)
$Nbr_Position$	Neighbor's (Nbr_ID) current position

Algorithm 2 *Recovery Message Transmission*

Input:1: $\mathcal{R}, \mathcal{RM}, \mathcal{D}$ **Output:** *Broadcast*(\mathcal{RM}): Broadcast this packet \mathcal{RM} among one hop neighbors

2: Update neighbors information for Nbr_ID in Table I

3: **if** $\mathcal{R} = false$ **then**4: **if** $\mathcal{D} = false$ **then**5: *Broadcast*(\mathcal{RM})6: **end if**7: $\mathcal{R} \leftarrow true$ 8: **end if**

and its energy level falls below a certain threshold value or it detects a sudden failure of its neighboring UAV belonging to set B . RM contains L-UAV's GPS coordinates and its identity as a sequence number. Broadcasting of RM serves two purposes i.e., (i) notify all UAVs to get ready for participation in replacement election, and (ii) UAVs get recent information about their neighbors. RM transmission procedure is presented in Algorithm 2. In this algorithm, \mathcal{R} becomes true whenever a node gets its first unique sequence recovery message \mathcal{RM} from any of its neighbors. \mathcal{D} is a variable having true value if a UAV is a direct neighbor of L-UAV and at least have one equal hop number UAV within its neighbors, and false otherwise. After reception of the first \mathcal{RM} , each UAV having false \mathcal{D} value rebroadcasts the received message within its one hop neighbors.

After the RM transmission phase, a UAV u_n with $u_n \notin B$ shows its willingness to replace L-UAV through broadcasting WM in the whole network. This message is composed of its distance to L-UAV and CV. The Haversine formula, presented in equation 1, is used to calculate the great-circle distance D_n from UAV u_n to L-UAV. In this equation, Φ_n and Φ_L are the latitudes (in radian) of u_n and L-UAV, respectively. R is the earth radius, while, ϕ_n and ϕ_L are the longitudes (in radian) of u_n and L-UAV, respectively.

$$D_n = 2R \arcsin \left\{ \sin^2 \left(\frac{\Phi_n - \Phi_L}{2} \right) + \cos(\Phi_n) \cos(\Phi_L) \sin^2 \left(\frac{\phi_n - \phi_L}{2} \right) \right\}^{1/2}, \quad (1)$$

For UAV u_n , MT is the time required to go from u_n 's current position to L-UAV's position and once the D_n is calculated, $(MT)_n$ can be calculated using equation 2, wherein v is the recovery speed.

$$(MT)_n = \frac{D_n}{v}, \quad (2)$$

E_{D_n} is energy that will be utilized by u_n in going from u_n 's current position to intended L-UAV's position. This energy consumption can be computed using energy model presented

in [15]. Assuming u_n is moving horizontally with constant speed v . The required thrust T_n is given by equation 3.

$$T_n = \sqrt{(mg)^2 + \left(\frac{D_a A_f v^2 C_d}{2} \right)^2}, \quad (3)$$

In equation 3, m is the mass of a UAV, g is gravitational acceleration, D_a is the density of air, A_f is the front cross-sectional area of a UAV, v is horizontal recovery speed, and C_d is a drag coefficient. Now, the power P_n required to generate the thrust T_n , is given by equation 4.

$$P_n = T_n \times v, \quad (4)$$

So, E_{D_n} utilized during the time $(MT)_n$ is given by equation 5.

$$E_{D_n} = P_n \times (MT)_n = T_n \times v \times (MT)_n, \quad (5)$$

From Eq. 2 and Eq. 5, equation 6 can be derived as

$$E_{D_n} = T_n \times D_n, \quad (6)$$

Now, CV at UAV u_n is calculated using equation 7 in which $E_{R_c}(n)$ and $E_I(n)$ are the current remaining and initial energy for u_n , respectively. $P_C(n)$ is the number of packets currently transmitted by u_n and P_{Max} is the total number of packets allowed to transmit by any UAV. P_C value is reset after UAV system moves to a new position from the predefined positions set. $N_T(n)$ is the total number of active neighbors for u_n and N_{Max} is the total number of allowed neighbors restricted by topology. In equation 7, α , β , and γ are the weight factors.

$$(CV)_n = \alpha \left(\frac{E_{R_c}(n) - E_{D_n}}{E_I(n)} \right) - \beta \left(\frac{P_C(n)}{P_{Max}} \right) + \gamma \left(\frac{N_T(n)}{N_{Max}} \right), \quad (7)$$

The highest priority given to α means the election of a reliable candidate with an excessive amount of remaining energy. More preference to β elects a UAV having less involvement in data transmission that ultimately leads to the lesser effect on other mostly used links. A topology is less likely to be affected if a candidate with the highest neighborhood density (i.e., higher γ) is selected. Removing a UAV from a higher neighborhood density also reduces overhearing wastage for the removed UAV.

Soon after the calculations of D_n , $(MT)_n$, and $(CV)_n$, each UAV u_n with $u_n \notin B$ broadcasts WM in the entire network. Each UAV maintains a 3-tuple $(n, (CV)_n, D_n)$ to record WMs received by all other UAVs. In this 3-tuple, n is the address of UAV that originated this WM. All intermediate UAVs receive, record in their 3-tuple, and rebroadcast the received message further. After the exchange of WMs, the distance between L-UAV and the nearest candidate plus one transmission range becomes a new election range. A candidate having the highest CV within this range qualifies for the selection. The selected candidate moves autonomously to the position of L-UAV with the coordinates already provided by the RM. During the availability of nearby replacing candidates, the election

mechanism restricts itself solely to direct neighbors of L-UAV.

D. Path Selection Criteria

Path selection criteria for the data packets is very simple. A UAV looks for a lower hop number UAV than itself having true value for *Link_Status* and the highest *Link_Expire_Time* value within its Table I.

IV. PERFORMANCE EVALUATION

To justify the assumptions made by the proposed LEAMU approach and to investigate its performance compared to state-of-art connectivity recovery protocol, we simulated LEAMU and C³RUN [14] in Network Simulator-2. The assessment of the protocols is based on three metrics: (i) number of packets received at BS with respect to time to validate the end-to-end link continuity, (ii) distance moved by replacing candidates to reach L-UAV from their current location, and (iii) average communication overhead in terms of energy.

In this simulation, a predefined topology set of UAVs is considered with single ground base station deployment. Total 17 UAVs were taken for the obtained results. The performance evaluation contains results for three experiments run under different scenarios. All sudden physical (electronics or mechanical), all energy depletion (announced departures), and the mixture of the first two failures are considered in Experiments I, II, and III, respectively. Values 0.6, 0.2, 0.2 were taken for α , β , and γ , respectively. Each UAV is equipped with an omnidirectional antenna. For the simulation of these protocols, *Two Ray Ground propagation* model is used for communication. The remaining simulation parameters are listed in Table II.

A. Experiment I

All the failures in this experiment occur due to the removal of UAVs owing to electronics or mechanical failures. To evaluate the end-to-end link continuity, we plotted the number of packets received at BS against simulation time in Fig. 2. Any horizontal line in the plot indicates link breakages while any non-zero slope line indicates data packet reception at BS, and eventually, the continuity of end-to-end link. LEAMU performance in this experiment is comparable to C³RUN as it aims for the best candidate even if it has to select a far away UAV that results in a longer repairing time. Moreover, due to sudden failures of UAV, the anticipatory effect of LEAMU gets

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Network size	4000 m x 4000 m
Speed of UAV during recovery	15 m/s
Transmission range of each node	500 m
Size of each packet	200 Byte
Traffic Type	CBR
Simulation time	2300 sec
MAC protocol	Mac/802_11

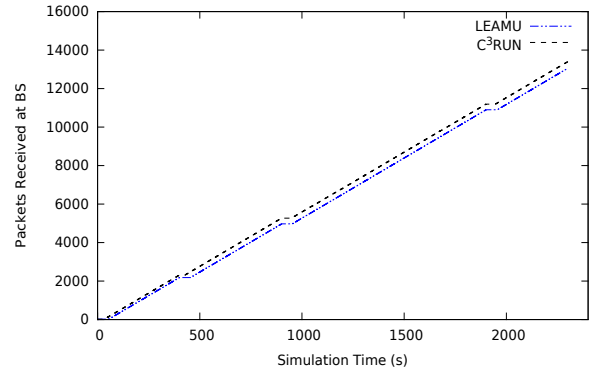


Fig. 2. Number of Packets Received at BS with Time (Exp. I)

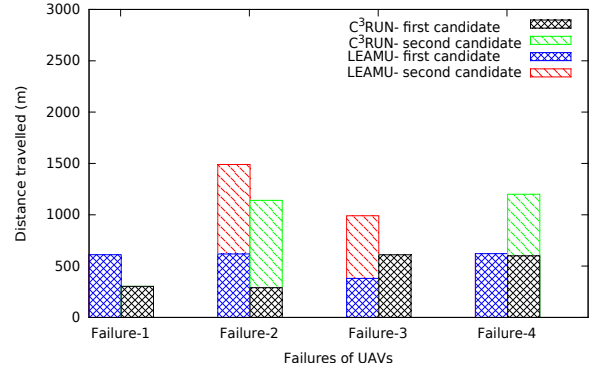


Fig. 3. Distance traveled by replacing UAVs (Exp. I)

nullified. C³RUN, on the other hand, makes a quick recovery because it selects the first nearest available candidate.

For each specific failure, Fig. 3 shows the number of replacing UAVs moved along with the total distance traveled for replacement. In this figure, *Failure-1* results in a displacement of only one UAV for both the compared schemes. Replacing UAV travels 302 m and 611 m for C³RUN and LEAMU, respectively. For the case of *Failure-2*, LEAMU's first candidate travels a distance of 618 m and the second candidate travels 872 m, making 1490 m in total. C³RUN, on the other hand, selects its first and second candidates at 290 m and 850 m, respectively, making a total of 1140 m. For *Experiment I* with four registered failures, both schemes result in the movement of six UAVs and a total distance of 3712 m and 3252 m for LEAMU and C³RUN, respectively. Due to the technological growth in the domain of UAVs, these kinds of sudden failures occur very rarely.

B. Experiment II

This experiment considers UAV's failure arising due to the depletion of energy resources owing to which it leaves the network (announced departure). Fig. 4 shows the end-to-end link continuity by plotting the number of packets received at BS against simulation time. LEAMU exploiting its anticipatory feature up to its full potential can be inferred from this figure. LEAMU keeps an eye on the energy resources

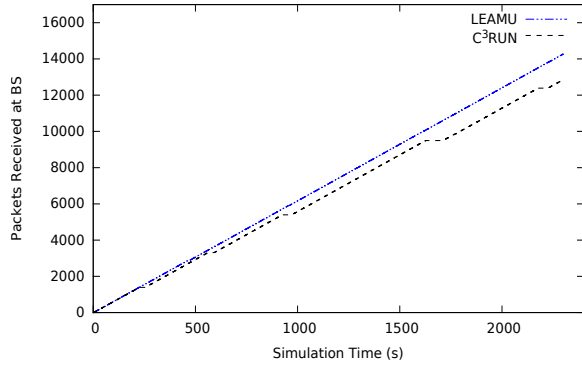


Fig. 4. Number of Packets Received at BS with Time (Exp. II)

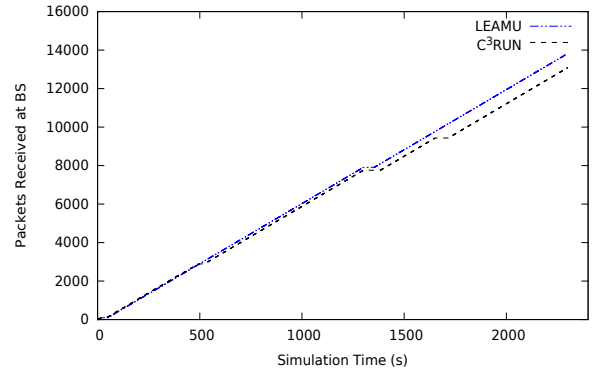


Fig. 6. Number of Packets Received at BS with Time (Exp. III)

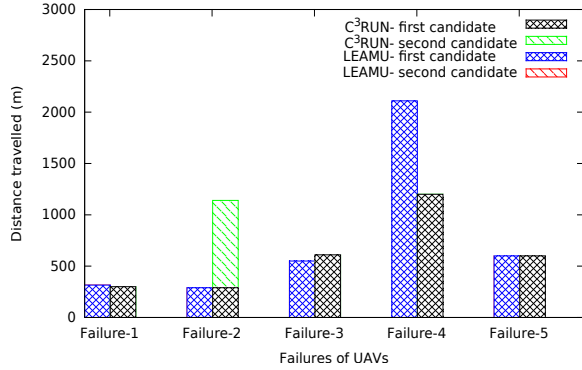


Fig. 5. Distance traveled by replacing UAVs (Exp. II)

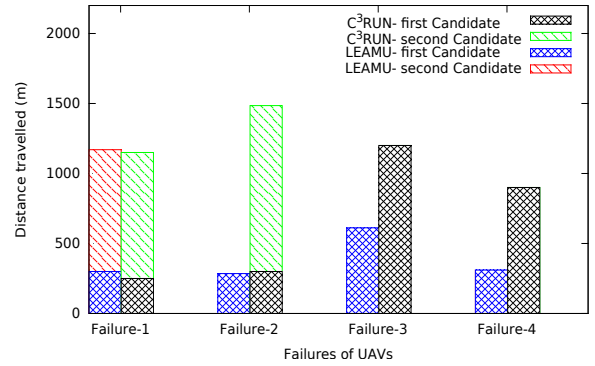


Fig. 7. Distance traveled by replacing UAVs (Exp. III)

of all the cut-vertex UAVs and initiates a recovery before they leave the network. Fig. 4 verifies that despite having five UAVs failures, LEAMU ensures continuity of the end-to-end link because it anticipates the failure occurrence and takes action in advance. C³RUN, on the other hand, initiates a recovery at the time of failure that results in a discontinuity of the end-to-end link.

Fig. 5 shows the distance moved by replacing candidates in *Experiment II*. The positive aspect of LEAMU's anticipatory recovery is the availability of the whole network connectivity during the replacing candidate election mechanism. LEAMU selects only one suitable candidate from the entire network and replaces the leaving UAV before its actual departure. C³RUN finds the network partitioned into two clusters during a failure scenario. It selects one or two replacing UAVs depending upon the availability of candidates in both the clusters. During the five failures in this experiment, replacing UAVs in LEAMU and C³RUN traveled nearly 3800 m distance with five and six UAV movements, respectively.

C. Experiment III

To make the simulation replica of a real-world scenario, we mixed two failures, i.e., sudden and announced departures, in this experiment. Fig. 6 depicts the end-to-end continuity for this experiment for both the simulated schemes. This figure reveals the effectiveness of the anticipatory part and

robustness of candidate selection in LEAMU. Fig. 6 shows that LEAMU has more continuity of the end-to-end link as compared to C³RUN in which a recovery mechanism initiates only with the occurrence of a UAV failure. LEAMU, on the other hand, anticipates the failure of a cut-vertex UAV and brings a replacing UAV near to it before its actual departure. The moment the failing node leaves the network, a replacing UAV takes charge that results in the continuity of the end-to-end link.

Fig. 7 presents the total distance traveled by the replacing UAVs. LEAMU and C³RUN travel 2377 m and 4735 m total distance along with 5 and 6 UAV movements, respectively. C³RUN selects the nearest available options without considering their remaining energy resources which results in an another recovery request at a later time. For *Failure-1* in Fig. 7, the sudden failure occurrence results in the selection of two replacing candidates by LEAMU. For the following cases, the anticipation feature provides the opportunity to do the election campaign within the entire connected network resulting in the selection of only one robust candidate.

D. Average Energy Consumption of Communication Overhead

In Fig. 8, we plotted average energy consumptions of communication overhead for the three experiments to assess the burden imposed by the simulated recovery schemes on the network. LEAMU scheme turns up to be an energy-efficient

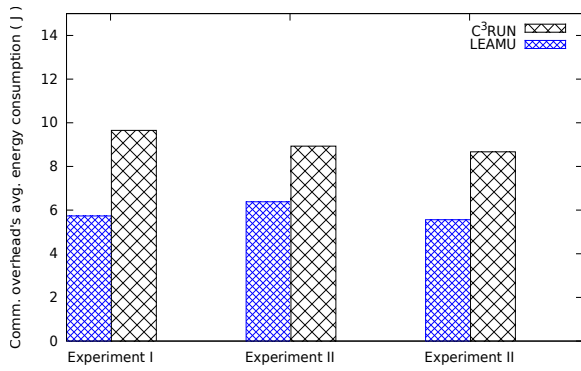


Fig. 8. Average energy consumption of communication overhead

solution owing to be having just HB messages with BS as a root. C³RUN, on the other hand, periodically transmits its neighbor's information among its direct neighbors in addition to periodic hello messages. LEAMU shows almost the same energy consumptions expect in *Experiment II* in which all the candidates transmit their CV value in the entire network resulting in a bit higher energy consumption.

The performance of LEAMU remains better as compared to C³RUN except for *Experiment I* in which it shows comparable results. Thanks to technological advancements in the domain of UAVs, sudden failures (*Experiment I*) occur very rarely that leads us to conclude that LEAMU's overall performance is better in all failure scenarios compared to C³RUN.

V. CONCLUSION

Network recovery in a distributive manner is the cornerstone of the proposed LEAMU scheme that is a desirable feature in AdHoc networks. LEAMU not only provides routing services but also acts as a fail-safe method during UAV failure scenarios. The anticipation of a forthcoming UAV failure and replacement of a suitable candidate in advance ensures a better end-to-end link continuity. This feature also facilitates LEAMU to run the election campaign in the entire network and come up with a single robust candidate to avoid frequent recovery requests arising due to the selection of unhealthy replacing UAVs.

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