Unmanned Aerial Vehicles in Opportunistic Networks

Salih Safa Bacanlı and Damla Turgut
Department of Computer Science
University of Central Florida
Email: {sbacanli,turgut}@cs.ucf.edu

***Abstract*—The unmanned aerial vehicles (UAVs) are widely used in many application areas including the opportunistic networks. In this paper, we investigate the efficient usage of UAVs in Unmanned Aerial Vehicle aided Opportunistic Networks (UAON). The UAVs act as message distributors whereas the nodes on the ground generate the messages. The simulation study is conducted on the real-world dataset of nodes moving around North Carolina State University. We have tested different cruising techniques and the cases without the usage of UAV. The simulations showed improved results in terms of message delay and success rate when the UAVs were used in an opportunistic network settings.**

I. Introduction

Unmanned aerial vehicles (UAV) are typically used for monitoring purposes on areas where human intervention is either not possible or practical. While UAVs are used in various applications [1], [2], it is also possible that these vehicles can be leveraged in an opportunistic wireless communication environment. Opportunistic network is defined as network of mobile nodes where the neighborhood between nodes changes as the nodes move [3]. In such a situation, nodes may enter or exit the network and the nodes communicate through multiple hops. Since disconnections are the nature of the opportunistic networks, the routing strategy allows the effective communication between nodes.

The opportunistic networks becomes more challenging when UAVs are added to the environment. We defined the term UAV Aided Opportunistic Network (UAON) for the networks including one more UAVs. The UAVs communicate with other nodes or with other UAVs for relying messages towards destination nodes while aiming to follow the shortest path possible. Going to abandoned locations frequently or rotating around certain location can cause the UAV to waste its energy. Similar to the mobile nodes on the ground staying idle to conserve energy, the UAV may follow similar strategies to save energy, meaning that they may choose not to deliver messages immediately.

In this paper, we have tested epidemic routing based approaches with different types of trajectories. We have different shapes of trajectories for the UAVs while they are patrolling the sky. We have conducted experiments and compared meander scan and random spiral scan approaches along with other two clustering based approaches, namely, state based campus routing (SCR) and epidemic routing with no UAVs.

II. Related Work

Although the application of using the UAVs in opportunistic networks is reasonably new development, there have been significant amount of existing literature on opportunistic network routing. Some of the opportunistic routing or delay-tolerant network forwarding approaches use random mobility for the node movements [4], [5]. In order to implement a more realistic approach, we have simulated our proposed strategy on a real-world dataset [6].

Gondaliya and Gondaliya [5] compared different opportunistic routing strategies. Bacanli et al. [3] proposed State based Campus routing (SCR) in opportunistic network and compared different routing strategies for different university campus data sets; however, they did not leverage the UAVs in their work. Wang et al. [7] reduced the number of excessive packets in an ad hoc networking environment by implementing a similar structure with times-to-send value for a message.

While there are few existing research wok on how to take advantage the UAVs in opportunistic networks [8], [9], [10], [11], [12], none of these approaches have used a real-world dataset. Ma et al. [9] used velocity information of the nodes in which all of them move towards the same direction. Xu and Zhang [13] introduced a routing algorithm where the UAV travels between three dense group of nodes. Valentino, Jung and Ko [11] provided a theoretical model for clusters of the UAV communicating with each other. Zhong et al. [14] examined path assignment for the UAVs in disaster areas. Wang et al. [15] proposed an improvement on PROPHET routing strategy, called (PROPHET-CLN), for opportunistic networks which also requires nodes to exchange their encounter histories, causing extra overhead to protocol messages.

In our proposed approach, we aim to keep our protocol lightweight and use minimum amount of information about the nodes. The nodes or the UAV are not exchanging any location information or encounter history with each other. The only exchanged information is the message IDs of the nodes that they store in their buffer. The minimal information usage allows us to decrease the overhead in packet communication and the make the system more suitable to networks with larger number of nodes.

III. Application Scenario

In this paper, the opportunistic network environment is considered a university campus. The dataset we are using contains the mobile traces of people walking with a mobile device on the university campus. We assume that the mobile devices are communicating with each other on ad hoc fashion and there is a UAV cruising on top of the university campus.

The users with mobile phones create messages in every hour and the lifetime of the message is three hours long. This means that the message is broadcast around the whole campus in less than three hours. Whenever a person encounters with another person, the mobile devices exchange the messages. If a node has a message whose creation time is older than three hours, the node keeps the message but forwards it to other encountered nodes. Until that point, this is an opportunistic network environment.

We have then added a UAV to this environment. The UAV cruises on top of the campus and collects the messages from the nodes and deliver them back to its encountered nodes. The UAV itself does not create any messages since it is responsible only for delivering the messages created on the ground to as many nodes as possible.

The maximum speed of UAV is 33 meters per second and the maximum cruise time for the UAV is 24 hours (see Bayraktar UAV [16]). Maximum wireless communication range both for nodes and the UAV is 250 meters which is appropriate with 802.11 wireless communication standard. The altitude of the UAV is 100 meters.

The intuition behind adding a UAV in the opportunistic environment is that the nodes on the ground can conserve their energy by not engaging in much wireless communications. We argue that it may be easier to charge the battery of the UAV then draining the batteries of the nodes on the ground.

An example application case might be at a time which an event such as conference or meeting is taking place at the university campus and the participants are sending messages to each other about the events. Another application case might be yellow pages applications where people are sending messages about the items that they would like to sell or buy. The application scenario can be potentially extended to city areas since for both city centers and university campuses specific locations can become more crowded at different times of the day due to a specific event or some areas are almost always occupied during certain hours of the day due to regularly scheduled events such as classroom buildings, city offices and so on.

IV. Our Approach

In this section, we first discuss the properties for the forwarding strategies followed by our proposed approach along with the summary of the compared protocols.

The nodes only forward the messages in their memory whose expiration time have not passed. There is no protocol message except the one that contains the vector of message IDs. The nodes first exchange the vector of their message IDs. This is the only protocol message that is also stated in the epidemic routing by Vahdet and Becker [17]. For large networks, stored and collected information about the neighbor nodes may become too large and hence impact the processing time and storage space of the nodes. We avoid excessive information exchange between the nodes in order to make the routing strategy suitable for large networks. Exchanging only the actual messages also enhances the privacy and security of the mobile nodes as the encounter history information is not shared between the nodes. Having lightweight protocol message system also saves memory space for the nodes. For instance, State based Campus Routing (SCR) uses small amount of memory for the communicating nodes [3]. In the DBSCAN approach, only the UAV keeps track of the encounters since there are always significantly less number of UAVS in the opportunistic network than the nodes.

The UAV keeps the records of its encounter history such that it can make a decision about its routing strategy. The encounter history is deleted after the UAV completes the route. Even though monitoring of the memory consumption of the UAV is not subject of this work, we remove the history to save the memory space of the UAV.

Besides, the encounter entries in the UAV contains the UAV's location when the UAV encounters a node. The proposed technique does not require sending the location information to the neighboring node or UAV. Since the maximum communication distance is 250 meters, the UAV can provide an approximate location information about the node. The UAV not knowing the exact location of the nodes helps to preserve the location privacy of the nodes on the ground.

We have tested six approaches in the simulation study. In our application scenarios, the nodes create and forward messages to each other. Besides the nodes, the UAV scans the environment using different approaches and helps the opportunistic network through message flooding.

A. Meander scan

Meander scan approach scans the area similar to a meander shape. The density of the path is parameterized with two parameters: a and b. One of the parameter decides the distance between horizontal lines whereas the other decides the distance between vertical lines. Figure 1 shows the DBSCAN clustering approach while it uses meander scan, showing the parameters a and b. By adjusting the parameters, more densely scanning paths can be created. The UAV starts from the upper rightmost corner of the area. When the UAV finishes the path, it goes back to its starting point to start scanning again. Both the UAV and the nodes on the ground use Epidemic routing for the meander scan approach.

B. Random spiral scan

Random spiral scan approach scans the area using random spiral paths. Our main objective is to develop a technique for scanning small cluster areas. To serve that purpose we have used spiral scanning technique. In order to show the efficiency of our technique, we also tested the random spiral scanning approach. For the random spiral scanning, the UAV creates a

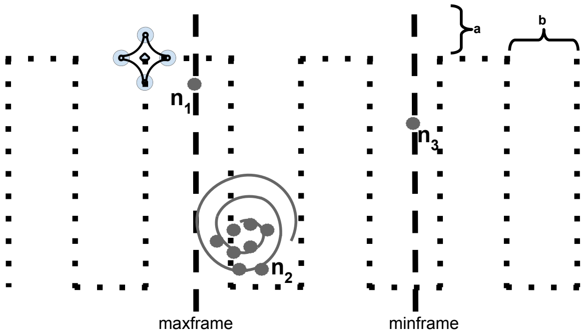

Fig. 1. DBSCAN clustering approach with framing.

spiral way-point based on parameters *a* and *maximum radius (R)*.

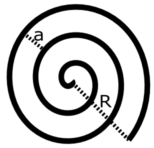

Fig. 2. Spiral parameters.

The parameters of a spiral is shown in Figure 2. The distance between two consecutive arcs is *a*. The maximum displacement that the UAV makes from the initial point is called *maximum radius(R)*. For this specific spiral shown in Figure 2, *R* is triple of *a*. The spiral we are using in our approaches is Archemedes spiral. For the random spiral approach, the UAV picks a random location in the area with a random maximum radius(*R*). When the UAV reaches the limits of the area or reaches the maximum spiral radius distance from the starting point, it selects another random location with a random maximum radius. Afterwards, it starts scanning as a spiral again. For the routing strategy,the UAV and the nodes on the ground use Epidemic routing protocol.

We have used parametric function of spiral shown in equation 1 in order to draw the location of a node at each second. The θ is increased and contiguous locations are created at each second until the distance between initial and last projected locations is less than *R*.

$$\begin{aligned} x(\theta) &= a \times \theta \times \cos(\theta) + x_{initial} \\ y(\theta) &= a \times \theta \times \sin(\theta) + y_{initial} \end{aligned} \tag{1}$$

C. State based Campus Routing (SCR) with no UAV

We only tested SCR routing for the nodes on the ground. No UAV exists in that test environment. The nodes on the ground follow SCR approach while sending messages to each other. The parameters of the simulation is set as $\alpha = 0.25, P_{wanted} = 0.99, \lambda = 0.99$, as suggested by Bacanli et al [3].

D. Epidemic routing with no UAV

We only tested Epidemic routing for the nodes on the ground. No UAV exists in that test environment. The nodes on the ground are sending messages whenever they encounter each other. We have added this approach in our test environment in order to compare the results where no UAV is leveraged while the success rates and message delay results are reasonable.

E. SCR with DBSCAN clustering

In this approach, the UAV first makes one complete tour of the meander scan. Based on the encounter data, it creates clusters of nodes with given DBSCAN parameters. The UAV starts spiral scan for the cluster points. After it finishes the cluster scanning, the UAV sets maximum and minimum x-axis locations to create a frame. Maximum location for the frame is the x coordinate of the farthest node while the minimum location for the frame is the x coordinate of the closest node. Once the frame limits are created, the UAV travels following the meander scan from the minimum location to the maximum location. Based on that framed scan, the UAV repeats clustering approach for the encountered nodes. The limits for the frame stays for *framelimit* number of meander scans. In our simulation runs, *framelimit* is 5. Once the UAV starts meander scan the sixth time, the UAV again scans the whole area in order to set the new frame limits. The motivation behind the framing approach is that the map may not always be equally dense. The dense locations on the map may change over time so in order to find the new dense points, the frame limits are reset once in every *framelimit* times.

Figure1 shows the scanning pattern in the environment. n_1 is the maximum point of the frame whereas n_3 is the minimum point of the frame. Once the UAV finishes scanning the whole map, it sets the maximum and minimum points based on n_1 and n_3. After that, based on the encounter history it has around the n_2 node, the UAV makes a spiral scan around the n_2. The radius of the spiral will be the half of the maximum distance between the two points in the cluster. Once the spiral scan is finished, all the points in that cluster will be encountered again considering that their positions stayed in the same cluster group.

In terms of the routing strategy of the SCR with DBSCAN clustering technique, the nodes on the ground use SCR routing whereas the UAV uses epidemic approach. The DBSCAN algorithm requires the maximum distance parameter between two nodes which is given as 1000 meters.

F. Dataset

We have used the dataset by Rhee et al. [6]. The dataset contains locations and times of the nodes calculated by referencing a local point. The location coordinates are in meters. The real location (GPS coordinates) of the reference point is unknown. The dataset contains the location records taken in every 30 seconds. We have extended the dataset by filling the location data between 30 seconds assuming that the nodes continue to follow a line path with constant speed.

The North Carolina State University dataset [6] contains the location records of the nodes that varies in duration times from about 1 hour to 21 hours with total of 35 nodes. We also projected their locations between data collection times for every second.

V. Simulation study

We have conducted simulations for the application scenario using Java. The simulator, used by Bacanli et al. [3], is further developed to test the approaches and use the location and the time data rather than just encounters. The simulation metrics include the success rate, message delay, number of packets sent and the distance travelled by the UAVs.

The success rate is defined as the percentage of the nodes that have a specific message. The higher the success rate for a message, the higher that percentage is. The message delay is calculated as the average delay of a message received by the nodes and the UAVs. The delay term here is defined as the time difference between the creation time of the packet and the receiving time of the packet by a UAV or a node.

The energy efficiency of a technique should include the number of packets sent by the nodes and the UAV. We also need to take into account the distance travelled by the UAV to determine the energy efficiency of the approach. The distance travelled by the UAVs are calculated whenever they finish a route between two calculated points and adding them up through the simulation run. The aim is that the UAV should travel as small distance as possible.

Counting the number of packets sent by the nodes and the UAV gives us the total number of packets sent. This metric only shows the sent messages. As there is 10% error rate in the system, not all messages are received by the target nodes every time.

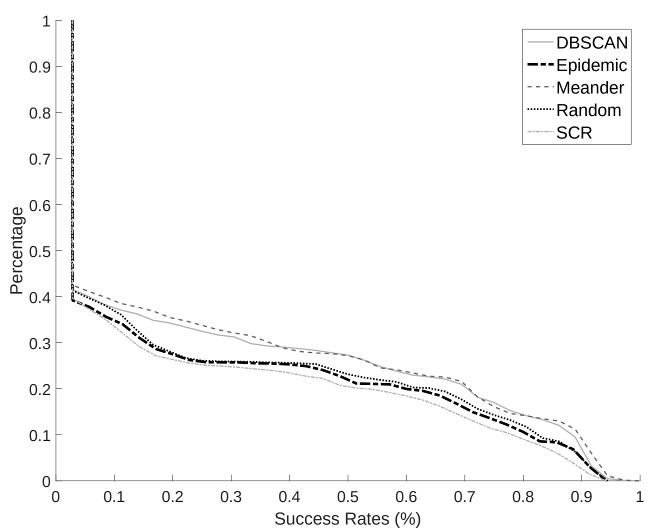

Fig. 3. Complementary cumulative distribution function of success rates.

Figure 3 presents the complementary cumulative distribution function of success rates. Complementary cumulative distribution function essentially complements cumulative distribution function (CDF). Complementary cumulative distribution function shows the success rate (x) on the x axis whereas the percentage of the values that are greater than the success rate (x) are on the y axis. Figure 3 shows that meander scan and DBSCAN have similar performance. Meander scan appears to be efficient in terms of success rates as the UAV keeps cruising all the area. Random spiral scanning has similar success rates with the case where there is no UAV. This is expected as it is possible that the random spiral scanning technique might be visiting less dense areas. It can be seen that the UAV usage in an opportunistic network environment can improve the success rates.

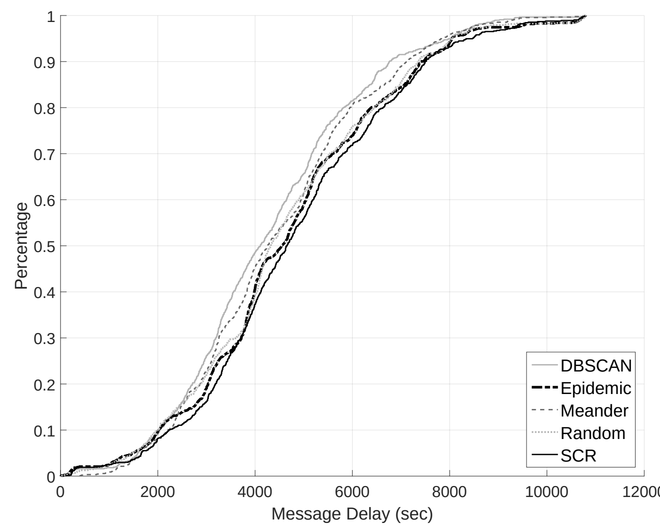

Fig. 4. Cumulative distribution function of message delays

Figure 4 shows the cumulative distribution function graph of message delay. Cumulative distribution function shows the success rate (x) on the x axis whereas the percentage of the values that are less than the success rate (x) are on the y axis. Figure 4 shows that the DBSCAN has better message delay compared to other techniques. Once the messages are collected from the nodes, the UAV scans the cluster of nodes, essentially specific dense locations. Meander scan shows better message delay results than random approach because after the first round of meander scan, it is highly possible that the UAV has already encountered with most of the nodes. However, random spiral scanning does not guarantee encountering with any node in the first round of scanning. The approaches with no UAV shows the worst results, similar to random spiral scanning. This shows that just randomly scanning the area might not be more efficient technique than not using an UAV. It appears that using an UAV in a planned way gives better results in terms of message delay.

We have used number of packets sent metric to compare the energy usage of the techniques since for a wireless communication device sending a packet requires more energy then listening. According to Figure 5, DBSCAN has sent around

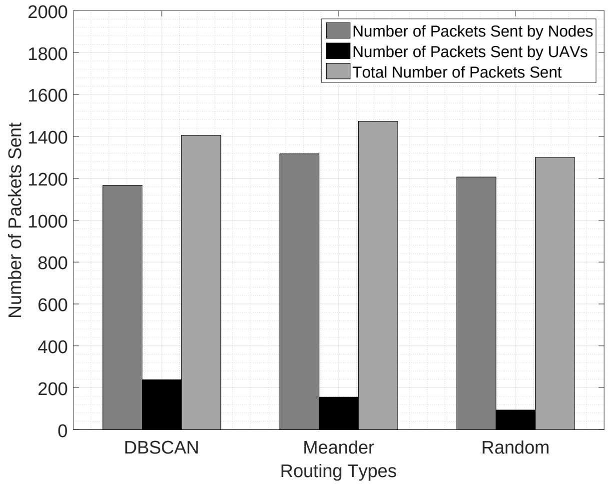

Fig. 5. Number of packets sent.

10% less number of packets than meander scan approach considering the number of packets sent in total. This result shows the real success of DBSCAN approach. It has the lowest message delay and the most energy efficient strategy compared with meander and random spiral scanning. Random spiral scanning has sent the least amount of packets but the results for message delay and success rate was not as satisfactory.

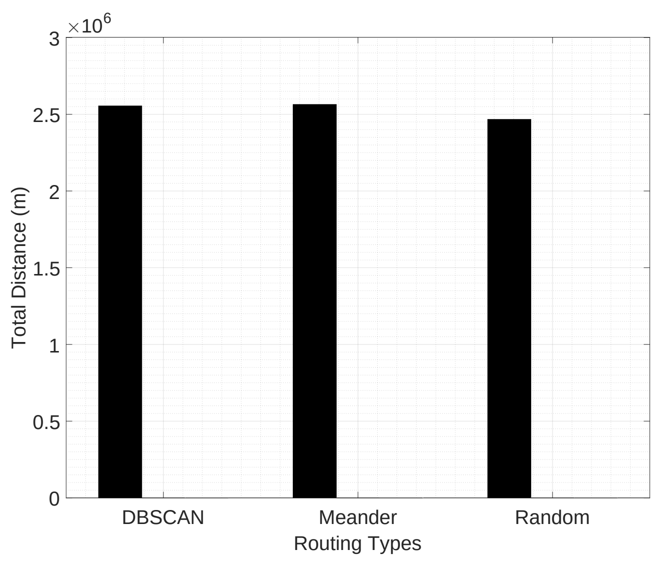

Fig. 6. Distance travelled by the UAVs.

Figure 6 presents the distance travelled by the UAVs for the techniques in which the UAVs were used. The DBSCAN and meander scan achieves similar results. The random spiral scanning approach results in lesser travelled distance than the other two approaches; however, the difference is not significant.

VI. Conclusion

In this paper, we have proposed the DBSCAN routing strategy for the application case where unmanned aerial vehicles (UAV) are used in an opportunistic network environment. In order to show the effectiveness of the UAV usage upon the cases where no UAV is used, epidemic and SCR routing approaches are compared. Additionally, meander and random spiral scanning approaches are compared with the proposed DBSCAN approach. The DBSCAN approach gives better results in terms of message delay. While the DBSCAN sends less number of packets than the meander scan, it still has similar success rate as the meander scan approach.

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