Unmanned Aerial Vehicle (UAV) Communication

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***Abstract*—A UAV-based communication system designed for forest fire detection and management, featuring inter and multi-UAV Communication. Through advanced communication protocols and path planning algorithms, the system aims to boost the efficiency and precision of forest fire monitoring. By utilizing multiple UAVs, the approach enhances the system's ability to detect and respond to potential fire incidents in various areas, and responding to them correctly. Providing a more comprehensive and timely monitoring solution and ensures the co-ordination between the UAVs. The integration of multi UAV communications contribute to reliable, faster and a systemised operation, contributing to improved overall effectiveness in forest fire detection and response reaction.**

***Index Terms*—UAV communication, Multi UAV Communication, Path Planning, Pathloss, Forest fire detection**

I. Introduction

Unmanned Aerial Vehicles (UAVs) have proven successful in information gathering tasks, surveillance and communicating with each other. Unmanned Aerial Vehicles (UAVs) is the key component in detecting forest fire according to the system designed and also it works well for any provided situation and efficient approach to challenging places, especially in cases of emergency requirement. Initally a single UAV in the system is responsible and had a predefined path for its flight. In this study, the introduction of multi-UAV communication plays an important role in enhancing the effectiveness of the forest fire detection and response. The process begins with the UAVs with an advanced sensor which is used to detect the forest fire. Once the forest fire is detected the UAV will send the signal to the base station which will send the locations back to the base station. The base station acts a central hub and plays an important role in coordinating the response for the uavs. Using the multi-UAV communication the base station will determine which UAV is best suited to approach the forest fire. This methodology improves coordination among the UAVs and uses energy efficiently.

II. Objectives

Performance analysis of UAV - Base station network communications.

• For Each UE in NetSim, a UAV is instantiated in MATLAB as per the UE (UAV) ID.
• MATLAB calculates the flight path and passes the Mobility information to NetSim.
• In NetSim UE movement is modelled as per MATLAB UAV co-ordinates
• Pathloss calculations done in NetSim per 36.777
• To efficiently manage emergency situation using multi UAV communication
• To make it adaptable for forest fire detection at different places and analyse the scenarios more efficiently

$$PL_{RMa-AV-LOS} = max(23.9 - 1.8\, log_{10}(h_{UT}), 20)\, log_{10}(d_{3D}) + 20\, log_{10}\left(\frac{40\pi f_c}{3}\right)$$

Fig. 1: Pathloss Formula

III. Literature Survey

A. Advancements in UAV Technology

Unmanned Aerial Vehicles (UAVs) have become a dynamic and versatile technology for forest fire detection. It has a specialized sensors, UAVs can fly at low altitudes, offering detailed and real-time information on fire incidents. Their mobility allows for targeted monitoring in challenging terrains where traditional methods may be less effective.

B. UAV Applications in Environmental Monitoring

Review literature related to the use of UAVs for environmental monitoring, especially in the context of forest ecosystems. Highlight any studies or projects that showcase the efficacy of UAVs in detecting and responding to forest fires.

C. Machine Learning for Path Planning

Future directions should explore the integration of machine learning algorithms for dynamic path planning. This adaptive approach can enhance UAVs' ability to navigate complex terrains and optimize routes in real-time, improving overall efficiency. A few directions that could be explored are implementing reinforcement learning techniques to enable UAVs to learn from their past experiences. This can enhance the decision-making process by allowing UAVs to remember successful paths and avoid previously encountered obstacles, leading to more efficient and reliable path planning over time.Explore collaborative learning frameworks where UAVs can share learned information with each other. This can lead to a collective intelligence among a swarm of UAVs, allowing them to collaboratively plan paths, share knowledge about the environment, and adapt collectively to changes.

IV. Methodology and Novelty

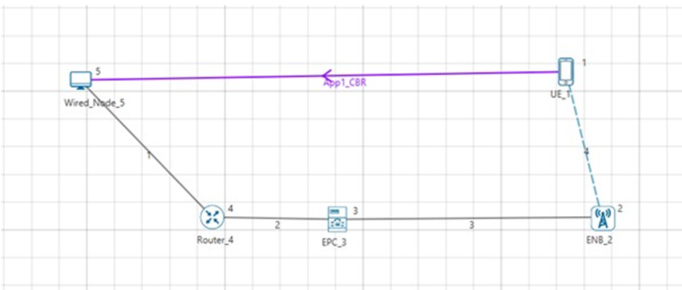

Fig. 2: Initial Netsim Simulation Model

In figure 2, the initial scenario involves a single UAV connected to a sole base station. The operational tasks of this lone UAV include detecting a forest fire, reporting the incident to the base station, receiving instructions or queries from the base station, and subsequently proceeding to the forest fire location for firefighting operations. However, it becomes apparent that a single UAV may not possess the capability to effectively manage and mitigate the forest fire independently, prompting the exploration of a multi-UAV approach.

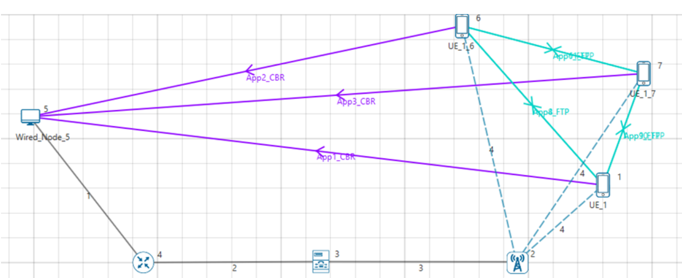

Fig. 3: Initial Multi-UAV Netsim Simulation Model

In figure 3 ,the introduction of multi-drone communication reveals a system where three drones are interconnected in a 2-way communication path (front and back) with each other via FTP. However, with all three drones connected to the base station, the potential for data collision arises, particularly when transmitting critical information such as the location of a forest fire. This situation may lead to data loss and complications when the base station responds, as

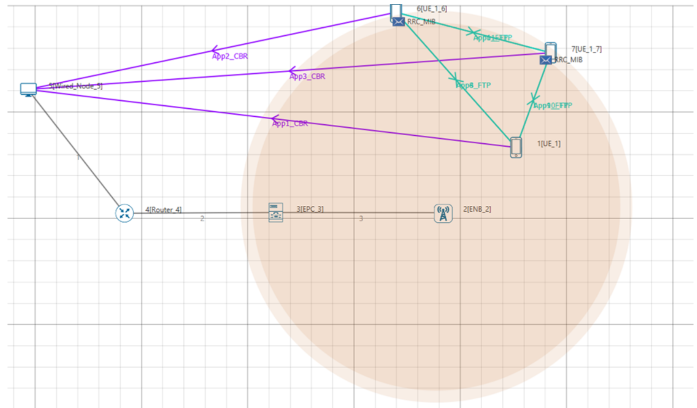

Fig. 4: Animation Output of Initial Multi-UAV Netsim Simulation Model

determining which UAV to address becomes uncertain. Two key issues emerge: the need for each drone to understand its designated surveillance area effectively, and the necessity to mitigate the risk of data collision by implementing a controlled communication strategy with the base station. Also, having all the drones communicate back to the base station also increases the load on the base station to process all the information received by each individual UAV. Figure 4 shows the corresponding animation output for the initial multi UAV model designed.

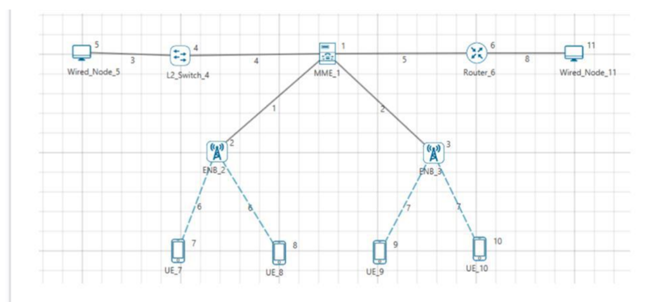

Fig. 5: Stage 2 Multi-UAV Netsim Simulation Model

In addressing the area segmentation challenge, as illustrated in Figure 5,a strategic solution has been implemented to allocate specific drones to distinct areas, each with its own designated surveillance responsibilities. However, a potential issue persists when multiple drones within a given area simultaneously detect a forest fire, leading to simultaneous communication with the base station. To enhance the efficiency and avoid redundancy in reporting, additional measures can be implemented.

In Figure 6, a hierarchical structure has been introduced to address the challenge of simultaneous fire detection by multiple drones within a specific area. The hierarchical arrangement involves designating leader drones within each surveillance area, and only these leader drones have the capability to

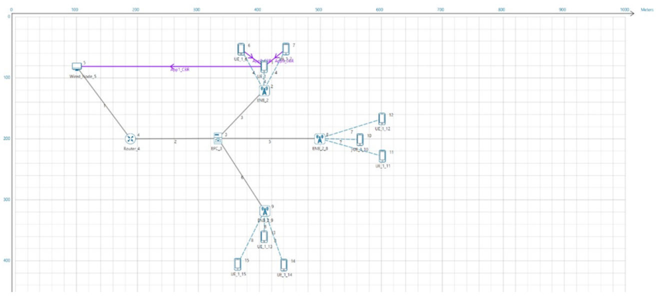

Fig. 6: Final Multi-UAV Netsim Simulation Model

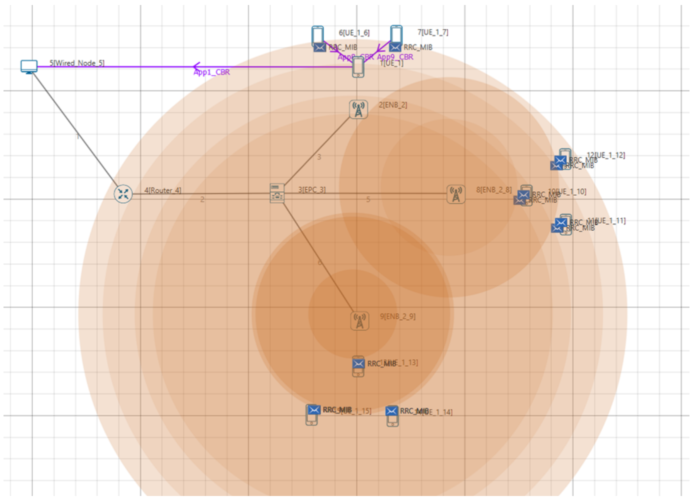

Fig. 7: Animation Output of Final Multi-UAV Netsim Simulation Model

communicate critical information, such as forest fire detection, to the base station. This hierarchical approach significantly reduces the risk of collisions and optimizes the communication process in scenarios where multiple forest fires are detected across various areas. The hierarchical structure establishes a leadership hierarchy within each surveillance area. Each group of drones is led by a designated leader drone, which assumes the responsibility of coordinating and communicating with the base station. This leader drone is strategically positioned to manage and consolidate information from the drones within its assigned area. The hierarchical structure allows for scalability and adaptability, enabling the system to accommodate an increasing number of surveillance areas or drones. New drones can be seamlessly integrated into existing hierarchies, and additional leader drones can be appointed as needed, ensuring flexibility and efficiency in the face of dynamic scenarios. Figure 7 shows the corresponding animation output for the initial multi UAV model designed.

In Figure 8,the displayed MATLAB window serves as a pivotal interface, enabling users to fine-tune and customize the features of the environment for detecting and setting the flight path. Using MATLAB we enable the developers to dynamically adjust parameters, such as environmental characteristics, to optimize the drone's ability to detect and respond to its flight path. Here, the environmental factors are taken into consideration such as wind, wind direction and strength can be set. By providing this level of control over environmental features, Figure 5 enhances the adaptability and realism of the simulation, allowing for a more nuanced examination of the drone's performance in diverse and adjustable settings.

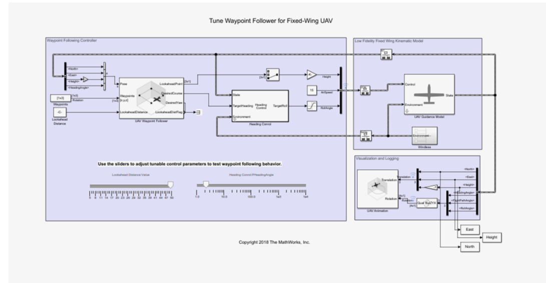

Fig. 8: uav model1

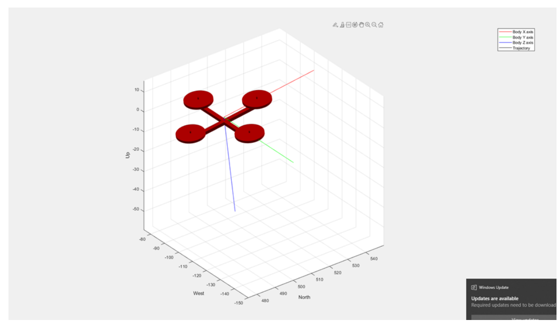

Fig. 9: uav model1 output

In Figure 9, the displayed output provides a visual representation of a simulated drone diligently adhering to a predefined path. The simulation captures the dynamic movement of the drone as it navigates along the specified trajectory.As this output window runs we see the drone move as it follows its pre defined path. This visualization offers valuable insights into the effectiveness of the drone's path-following capabilities, showcasing its ability to maintain a precise course under the set and simulated environmental conditions.

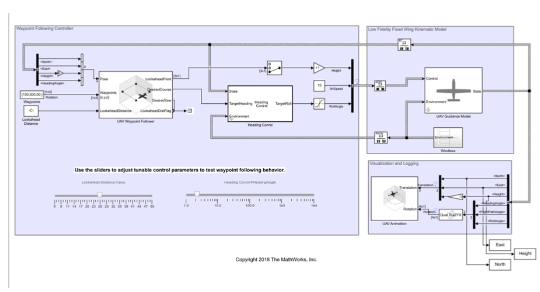

Fig. 10: uav model2

In Figure 10, the picture shows a different environment for UAV 2 compared to UAV 1. It represents various landscapes, demonstrating how adaptable the simulation environment is.

Importantly, this figure lets us change settings, highlighting the simulation's flexibility. By presenting a different environmental context, the simulation provides an opportunity to assess how UAVs respond to diverse conditions and challenges. This capability to manipulate parameters adds a layer of complexity and realism to the simulations, enabling a more comprehensive evaluation of UAV behavior in different scenarios. Figure 7 thus stands as a valuable tool for researchers and developers to explore and optimize UAV performance across a range of environmental settings.

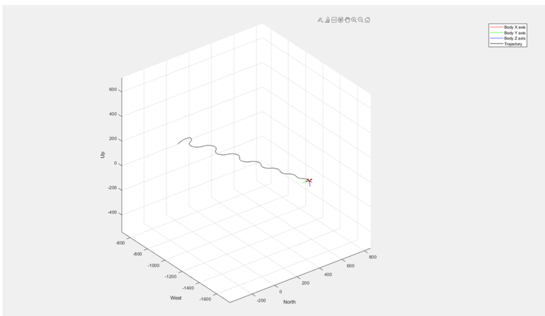

Fig. 11: uav model2 output

In Figure 11, the picture shows a complete 3D view of the entire path the drones take. This helps us see how the drones move in space from start to finish. The 3D image gives us a detailed look at not just the path on the ground but also how high or low the drones go during their journey. It provides a full picture of how the drones move in both horizontal and vertical directions.

V. Theory

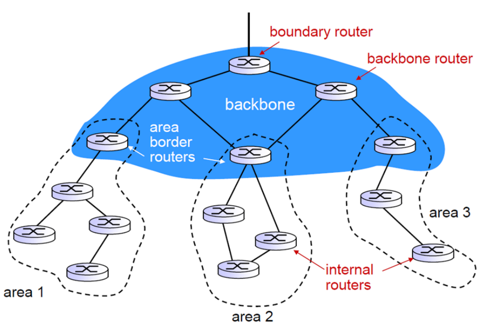

Fig. 12: Hierarchical OSPF

The latest simulation model draws inspiration from the concept of hierarchical OSPF (Open Shortest Path First), adapting it to the context of a multi-drone system. In this analogy, the internal routers represent the UAVs, each allocated to specific areas for surveillance. The hierarchical structure is established by designating certain UAVs as area leader drones, akin to area border routers in OSPF. These area leader drones possess the dual capability of communicating with UAVs within their designated area and serving as mediators between the UAV field and the base station. Furthermore, the boundary router in the analogy corresponds to the base station, functioning as the central hub for processing incoming data and making decisions regarding subsequent actions. Area leader drones play a crucial role as mediators between the internal routers (UAVs) and the boundary router (base station). They are equipped to communicate bidirectionally, relaying critical information from UAVs within their assigned area to the base station and vice versa. This hierarchical arrangement streamlines the communication process, preventing data collisions and ensuring that only relevant and prioritized information reaches the base station. Inspired by OSPF's adaptability and scalability, the simulation model is designed to accommodate changes in the system seamlessly. As the number of surveillance areas or UAVs fluctuates, the hierarchical structure can be adjusted dynamically, and new area leader drones can be appointed to maintain an efficient and organized communication framework. By integrating the principles of hierarchical OSPF into the simulation model, the multi-drone system achieves a well-organized and adaptable communication structure. This hierarchical approach enhances the efficiency of data transmission, reduces the risk of collisions, and ensures that the base station receives relevant and prioritized information for effective decision-making in response to events detected by the UAVs in different surveillance areas.

VI. Results and Analysis

A. Phase 1

we concentrated more on multi-UAV communication and and tried to improve the scalability of our project as forest area and vast. The project works well when UAVs put off the fire using carbon dioxide gas. Carbon dioxide gas cuts off the oxygen supply to the fire by acting as a shield. Using carbon dioxide is best because even the weight of the drone does not increase by much. The main problem was collision of data. As the forest area increases, we have to introduce more and more drones for surveillance. This adds to the problem of collision of data. For this problem, we introduced idea of assigning a fixed amount of drones for a single area.

B. Phase 2

Our main aim here is to decrease collisions. As huge amount of drones are used, there is high chance for collisions and loss of data. Then we introduced the concept of "Leader-Drone". Each area has its own assigned leader drone. Only leader drone can communicate to the base station. So if we have 10 areas, we'll have 10 leader drones. each leader drone can have its own slave drones. slave drones can only communicate to its leader drone. Leader drone only can communicate to the base station and if the base station wants to communicate with an area, it can only happen via the leader drone. By this hierarchical organisation, collisions are somewhat reduced. Even if there is fire in different regions of the forest (this can mainly happen due to thunderstorms) the drones can communicate smoothly and the assigned drones for that particular area, will take care of the fire in their specific regions.

VII. Conclusion

In conclusion, the integration of multi-UAV communication has proven to be a transformative and highly effective approach in the context of forest fire detection. The utilization of Unmanned Aerial Vehicles equipped with advanced sensors, coupled with a robust communication network, has significantly enhanced our ability to monitor and respond to potential fire incidents in challenging landscapes.

The collaborative efforts of multiple UAVs, facilitated by seamless communication with a centralized base station, have demonstrated improved coverage, responsiveness, and data reliability. This approach not only allows for swift detection of forest fires but also optimizes the allocation of resources by strategically dispatching the most suitable UAV to the incident site.

The multi-UAV communication system ensures that critical information, such as fire location and severity, is accurately relayed to the base station, enabling informed decision-making. This, in turn, enhances the overall efficiency and effectiveness of forest fire response efforts.

As we continue to face the escalating challenges of wildfire management, the integration of multi-UAV communication stands as a beacon of innovation, offering a proactive and technologically advanced solution to safeguard ecosystems and human lives. Through this approach, we forge a path toward a more resilient and adaptive framework for forest fire detection and mitigation.

References

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