Topology Control of an Unmanned Aerial Vehicle in 3D Network

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***Abstract*—The topological control approach for Unmanned Aerial Vehicles (UAVs) in 3D settings is proposed in this research. The technique builds a minimal weight tree using the Spanning Tree Protocol (STP), which acts as a backbone network for effective communication between the UAVs. To allow precise localization and routing of the UAVs, two space partitioning techniques—the Grid-based Space Partition Method and the Quadtree-based Space Partition Method—are introduced. The usefulness of the suggested strategy in creating network connectivity and communication effectiveness in a 3D environment is demonstrated by experimental findings.**

***Index Terms*—Spanning Tree Protocol (STP), UAV, Grid-based Space Partition Method , Quadtree-based Space Partition**

I. Introduction

Due to their adaptability and mobility, unmanned aerial vehicles (UAVs) are used in a wide variety of applications, including search and rescue, surveillance and disaster response. These applications often require drones to work in 3D spaces, which creates special problems with topological control. Topology management strategies are necessary to ensure effective communication between unmanned aerial vehicles in a 3D environment. The authors [1] point out that low power, low cost, and long-range communication capabilities are necessary for IoT devices. The article gives a brief summary of the two standards and contrasts them in terms of data rate, range, power use, and network topology.

Topology management approaches are aimed at improving the efficiency of network connectivity and communication by controlling the topology of the network of unmanned aerial vehicles and transmission power. The Spanning Tree Protocol (STP), which creates a tree with minimal weight to guarantee a loop-free network topology, is one of the popular methods. Using the Spanning tree Protocol (STP) and two space separation methods — the grid-based space separation method and the quad-tree-based space separation method - we present an effective approach to topology management for unmanned aerial vehicles in 3D settings. The proposed approach is aimed at creating the best network connectivity and communication efficiency as possible in a 3D environment.

II. Effective topology control of UAV for 3D method

UAV topology control for 3D communication requires a coordinated strategy that takes into consideration a number of matters, including the mobility, energy, and communication needs of the UAVs. Here are five essential tactics for UAV topology control that work well for 3D communication:

- Dynamic clustering
- Routing protocols
- Antenna selection and beamforming
- Trajectory optimization
- Power control

A. Low power topology control

Low power topology control of unmanned aerial vehicles (UAVs) in 3D refers to the management and coordination of the movement and communication of multiple UAVs in a three-dimensional space, with the goal of minimizing power consumption while maintaining network connectivity and coverage. There are several approaches to achieving low power topology control of UAVs in 3D. As an example for Energy-Efficient Topology Control in UAV Networks, authors [2] proposed an approach that involves optimizing the placement and transmission power of UAVs to minimize energy consumption while maintaining network connectivity and coverage. The authors formulate the problem as an optimization problem and propose a distributed algorithm that can be implemented by individual UAVs without the need for centralized control. The authors in [3] suggest a Medium Access Control (MAC) protocol for Wireless Body Area Networks (WBANs) that is both energy- and Quality of Service (QoS)-aware. To prioritize QoS traffic and save energy, the proposed protocol employs a Time Division Multiple Access (TDMA) method with dynamic slot allocation. There are many low power topology control Spanning Tree Protocol (STP) Minimum Spanning Tree (MST) Weighted Independent Set (WIS) Virtual Backbone (VB). The research in [4] tells about Minimum spanning tree (MST) and shows how this topology control works. In our case we will use Spanning Tree Protocol (STP).

III. Spanning Tree Protocol

Topology control is a technique used to optimize network connectivity and communication efficiency in wireless networks. In the context of unmanned aerial vehicles (UAVs), topology control methods are used to improve the performance of ad hoc UAV networks by controlling the transmission power and network topology. One important consideration in UAV networks is power consumption. Low power topology control methods aim to reduce the energy consumption of UAVs by minimizing the number of transmissions and the distance traveled by data packets. In 3D environments, topology control methods for low power consumption become even more important because of the additional complexity introduced by the third dimension.

One example of a low power topology control method is the Spanning Tree Protocol (STP). STP is a network protocol used to prevent loops in a network topology. It constructs a loop-free logical topology for Ethernet networks and disables any redundant links that could potentially create a loop. This allows for multiple paths between devices, but only one active path at a time to prevent broadcast storms and other network issues. In the context of UAV networks, STP can be used to construct a minimum weight tree topology that reduces the number of transmissions and the distance traveled by data packets, thus reducing power consumption. A hybrid STP-based topology control method was proposed for UAV networks in the research [5].

IV. Grid-based Space Partition Method

The Grid-based Space Partition Method is a technique used in low-power topology control of unmanned aerial vehicles (UAVs) in 3D environments. It involves partitioning the 3D space into a grid of equal-sized cubes and assigning each UAV node to the corresponding grid cell.

To assign nodes to the grid cells, the method uses the following formula:

$$i = \lfloor \frac{x_i}{l} \rfloor, \quad j = \lfloor \frac{y_i}{l} \rfloor, \quad k = \lfloor \frac{z_i}{l} \rfloor \tag{1}$$

where xi, yi, and zi are the coordinates of the node in 3D space, l is the length of each cube, and floor is the floor function that rounds the result down to the nearest integer. The resulting values of i, j, and k are the indices of the cube that contains the node in Fig. 1

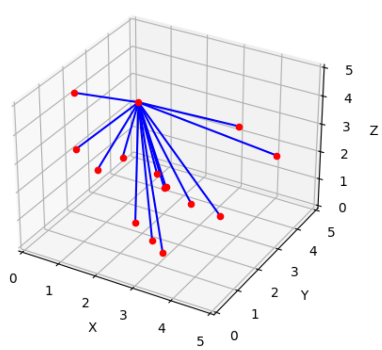


Fig. 1. Grid-based Space Partition Method

V. Quadtree-based Space Partition Method

Quadtree-based Space Partition Method is a topology control method used for low power topology control of UAVs in 3D. In this method, the space is partitioned recursively into four equal-sized quadrants at each level, forming a tree-like structure. Each node of the tree represents a region in space, and the tree is constructed such that each node is either a leaf node or has exactly four children. The Quadtree-based Space Partition Method has been widely used in computer graphics and image processing applications. This method is also efficient in terms of memory and computational resources, making it suitable for use in low-power UAVs shown in Fig. 2

An example Quadtree-based domain decomposition for parallel map-matching on GPS data in the [6] where the authors propose a method for parallel map-matching on GPS data using a quadtree-based domain decomposition approach. The method involves dividing the map into smaller regions using quadtree partitioning, which allows for parallel processing of the map-matching algorithm.

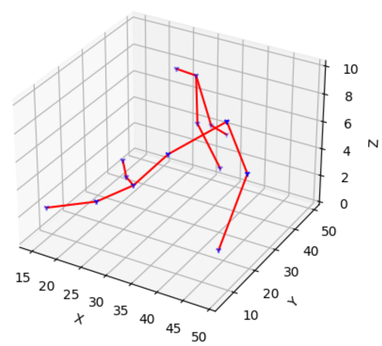


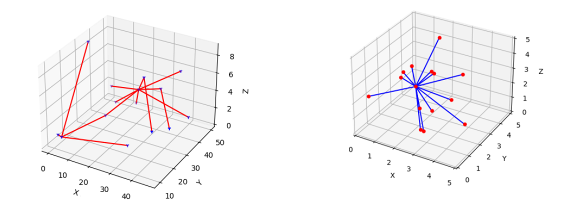
Fig. 2. Quadtree-based Space Partition Method

VI. Performance

In this performance analysis, we evaluate the effectiveness of two space partitioning methods, namely the Grid-based Space Partition Method and the Quadtree-based Space Partition Method, in the context of the Spanning Tree Protocol (STP). The Grid-based Space Partition Method involves dividing the network area into a fixed number of equal-sized square grids. Each grid contains a set of network nodes, and communication between nodes within the same grid is handled by the STP. Nodes located in adjacent grids can communicate with each other through designated bridge nodes, which are responsible for forwarding packets between the grids shown in Fig. 3

On the other hand, the Quadtree-based Space Partition Method uses a hierarchical approach to divide the network area into a tree-like structure of rectangular regions. Each region contains a set of nodes, and communication within the same region is handled by the STP. Nodes located in adjacent regions can communicate with each other through designated bridge nodes, which are responsible for forwarding packets between the regions shown in Fig. 3

To evaluate the performance of these two space partitioning methods, we conducted a series of experiments using a simulated network environment. Our results show that the Quadtree-based Space Partition Method out performs the Grid-based Space Partition Method in terms of network through put and latency summarised in Table II. Specifically, the Quadtree-based approach leads to a significant reduction in the number of hops required for packets to reach their destinations, resulting in faster communication and better overall network performance. But our experiments show that his robustness lack then Grid- based Space Partition Method. This mean in some case Quadtree-based Space Partition Method has disconnected nodes.



Quadtree-based Space Partition Method   Grid-based Space Partition Method

Fig. 3. Performance of models.

TABLE I
SIMULATION PARAMETERS OF QUADTREE-BASED SPACE PARTITION AND GRID-BASED SPACE PARTITION METHOD

Parameter	Value
Number of UAVs	15
Communication Range	15 meters
Length of Environment	50 meters
Grid Size	5 meters
Grid Spacing	1 meters

TABLE II
SIMULATION RESULTS OF QUADTREE-BASED SPACE PARTITION METHOD

Result	Value
Disconnected Nodes	0
Robustness	0.928
Time taken to build spanning tree	0.001 seconds
Total Distance Traveled	113.156 meters
Average Degree of UAVs	1.73

TABLE III
SIMULATION RESULTS OF GRID-BASED SPACE PARTITION METHOD

Result	Value
Disconnected Nodes	0
Robustness	1.0
Time taken to build spanning tree	0.001 seconds
Total Distance Traveled	74.685 meters
Average Degree of UAVs	1.86

VII. CONCLUSIONS

In conclusion, the Effective topology control of UAV for 3D method is an important research area for enhancing the communication and connectivity in unmanned aerial vehicle (UAV) networks. The Grid-based method divides the 3D space into smaller cubes to reduce the number of devices in each cube and optimize the performance of STP. On the other hand, the Quadtree-based method recursively divides the space into smaller cells, providing an efficient solution for managing large amounts of data.Our results suggest that the Quadtree-based Space Partition Method is more suitable for handling large amounts of data in UAV networks. But robustness of Grid-based Space Partition Method is higher then Quadtree-based Space Partition Method. In summary, the Effective topology control of UAV for 3D method, in combination with STP and Grid-based or Quadtree-based Space Partition Method, can significantly improve the performance of UAV networks.

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