

Supporting Seamless Connectivity in Drone-assisted Intelligent Transportation Systems

Nico Saputro, Kemal Akkaya and Selcuk Uluagac

Dept. of Electrical and Computer Engineering, Florida International University,

Miami, Florida, 33174, USA

{nsapu002, kakkaya, suluagac}@fiu.edu

Abstract—Considering emergency scenarios for intelligent transportation applications, we propose a swarm of drones communication architecture that can sustain connectivity to assist the authorities for damage assessments. The connectivity sustenance needs stem from the fact that drones may move to various locations in response to service requests from the authorities but they still need to cooperate for data collection and transmissions. To address this need, we propose a centralized connectivity maintenance heuristic which will enable the swarm to dynamically adapt its formation in response to the service requests while ensuring uninterrupted live assessment reports. To select the moving drone(s), the minimum connected dominating set concept is utilized to come up with three strategies of mixed stretching or moving heuristic for the connectivity restoration. The proposed architecture and heuristics are implemented in ns-3 network simulator and the effectiveness is tested in terms of providing undisturbed services under heavy multimedia traffic. The results indicate that the proposed approaches enable uninterrupted multimedia traffic delivery.

Index Terms—Drones; ITS; IEEE 802.11s, connected dominating set

I. INTRODUCTION

The road transport system can be affected, either indirectly or directly, by the human-induced disasters (e.g., accidents) and natural disasters (e.g., floods, power outages, earthquake, etc). Therefore, it is imperative for the transportation authorities to quickly perform the disaster assessment while continuously notifying vehicles around the area for the situation awareness, and then perform the restoration actions to prevent any subsequent transportation issues (e.g., heavy traffic congestion, traffic accident, etc.) and to recover road services.

The transportation authority can perform the damage assessment and notification actions by utilizing the available Intelligent Transportation System (ITS) applications. To notify vehicles surrounding the area, the dynamic message boards located above the road or Roadside Units (RSUs) can be used to continuously disseminate the public safety messages to vehicles. However, for some cases, the disasters may cause not only the road infrastructures damages (e.g., traffic signs, traffic lights, RSU, etc), but also can affect the infrastructures and services from the telecommunication and power companies. Therefore, recently, Unmanned Aerial Vehicles (UAVs) or drones, have been envisioned as one of the tools that may provide the aforementioned services due to their ability for easy deployment, hovering capability, and bird's-view-from-the-sky features. [1][2][3]. In particular, a swarm of drones as

used in many other civil applications such as for archaeological site mapping [4], and natural disaster management [2] can also be applied to our ITS setting.

In such a setting, the drones may be requested to move to certain spots temporarily to capture videos or act as relays for any incoming traffic from the ground. However, at the same time, these drones need to be maintaining their group ties so that they can enable communication not just among themselves but also with remote control center(s) through a cellular communication link. Therefore, there needs to be a close coordination among the drones to sustain these services in a seamless manner.

In this paper, we consider a drone-assisted intelligent transportation system application that utilizes a swarm of autonomous drones to assist multiple parties (e.g., transportation authority personnel, emergency medical teams, fire rescue, police, etc.) for providing timely evaluation and response to any emergency road-related events with limited cellular communication support and investigate the ability of this swarm in terms of providing undisturbed services to various parties. To this end, we propose two centralized heuristics that will enable seamless connectivity among the drones for service sustainability: 1) A Minimum Connected Dominating Set (MCDS) heuristic for the moving drone selection. The drone that will move to another service area is selected in such a way that it will not cause major topology changes in the initial swarm; and 2) Another heuristic for connectivity restoration problem that can be used to enable the swarm to dynamically adapt its formation in response to the multiple drone movement requests with the minimum drone traveling distance and without disrupting the on-going transmission. In this case, any topology changes that may be caused by the movement of the selected drone is handled. Note that the minimization of movement distance is crucial to increase the lifetime of the swarms as any movement will put a major burden on the battery.

We utilize the swarm communication architecture in [5], which utilizes three communications technologies: (1) IEEE 802.11p [6] is proposed for the communications between vehicles and drones; (2) IEEE 802.11s [7] wireless mesh network is used to support the internal swarm communications; and (3) LTE [8] public cellular network is used for the long-range communications between drones in the swarm to the control center and/or other parties through a *flying gateway*. Under

this communication architecture, the tackled MCDS problem is different than the traditional one of just finding any MCDS in the swarm as we must include the *flying gateway* as a member of the MCDS. The other challenge stems from the 3-D nature of the MCDS formation that has been done in 2-D settings in the literature.

We implemented the proposed swarm communications architecture and protocol under ns-3 network simulator [9]. The performance of the proposed swarm application and the video quality are evaluated using the EvalVid tool-set [10]. The simulation results demonstrated the feasibility of the proposed drone-based ITS.

The paper is organized as follows. In Section II, we discuss the relevant work while Section III describes the drone communications architectures and the authorization and access mechanism of the proposed system model. Detailed performance evaluation of the proposed model is given in Section IV. Finally, we conclude the paper in Section V.

II. RELATED WORK

Our work addresses the leaving node selection and expanding the connectivity to a new location problem by utilizing Connected Domination Set (CDS) and the connectivity restoration-based heuristic approaches. Therefore, the works that related to ours are the works that based on CDS and connectivity restoration, the two research areas that have been intensively studied in Wireless Sensor Network (WSN) for years. In WSN, CDS has been used to form an underlying virtual network architecture that can be used for various applications such as media access coordination; unicast, multicast/broadcast, and location-based routing; energy conservation, and topology control [11]. Finding the minimum connected dominating set problem is NP-complete [12]. Hence, the proposed algorithms used for those applications are typically greedy-based approximation algorithms. Many of these greedy based approaches are motivated by the two proposed greedy heuristics for the general graph from Guha and Khuller [13]. Our work that proposed a greedy-based heuristic for the considered moving drone selection is motivated by their work as well. However, our work has some differences when compared to their work. Our work takes into account the inherent hard and soft constraints of the moving drone selection problem due to the different roles of the nodes. These roles require that some nodes must be in the virtual backbone, and some other nodes have the higher priority than other nodes during the selection process. To the best of our knowledge, no previous greedy-based approaches in the WSN applications that considered these role-based constraints in their virtual backbone construction process. Section III-D explains these constraints in detail.

Similarly, connectivity restoration also has been studied in WSN for years to address the failure node problem, which may cause the disjoint segments in the network and hinder the WSN operations. The proposed approaches in WSN can be classified as the proactive and reactive approaches [14]. Proactive typically strives to provision resources at the setup

by introducing redundant nodes as spares while reactive strives to provide the real-time restoration of the lost connectivity. With respect to these two types of approaches, our proposed greedy can be considered as the reactive part, which strives to expand the connectivity to the new location.

In WSN, the reactive approaches can be divided into three categories [14] by utilizing: (1) nodes that are part of the network by re-positioning them; (2) stationary relay nodes; and (3) mobile relay nodes to minimize the number of stationary relays by providing intermittent links. Our proposed heuristic connectivity restoration can be viewed as a combined effort from the previous two categories. Our proposed heuristic basically strives to utilize the existing nodes that are part of the swarm by re-positioning them, either by re-positioning one or more non virtual-backbone nodes as relay node(s) in between the node in the new location and the closest virtual-backbone node to this node; or by stretching some of the virtual-backbone nodes' locations toward the new location node.

Examples in WSNs that can be viewed to be a similar idea to our stretching approach are the cascaded node relocation movement [15] and the shifted node relocation method [16]. Both approaches rely on the presence of redundant sensor node(s) in the network that can be used for any sensor node replacement(s) to maintain the network's coverage. They are different, however, in the way they find the replacement node and perform the node relocation. In [15], we can obtain the information on all nodes directly that can be used in the replacement node selection since they are active nodes that involve in the current network activities. In [16], however, we need to get it from a proxy node since they are in-active nodes that sleep periodically to conserve energy and not involve in the current network activities. After the replacement node is selected, path discovery is used to construct a relocation path between the failed sensor node and the selected replacement sensor node. Then the node relocation is performed to all the intermediate nodes' positions along this path (including the replacement sensor node's position by shifting toward the failed node. While in [15], the shifted relocation process begins after the relocation path construction, in [16], the relocation path discovery and the node relocation are performed in parallel to reduce the relocation latency. In our approach, however, the relocation path discovery is part of the leaving node selection heuristic that takes into account the different node' roles when finding the candidate for the leaving node. The heuristic creates the virtual backbone and also provides the relay node candidate(s). This virtual backbone is the relocation path for our stretching approach. When selecting the nodes along this path for shifting, our approach also takes into account the hard and soft constraints as explained in Section III-D while ensuring uninterrupted on-going transmissions. Thus, not all nodes in the relocation path are shift-able. In this case, the stretching approach will select the relay node candidate(s) that will be moved to fill the gap between the node in the new location and the virtual backbone to ensure connectivity.

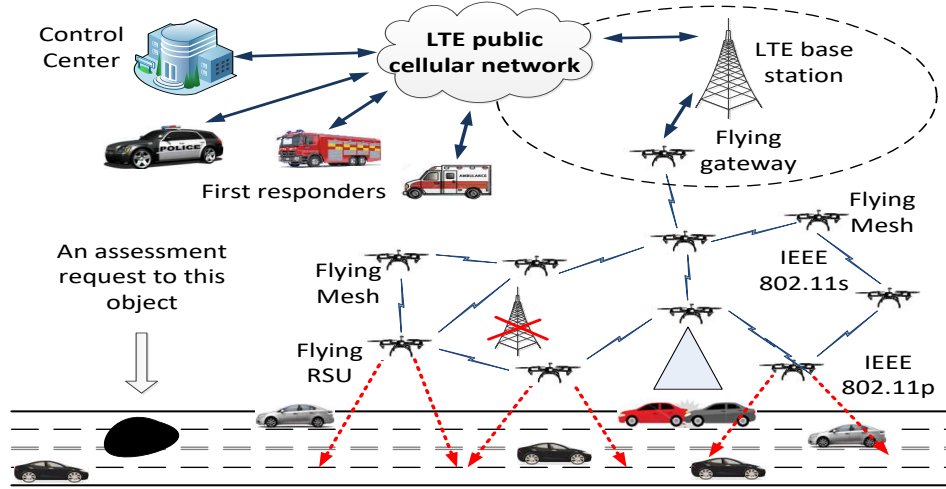


Fig. 1: The connectivity and sustainable service-aware moving drone selection problem. A drone needs to be selected from the swarm to do the damage assessment to a new location.

III. DRONE-ASSISTED INTELLIGENT TRANSPORTATION SYSTEM

In this section, we first describe the overview of the system model. Then, we present the problem formulation and the proposed detailed solutions. The detailed communications protocol and two proposed heuristics are explained in this section.

A. System Overview

The proposed swarm of drones is used to assist the first-responder personnel, who may come from multiple parties, to perform the initial assessments remotely by utilizing various drone's onboard sensors and camera to collect the visual and other relevant information from the objects of interests. In the area of interest, which can be large, the LTE public cellular network coverage may not be available in every spot (e.g., the LTE base station is damaged). In this case, the deployed drones form an IEEE 802.11s Wireless Aerial Mesh Network (WAMN) to cover this blank spot area. Each member of the WAMN is called as the *flying mesh*.

The drone deployment must be done such that at least one of the *flying meshes*, is under the coverage of an active LTE base station. In this case, this *flying mesh* uses two communications protocols (i.e., IEEE 802.11s and LTE) and becomes the *flying gateway* for the WAMN. The default path selection mechanism in IEEE 802.11s, the Hybrid Wireless Mesh Protocol (HWMP) [7], is used in the WAMN. HWMP has two path selection modes: (1) on-demand that enables peer-to-peer communications between drones; and (2) proactive tree that requires the presence of a root node in order to build a tree that connects all drones in the mesh to the root node. In this case, the *flying gateway* also acts as the root node in the WAMN.

Two other types of drones that use more than one communication protocols (i.e., IEEE 802.11s and IEEE 802.11p) are the *flying RSU* and the *flying investigator*. Both types of drones act as the RSU for the drone-to-vehicle communications.

Additionally, the *flying investigator* can sense the area or inspect infrastructure using one or more on board sensors (e.g., visual sensors, ultrasound sensors, high definition video, etc). We envisioned that each drone is equipped with a sustainable power source (e.g., solar cell, other types of energy harvesting devices) and an onboard GPS. Note that the GPS coordinate information in terms of Geographic latitude and longitude will be converted to the Cartesian coordinate (x, y, z) . Additionally, each onboard sensor and communications technology in the drone can be activated/deactivated on demand.

B. Problem Formulation and Contribution

We assume a swarm of N autonomous drones that form a connected mesh network G . Each drone in G has been assigned to one of the following roles $R = \{\text{flying gateway}, \text{flying investigator}, \text{flying RSU}, \text{flying mesh}\}$. Let $N_g(t)$, $N_i(t)$, $N_r(t)$, and $N_m(t)$ be the number of drones in the swarm at any given time t that has the *flying gateway*, *flying investigator*, *flying RSU*, and *flying mesh* roles respectively, $N_g(t) + N_i(t) + N_r(t) + N_m(t) = N$, and $N_g(t) = 1, \forall t$ since only a single drone can have the non-transferable *flying gateway* role all the time.

On receiving k disaster assessment requests to k locations at time $(t + 1)$, $k \ll (N_r(t) + N_m(t))$, then the problem of **connectivity and sustainable service-aware moving drone selection** can be formulated as follows (as illustrated in Fig. 1: *How to select k drones from G subject to (1) $(N_g(t) + N_i(t))$ drones cannot be selected for moving; (2) $N_i(t)$ on going video transmissions are not interrupted; (3) k new video transmissions can be delivered to the requester; and (4) the total traveling cost C_t is minimum. This cost consists of C_k , the traveling cost of moving k drones to their new locations, and C_s , the traveling cost of shifting other drones (if any) in the swarm such that the swarm new formation is also a connected mesh network G' .*

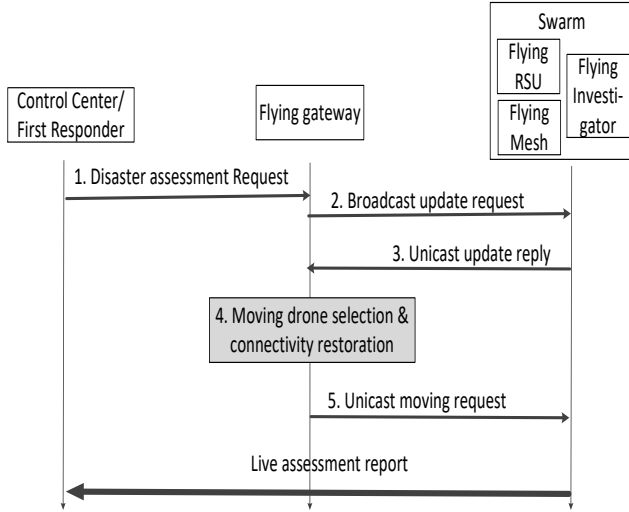


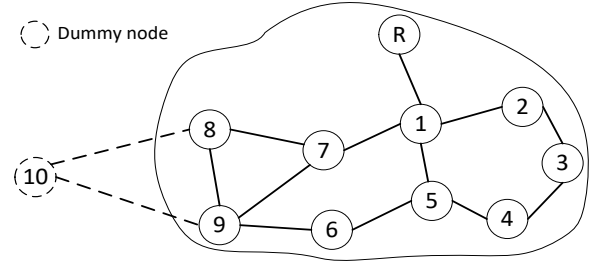
Fig. 2: Proposed swarm message exchanges.

We consider the **connectivity and sustainability service-aware moving drone selection** problem as two sub-problems: the moving drone selection problem and the connectivity restoration problem. We propose a greedy-based heuristic solution for each sub-problem. The MCDS heuristic is proposed for the moving drone selection problem and the connectivity restoration heuristic is proposed to find the set of movements for maintaining the mesh network connectivity. The details of the proposed mechanisms are discussed next.

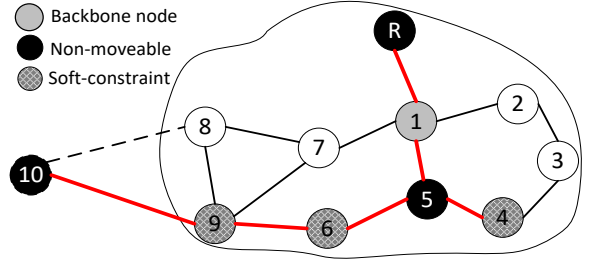
C. Centralized Swarm Control Protocol

In our proposed scheme, the *flying gateway* is the central coordinator for the swarm. It receives the disaster assessment request to a specific location from the control center/first responders, determines which drone(s) should be moved, and then informs the selected drone(s) to move to the desired position(s) as well as the role in the new location. Fig. 2 shows the message exchanges between the *flying gateway* and the rest of the drones in the swarm. In the disaster assessment request, the requestor (i.e., control center/first responders) must specify the expected role (e.g., *flying investigator* or *flying RSU*) and the target location. The *flying gateway* requests an update from all drones about their current positions, roles, and their connected neighboring nodes in order to create the existing connected mesh network G .

On receiving the broadcast update request from the *flying gateway*, each drone can provide its current location from the onboard GPS (in terms of Cartesian coordinates) and its currently connected neighboring drones from the IEEE 802.11s peering mechanism [7]. We would like to recall that an IEEE 802.11s mesh network is formed by the discovery and peering mechanisms. Every mesh node needs to send periodically a small one-hop management frame called *beacon* to announce its presence to its surrounding. A peer link between two neighbor nodes can be established after a successful mesh peering mechanism. Each mesh node can establish a peer link with multiple neighbor mesh nodes.



(a) An example of the graph representation of the swarm formation and the new location of the moving drone from Fig. 1.



(b) An example of the selected virtual backbone nodes (i.e., dominators): (R, 1, 4, 5, 6, 9, 10). Nodes (2, 3, 7, 8) (i.e., dominees) are candidates for the moving drone.

Fig. 3: The illustration for the proposed heuristics of MCDS: a) The connected mesh network G ; b) the heuristics MCDS finds the virtual backbone and selects node 8 as the moving node since it has the minimum traveling cost. Node ID 9 is the closest virtual backbone node to the dummy node.

Based on the received update reply messages, the *flying gateway* creates a temporary graph G_1 that consists of the existing connected mesh network G and the new location(s) for the selected moving drone(s).

In this case, we propose to use a dummy node to represent the new location. To create a connected graph G_1 , the dummy node is assumed to be connected to its nearest nodes in G in one hop, regardless of its actual distance to the nearest nodes in G . To determine the nearest nodes of the new location, the Euclidean distance to the new location is used. In this case, the Euclidean distance from each node to the new location is calculated and then sorted in ascending order. A node is selected as the nearest node to the new location if the Euclidean distance $\leq$ two times the transmission range. If no node is selected based on this criterion, the first node in the sorted list is selected.

Fig. 3a shows an example of the graph G_1 that represents the connected mesh network of the swarm and the new location for the moving drone in Fig. 1. This graph G_1 will be used by the MCDS heuristic to select the drone that can be moved to the new location as explained next. Note that even though the drone coordinate is in 3-D, we draw the graph in 2-D for the presentation simplicity and clarity.

D. Heuristic for the Minimum Connected Dominating Set

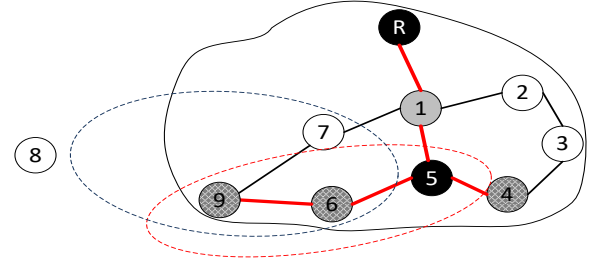
The main idea of our proposed heuristic is to find a virtual backbone that connects all the *flying investigators* (including the new location) to the *flying gateway* and then select the *flying mesh* that is not part of the virtual backbone with the minimum distance to the new location as the moving drone. In building the virtual backbone, the *flying RSU* has a higher priority to be selected in the backbone than the *flying mesh*. In case where finding the *flying mesh* as the moving drone is not possible because all of the *flying meshes* are part of the virtual backbone, a *flying RSU* can be considered as a soft constraint and it can be selected as the moving drone if more than one of its directly connected drones are *flying RSUs* or *flying investigator* (i.e., there are more than one drones serving as RSUs in its adjacent area). In other words, we need to select an MCDS C of G_1 that induces a connected subgraph of G_1 such that all non-moveable nodes must be in C (i.e., hard constraint) and the soft-constraint node is more preferable to be selected in C rather than the mesh nodes. Fig. 3b shows the selected virtual backbone C (i.e., dominators) of G_1 and the selection of node 8 as the moving node. Additionally, since the new location is now part of the virtual backbone C , the closest virtual backbone node to this new location can be identified as well (e.g., node 9 in Fig. 3b).

The next step after selecting the moving node is to check whether after the selected node is in its new position, a connected mesh network, G' , can be built. If this is not the case (i.e., the new location is not within the transmission range of the closest node in the graph) and there will be more than one connected graphs, then the heuristic connectivity restoration algorithm kicks-in as explained next.

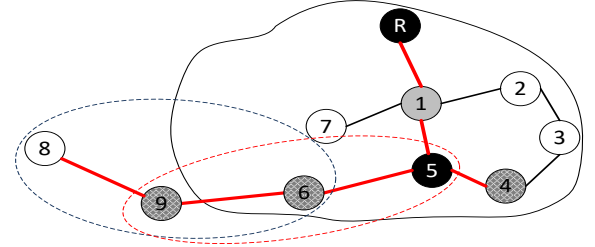
E. Heuristic for the connectivity restoration

To expand the connectivity to the *flying investigator* in the new location, we propose a heuristic connectivity restoration that strives to identify a set of movements with the minimum traveling cost by evaluating three strategies as shown in Fig. 4 by: (1) stretching the virtual backbone C towards the *flying investigator* in the new location as illustrated in Fig. 4b; (2) moving one or more *flying meshes* (i.e., dominee node(s)), which will act as the *flying mesh(es)* (i.e., relay node(s)), to certain location(s) in between the *flying investigator* in the new location and the closest virtual backbone drone, which has been previously determined from the MCDS heuristic as shown in Fig. 4c; and (3) a combined stretching and moving strategy.

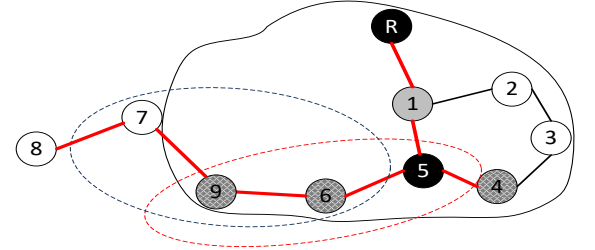
The Euclidean distance between the new location and the closest virtual backbone node and the transmission range are two factors that determine the number of required relay nodes and the possibility to stretch the virtual backbone nodes positions. Additionally, the role of every node in the backbone and the maneuverability area, an area where a drone can move within the area without affecting the existing connectivity between nodes, are also other two important factors in the stretching node attempt.



(a) Graph representation the network partition since the new location is not in the transmission range of the closest drone



(b) Stretching the virtual backbone in an attempt to build a connected mesh network.



(c) Moving one of the dominee to enable the connectivity.

Fig. 4: The proposed heuristics connectivity restoration illustration. Note that for the presentation clarity, we show the transmission range and node position in 2-D while in the algorithm we assumed that the transmission range is spherical.

As an example, when the Euclidean distance between two drones is close and much less than the maximum transmission range, both can move in the opposite directions up to the maximum distance between nodes is equal to theoretically the maximum transmission range to stay connected. However, due to the drone assigned role, its maneuverability area is much smaller with respect to its current location. For example, the *flying investigator* is only allowed to move around the observed object of interest in a close proximity.

If all these strategies are not able to create a connected mesh network G' , then the drone movement request will be postponed until one or more *flying investigators* have finished their existing tasks and changed their roles as the *flying mesh*. In this case, the proposed two heuristics will kick-in again.

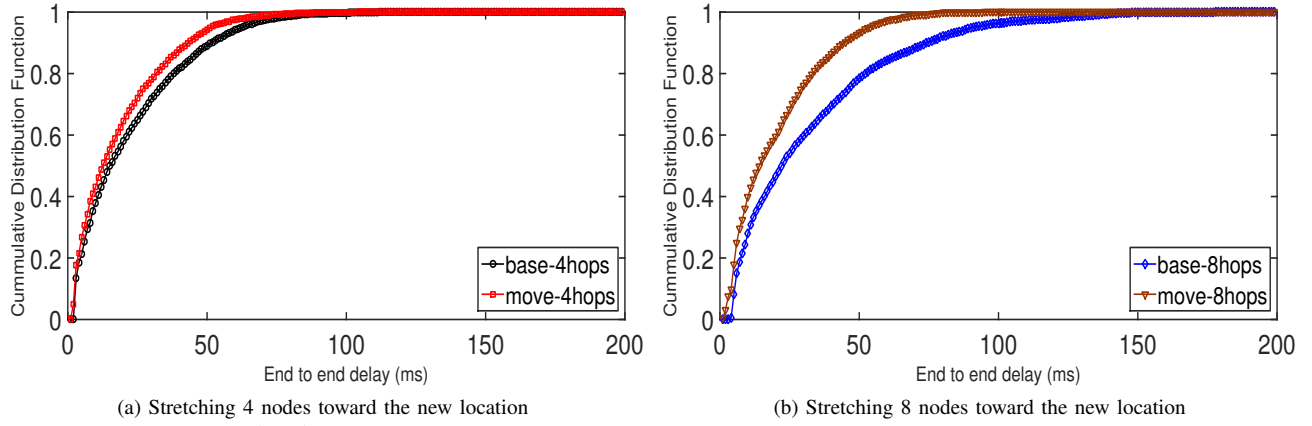


Fig. 5: End-to-end Delay performance from stretching the virtual backbone nodes

IV. PERFORMANCE EVALUATION

A. Experiment Setup

We implemented and simulated the proposed swarm of autonomous drone communications architecture in ns-3 network simulator version 3.27. We used the highway video from the Evalvid [10] video library that consists of 2000 frames for the video transmission during the simulation and the Evalvid's tool-set in the performance evaluation. The following parameters are used during the simulation: the minimum drone's height is 15m, the minimum Euclidean distance between drone is 80m, the LTE base-station's height is 30m; and the IEEE 802.11s' transmission range is 120m. UDP protocol is used for the video transmission.

B. Experiment Results and Discussion

The most crucial part of the proposed method is to ensure the *flying investigator* in the new location can deliver its live video report to the requester while the on-going transmission from other *flying investigators* are still sustainable when the restoration strategy includes the attempt to stretch some nodes from the selected virtual backbone nodes. In this case, some nodes in the virtual backbone must shift their positions toward the new location. Therefore, our experiments in this paper focused on this restoration strategy.

We designed two experiment scenarios for the restoration strategy evaluations. In the first experiment scenario, we designed an experiment that investigates the impact of shifting some nodes in the virtual backbone on the on-going video transmissions. We varied this number to evaluate the impact. In the second experiment scenario, we used a static virtual backbone where all virtual backbone nodes are not moving during the on-going video transmission. We called the experiment results as the *baseline*. In designing these experiments, given that there may be many redundant paths from a source to a destination in the IEEE 802.11s wireless mesh network, we may not be able to observe the shifting impact since the video transmission takes any alternate paths instead of the virtual backbone path. Thus, we considered the worst case scenario for the experiment where only the virtual backbone is available.

We used the following performance metrics for the evaluation:

- 1) The *End-to-end delay* of data traveling from the *flying investigator* to the control center
- 2) The *percentage of lost frames* when transmitting multimedia traffic.

For the first experiment scenario, we performed two simulations. We shifted four virtual backbone nodes toward the new *flying investigator*'s position in the first simulation and eight virtual backbone nodes in the second simulation. We presented the simulation results in Table. I and Fig. 4. We labeled each simulation result as **Move** and then followed by the number of the shifted nodes. Similarly, we also performed two simulations for the second experiment scenario. We transmitted the video through four static virtual backbone nodes in the first simulation and eight static virtual backbone in the second simulation. We labeled each simulation result as **Base** and then followed by the number of hops.

Table I shows the frame lost of the on-going video transmissions for the different number of shifted nodes in the virtual backbone. The frame lost results indicate that when the number of shifted virtual backbone nodes is small (i.e., 4 nodes), the stretching process by moving the nodes towards the new location does not have an impact to the frame lost. However, as the number of the shifted virtual backbone increases, the stretching process has a slight impact on the on-going transmission as indicated in the increase of the frame lost.

TABLE I: Frame Lost for the experiment

Number of Node	Frame lost
Base-4hops	0.05%
Move-4hops	0.05%
Base-8hops	0.15%
Move-8hops	0.45%

On the contrary to the frame lost results, the end-to-end delay results are surprising. We expected that stretching the virtual backbone nodes may increase the end to end delay. However, the results as shown in Fig. 5, indicate that shifting the virtual backbone improves the end-to-end delay. This can

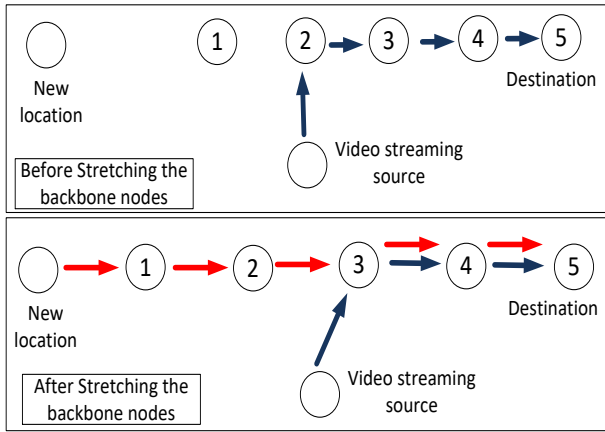


Fig. 6: The impact of the stretching virtual backbone strategy on the number of hops.

be explained as shown in Fig. 6. Stretching towards the new location can reduce the number of hops that originally taken by the video transmission. As a result, the end-to-end delay also becomes shorter.

V. CONCLUSION

In this paper, we proposed two centralized heuristics to enable seamless connectivity among IEEE 802.11s-based drones for service sustainability. The MCDS heuristic is used to ensure that the moving drone selection to a new location does not make a significant topology change while the connectivity restoration heuristic is used to ensure that the selected drone for moving to the new location will be able to talk to the rest of the swarm. The results indicated that connectivity restoration by stretching the virtual-backbone will reduce the end-to-end delay because of the reduced number of hops.

For future work, we plan to develop the distributed version of the presented centralized heuristics.

ACKNOWLEDGMENT

This work is supported by Qatar National Research Fund (QNRF) under the grant number NPRP-9-257-1-056.

REFERENCES

- [1] E. N. Barmounakis, E. I. Vlahogianni, and J. C. Golias, "Unmanned aerial aircraft systems for transportation engineering: Current practice and future challenges," *International Journal of Transportation Science and Technology*, vol. 5, no. 3, pp. 111 – 122, 2016, unmanned Aerial Vehicles and Remote Sensing.
- [2] M. Erdelj, E. Natalizio, K. R. Chowdhury, and I. F. Akyildiz, "Help from the sky: Leveraging uavs for disaster management," *IEEE Pervasive Computing*, vol. 16, no. 1, pp. 24–32, Jan 2017.
- [3] H. Menouar, I. Guvenc, K. Akkaya, A. S. Uluagac, A. Kadri, and A. Tuncer, "Uav-enabled intelligent transportation systems for the smart city: Applications and challenges," *IEEE Communications Magazine*, vol. 55, no. 3, pp. 22–28, March 2017.
- [4] R. Saleri, V. Cappellini, N. Nony, L. D. Luca, M. Pierrot-Deseilligny, E. Bardiere, and M. Campi, "Uav photogrammetry for archaeological survey: The theaters area of pompeii," in *2013 Digital Heritage International Congress (DigitalHeritage)*, vol. 2, Oct 2013, pp. 497–502.
- [5] N. Saputro, K. Akkaya, R. Algin, and S. Uluagac, "Drone-assisted multi-purpose roadside units for intelligent transportation systems," in *2018 IEEE 88th Vehicular Technology Conference (VTC-Fall)*, Agt 2018.

- [6] "Ieee standard for information technology– local and metropolitan area networks– specific requirements– part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications amendment 6: Wireless access in vehicular environments," *IEEE Std 802.11p-2010*, pp. 1–51, July 2010.
- [7] "IEEE standard for information technology–telecommunications and information exchange between systems–local and metropolitan area networks–specific requirements part 11: Wireless lan medium access control (MAC) and physical layer (PHY) specifications amendment 10: Mesh networking," *IEEE Std 802.11s-2011*, pp. 1 –372, 10 2011.
- [8] 3GPP, "Evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (E-UTRAN)(3GPP TS 36.300, version 8.11. 0 release 8), december 2009," *ETSI TS*, vol. 136, no. 300, p. V8, 2011.
- [9] ns 3, "ns-3: network simulator 3," Release 3.27, 2017. [Online]. Available: <http://www.nsnam.org/>
- [10] J. Klaue, B. Rathke, and A. Wolisz, "Evalvid – a framework for video transmission and quality evaluation," in *Computer Performance Evaluation. Modelling Techniques and Tools*, P. Kemper and W. H. Sanders, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2003, pp. 255–272.
- [11] J. Yu, N. Wang, G. Wang, and D. Yu, "Connected dominating sets in wireless ad hoc and sensor networks a comprehensive survey," *Computer Communications*, vol. 36, no. 2, pp. 121 – 134, 2013.
- [12] M. R. Garey and D. S. Johnson, *Computers and Intractability: A Guide to the Theory of NP-Completeness*. New York, NY, USA: W. H. Freeman & Co., 1990.
- [13] S. Guha and S. Khuller, "Approximation algorithms for connected dominating sets," *Algorithmica*, vol. 20, no. 4, pp. 374–387, Apr 1998. [Online]. Available: <https://doi.org/10.1007/PL00009201>
- [14] M. Younis, I. F. Senturk, K. Akkaya, S. Lee, and F. Senel, "Topology management techniques for tolerating node failures in wireless sensor networks: A survey," *Computer Networks*, vol. 58, pp. 254 – 283, 2014.
- [15] G. Wang, G. Cao, T. L. Porta, and W. Zhang, "Sensor relocation in mobile sensor networks," in *Proceedings IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies.*, vol. 4, March 2005, pp. 2302–2312 vol. 4.
- [16] X. Li, N. Santoro, and I. Stojmenovic, "Mesh-based sensor relocation for coverage maintenance in mobile sensor networks," in *Ubiquitous Intelligence and Computing*, J. Indulska, J. Ma, L. T. Yang, T. Ungerer, and J. Cao, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007, pp. 696–708.