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Adaptive path planning for Collaborative ground to air wireless networks

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Abstract

A collaborative ground to air network formed by ground nodes and unmanned aerial vehicles, gives service and coverage of the remote ground nodes. Unmanned aerial vehicle find there usage in reconnaissance, search and rescue operations, disaster relief operations, surveillance and homeland security operations. These operations have tendency to generate or search for objects of interest which are completely irregular, spatially distributed in a given space and are susceptible to fast changes, and thus making linear, randomized or study based search and acquisition practically non-feasible. This paper dives into the random nature of the ground nodes deployment. Finds area of interest in the network and classifies them into events. The UAV controller described in this paper then uses this event scenario to predict the optimized UAV path and placement co-ordinates for improving the data dissemination of the ground based nodes.

Keywords: Unmanned aerial vehicle, drone, wireless network, adaptive path planning, collaborative networks.

1. Introduction

Unmanned aerial vehicle (UAV) also know as a drone gives user 3D mobility performing a variable set of complex task. The flexibility in node mobility patterns has been used to provide service and coverage to ground nodes in a wireless network. Such type of collaborative network uses aerial node (UAV) in transmitting its packet from ground nodes to base station or a cloud depending upon the usage. UAV can act as a relay or as a aerial base station for the ground nodes. The major benefit of using a UAV in a collaborative network is its ability to switch trajectory and get in line of sight of a transmitting node. On one hand UAV's can overrule the use of fixed base station in wireless sensor network, on the other UAV' can improve the overall quality of service in remote areas of wireless network. However the task of planning a network with UAV's on horizon and optimizing the UAV trajectory for substantial benefit is still focus of research.

UAV in collaborative ground to air network opens a new paradigm of applications. Recently UAV's have been used aerial photography, reconnaissance, search and rescue operations, disaster relief operations, surveillance and homeland security operations. These operations have the tendency to generate or search for objects of interest which are completely irregular, spatially distributed in a given space and are susceptible to fast changes, and thus making linear, randomized or study based search and acquisition practically non-feasible. The proposed UAV controller features an adaptive path planning and selection property which can deal with such spatial randomness. The controller uses divides the entire wireless network into grid and then estimates the probability of events in that part of the grid adjust its flight path accordingly. The proposed approach ensures that the UAV is at right place at right time to assist in ongoing operations.

This paper makes following contributions.

- Efficiently grouping the ground nodes with little control flows in the network.
- Classification of events in a group to predict the behavior of an area.
- Adaptive path planning for UAV's to serve the areas that generate events.

2. Literature Survey

Sharma and Kumar [1] discussed collaborative network formation and optimized search operations in multi UAV guided networks. The authors employed Bayesian Kalman Filters and Topological Organizing Maps for coordinate detection and approximation. The area to be serviced is geographically mapped with the help of Virtual concepts introduced during cognitive mapping. Ho and Shimamoto [2] proposed PESC-MAC for eliminating multi-hop communication from the WSNs, by using UAV networks as relay junctions. Results demonstrate that the UAV elevation and trajectory serve as important factors towards minimizing packet error rates. The altitude criteria forced by increasing the number of ground nodes also mandates interference management. The proposed technique archives significantly high throughput levels and lower packet error rates when interference management and altitude detection mechanisms are employed in coordination.

Say et al [3] proposed an optimization technique for frame selection in multi UAV adhoc networks. The technique establishes that only those ground nodes which directly fall under the UAV beacon will be allowed to contest for channel allocation and data transmission. The priority-based framework organises the sensor nodes into frames in accordance to the UAV coverage beacon, in the area where they fall. Sharma et al [4] proposed multi UAV coordinated data dissemination between aerial and ground sensor nodes. The proposed techniques alters the generalized WSN deployment strategies by employing UAV nodes instead of WSN manager nodes. The proposed framework makes use of nature inspired Fire-Fly Algorithm for data dissemination. Berrahal et al [5] proposed a military surveillance technique using aerial nodes. The techniques efficiently maps the sensor nodes and facilitates transmission between aerial and ground networks. Sensor nodes are mapped using radio frequency identification (RFID).

UAV assisted data dissemination in Delay Tolerant Networks (DTN) is discussed in Reina et al [6] . The authors border lined that in cases of emergency the fundamental broadcast nature of dissemination algorithms cannot be put to use. The proposed technique makes use of multi objective genetic algorithm, for servicing requests in such scenarios. Ciobanu et al [7] proposed a history-based data dissemination scheme for DTNs. Tactical deployment of aerial nodes for disaster response is discussed by Sánchez-García et al [8]. The similarity among the served entities are estimated using Jaccard distances. The proposed scheme is tested real time by estimating the random movement of victims using mobile devices fitted to persons taking part in a conference. The random movement of victims is considered with an obligation that the movements are generally linear. Khan et al [9] proposed the traditional grid deployment of the WSN nodes, and data dissemination is facilitated using a single serial sink. The self-configuring nature of the WSN nodes is exploited by restricting that node closest to the centre of the virtual grid will be used for routing data towards an aerial node.

Wichmann and Korkmaz [10] proposed a multi UAV sink for enough exposure and smooth data dissemination. An algorithm for constructing a flawless path around the ground topology is generated using travelling salesman algorithm and is called Smooth Path Construction (SPC) algorithm. Tunca et al [11] proposed a technique where anchor nodes are deployed and are used as mobile sinks. The proposed approach is around ring routing and virtual sinks with dynamic structure are created for data dissemination. It supports both periodic and stimulated data transmission. Wu et al [12] proposed adaptive data processing and dissemination for drone swarms in the urban

SENsing (ADDSEN) framework, which balances energy and storage by means of sharing partially ordered knowledge.

Chandhar et al [13] proposed an omni direction antenna-based UAV system with base stations equipped with large array of directional antennas. The propagation model considered for testing and evaluation of the proposed framework only considers Line of Sight (LOS) propagation, along with a three-dimensional UAV rotational model and polarization model. The authors conclude that by means of deploying MIMO antennas at the base the uplink gains significant improvements without any additional UAV transmission capability. Cooperative relaying employing MIMO antennas in multi-UAV networks is discussed in Palat et al. [14]. The proposed technique aims at improving the coverage and reliability of the communication. Marinho et.al [15] proposed a technique for disconnection avoidance in WSN networks using aerial sinks. Chen et al. [16] discussed a comparative study between MIMO and SISO antennas with application in collaborative networks. The real-time test bed shows massive gains in coverage and energy saving as well as increased throughput.

3. Proposed Approach

The proposed approach starts by dividing the complete area of wireless network deployment. This grouping felicitates the wireless traffic as number of nodes served is reduced to the UAV's capability of providing service. It then distinguishes the areas with event classification over time, Finding the the specific points in a network that will be more burdened than others. After the events are identified a path planning strategy is developed for the UAV. Figure 1 describes the UAV controller.

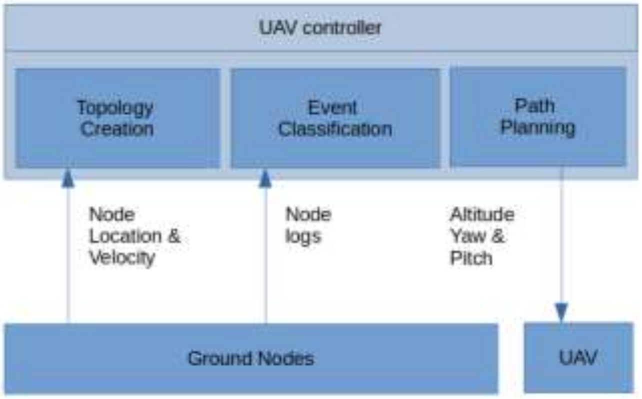

Figure 1: The UAV controller.

3.1 Grouping or clustering

In Literature the topology is partitioned into clusters. Dividing and clustering saves node energy by sending structured data via cluster-head and with short distance transmission. Clustering however poses challenges in a collaborative ground to air network. Clustering a large topological area in three dimensional space such as one used by UAV is complex computational task. The number of clusters required to effectively and efficiently cover the entire topology can be difficult to estimate in a random distribution of nodes. When Ground nodes are put in charge of the clustering process, control packet flow increases due the clustering algorithm used and selection of cluster-heads. Although non cluster-head nodes lose less energy in transmitting packet over shorter distance the cluster-head still transmitting packets over longer distance as base station may or may not be equidistant to all the cluster-heads. Cluster-head may become bottle-necked with increased incoming transmission.

The Proposed approach partitions the entire ground based topology into regular size hexagonal grid as shown in figure. The circumradius of the hexagons is taken as the radius of wireless radio beam of the UAV. Algorithm 1 shows the process of partitioning the topology. It can be noticed that no actual grouping or clustering is performed at the node level and if there is a requirement the grouping can be done again without informing the individual network nodes.

Algorithm 1 : Grid Creation and Maintenance Algorithm

```
Input: WSN Population Size and Positions as $W$ & $P(x,y,z)$
Input: Antenna beam width as $d$
Input: UAV positions as $U(x,y,z)$
Grid Allotments
Create hexagonal grid with circumradius = $d$
Map each node position $P_i$ to its hexagon $H_k$
If Node $W_i$ at position $P_i$ is mobile
    Node $W_i$ updates its position to UAV Controller periodically.
Calculating UAV Placement
For each Hexagon $H_k$
    If $H_k$ is empty
        Add $H_k$ to list of empty sets.
    Else find centroid of the WSN nodes in $H_k$ as $C_k$
End For
```

3.2 Event Classification

Network metrics is best possible way of defining the state of network at any given instance. Metric can be used to identify areas of network that have more load and congestion than others. Packet delay and packet drop are the network metrics that show the state of network links at all time. The throughput of the network is inversely proportional to the time a packet takes to travel from source to destination. Smaller the time taken from source to destination higher the throughput. A line of sight communication increases the prospects of lower packet delay. Packet drop on the other hand does not directly influence the throughput, However as the packets from a source are dropped, the source is required to re-transmit those packet. This decreases the overall efficiency of the network.

In ongoing transmission and receptions of packets from different sources in a network, A central authority can be established which monitors the network for the traffic patterns. These traffic patterns can then be analyzed over time to find areas that will have higher data traffic at a specific time interval, to remove congestion at that specific network location in the network at a given time.

The proposed approach intends to find areas in the network topology that are prone to higher load. Time based prediction is a step towards finding these areas. Time based prediction algorithm can establish the nature of the nodes in an area with great accuracy and help in outlier detection. These outliers are the events that we are looking for in our complete network topology.

Long Short Term Memory (LSTM) network[17] are widely used for making time based predictions. LSTM network is a form of recurring neural network that uses LSTM unit. Each LSTM unit is made up of a cell, input, output and forget gate. The working and adaptations are defined as follows[18].

Let $h^{(t-1)}$ be the input from previous cell and current input as x_t where $x_t \in$ the observed load in an area at time t. Equation 1 defines the forget gate layer

$$f_t = \sigma\left(W_f\left[h^{(t-1)}, x_t\right] + b_f\right) \tag{1}$$

Where σ is sigmoid function. W_f is the weight. The stored information at any time is defined by equation 2 and 3.

$$i_t = \sigma\left(W_i\left[h^{(t-1)}, x_t\right] + b_i\right) \tag{2}$$

$$C_t' = tanh\left(W_c\left[h^{(t-1)}, x_t\right] + b_C\right) \tag{3}$$

The update function that updates the value for unit time is given as.

$$C_t = f_t \times C_{(t-1)} + i_t \times C_t' \tag{4}$$

The output from the LSTM unit in consideration for time t is given by equation 5 and 6

$$o_t = \sigma\left(W_o\left[h^{(t-1)}, x_t\right] + b_o\right) \tag{5}$$

$$h_t = o_t \times tanh(C_t) \tag{6}$$

Where h_t is the output to LSTM unit for time $(t+1)$.

3.3 Topological Randomness and Predictions

The complete spatial randomness (CSR) asserts the given topological points of interest to be distributed within a given area $|Ar|$ according to poisson distribution and the mean number of points or events of interest being $\lambda|Ar|$. All the points and events are distributed independently with a uniform distribution over the area $|Ar|$ and for two independent areas the number of points or events can be different. The probability of each event in an area can be defined by equation 7.

$$P(Ar) = exp^{-\lambda|Ar|}\lambda\,|Ar|^n/n! \tag{7}$$

Where λ is the intensity of an event. The set of events in a given area can be sampled as densely clustered or frequent if $\lambda \geq 0.5$ whereas infrequent or loosely clustered if $\lambda < 0.5$. Where λ is the average measure of the events and can be defined by equation 8 , under the condition that $I_c = 1$, which is effectively a ratio of dispersion of events towards the average intensity.(intensity can be of variety of nature ex:- High bandwidth requirement, network clogging,)

$$\lambda = \sum_{n=1}^{A_n} n_i/Ar_i \tag{8}$$

$$I_c = \sum_{n=1}^{A_n} (n_i - \bar{n}) \Big/ (A_n - 1)\,\bar{n} \tag{9}$$

Where A_n is the number of areas and n is the number of events in a given area and

$$I_s^2 = (A_n - 1)\sum_{n=1}^{A_n} (n_i - \bar{n}) \tag{10}$$

is the spread of events in a given area $|Ar_i|$

Two independent areas can which are densely clustered with frequent events and infrequent events respective can be combined together to form a larger search space according to equation 11 as all the events in an area form in independent space from the uniform distribution of the area.

$$P\{N(A_i) = x, N(A_j) = y | N(A_{ij}) = n|\} = ((x+y)/x)p^x q^y \tag{11}$$

such that

$$p = |A_i|/|A_{ij}| \tag{12}$$

$$q = 1 - p\!: |A_i|/|A_{ij}| \tag{13}$$

and

$$A_{ij} = A_i \cup A_j \tag{14}$$

where $0 \le x \le n$ and $y = n - x$.
Under the condition that mean number of events in an area are $\lambda|Ar|$ with intensity λ the joint distribution of areas A_i and A_j as A_{ij} is defined as equation 15

$$P\{N(A_i) = x, N(A_j) = y\} = ((x+y)/x)p^x q^y \left\{exp^{-\lambda|A_{ij}|}\lambda\,|A_{ij}|^n/n!\right\} \tag{15}$$

that is

$$P\{N(A_i) = x, N(A_j) = y\} = \left\{exp^{-\lambda|A_i|}\lambda\,|A_i|^x/x!\right\}\left\{exp^{-\lambda|A_j|}\lambda\,|A_j|^y/y!\right\} \tag{16}$$

The areas marked according to the frequency of events and the regions having infrequent events or irregular events merged with the neighboring areas where frequency of events is higher a consistent virtual concept of topology is achieved. This virtual concept segments the overall geography into areas based on the events associated with the areas such that events in each area together form a separate independent sample space which is uniformly distributed from the area. The UAV can be marked to move from an event in area A_i to another event in area A_j with the distance being described as equation 17

$$d = \sqrt{\left(x_1A_i - x_2A_j\right) + \left(y_1A_i - y_2A_j\right)} \tag{17}$$

The distance between the two events in two separate areas can be visualized to form an exponentially distributed circle with radius d and the coordinates of the area A_i as the center of the circle, where area is πd^2. The distribution function of distance x from one event to another event in a different area is defined as equation 18

$$D(x) = 1 - exp^{-\pi\lambda d^2} : d \geq 0 \tag{18}$$

The direction θ from (x_1A_i, y_1A_i) to (x_2A_j, Y_2A_j) is described by the equation 19.

$$\theta = (A/\pi\, d^2) \times 360 \tag{19}$$

To keep UAV under the prioritized movement, the model calculates the expected possibility of an event in future. The function calculates the numerical priority value based on the probabilistic event characteristics.

$$E(x) = \{n(n-1)\}^{-1}|A| \sum_{i=1}^{n} p_i\, I(e_i \in Ar_i) \tag{20}$$

Where I is an indicator function. $(n-1)/A$ is the intensity distribution within an area and p_i is the probability of an event. Under the assumption of constant time t and acceleration a the final velocity v towards the point (x_2A_j, y_2A_j) under the direction θ is given by equation 21

$$v = r - r_0 + at^2/2 \tag{21}$$

where r is the final position vector (x_2A_j, y_2A_j) and r_0 is the initial position vector (x_1A_i, y_1A_i) and the magnitude of the position vector r is given by equation 22

$$|r| = \sqrt{x^2 + y^2} \tag{22}$$

4. Results

The proposed approach was tested using NS3 (Network simulator 3) details of the simulation are given in table 1. For the purpose of simulation IEEE 802.11 standard for wireless network are used.

Simulation Parameters	Values
Ground Nodes	200
UAV	4
Area	5000m x 5000m
Wireless Standard	IEEE 802.11
Mode	Adhoc

Data Mode	(DSSS) Rate 11 Mbps
Propagation loss model	Friis Propagation Loss Model
Packet Size	1500 bytes
Data Rate	1Mbps
Application	UDP (NS3 OnOffHelper)

Table 1: Simulation Parameters

The proposed approach is tested for event classification and prediction. A total of hundred simulations were performed the results represent the average of these values. Figure 2 gives the performance of proposed approach for event classification. The proposed approach outperform the SMA statistical approach by more than 5 %

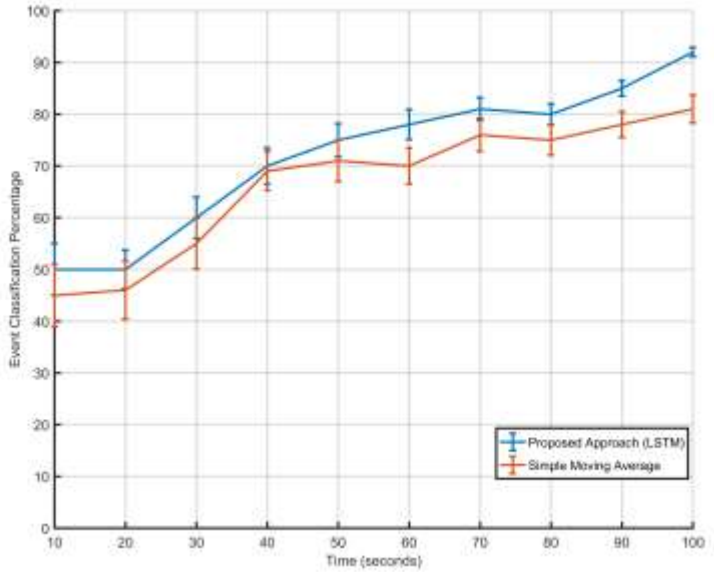

Figure 2: Event classification percentage.

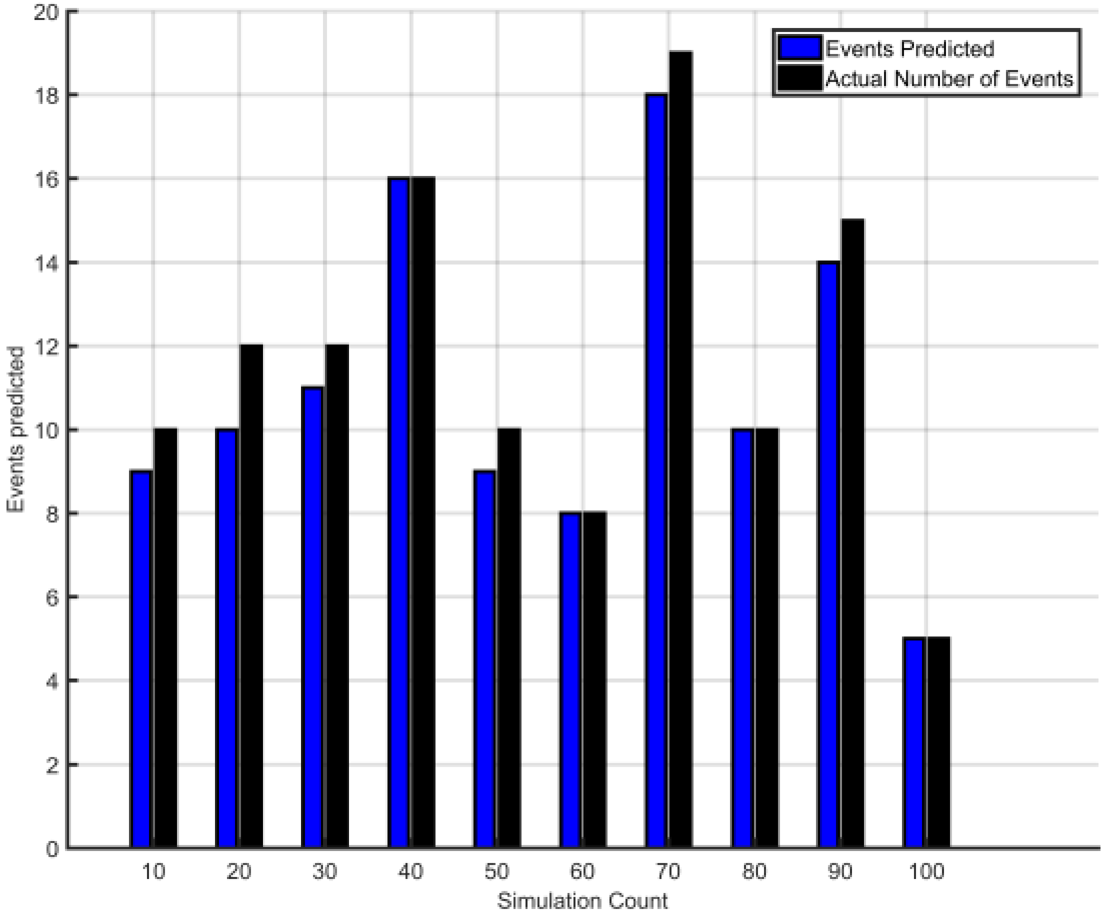

Figure 3: Event Prediction.

Figure 3 gives the event prediction capabilities of the approach. The proposed approach has 94% efficiency in prediction of events.

5. Conclusions and Future work

In this paper we presented an approach for adaptive path planing of UAV in ground to air based wireless network. The approach uses time based prediction for event classification and identifying events of interest where the UAV's presence is required. It the calculates the probability of an event happening to place the UAV in the vicinity of the event for providing service and coverage. From simulation results it can be concluded that the approach greatly enhances the service and coverage provides by UAV aerial network. In future the proposed model is to be simulated and tested with LoRaWan, 4G lte and 5G MIMO technology. The proposed approach will benefit greatly with the use of directional antenna.

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