2024 IEEE 14th Annual Computing and Communication Workshop and Conference (CCWC) | 979-8-3503-6013-4/24/$31.00 ©2024 IEEE | DOI: 10.1109/CCWC60891.2024.10427650

Rotational Flying Station for Wireless Access in Large Disaster Area

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***Abstract*—In disaster-affected areas, the lack of cellular network connectivity can be a matter of life and death. To address this issue, we propose the use of an unmanned aerial vehicle (UAV) equipped with a small base station that can provide emergency networks. However, existing research shows that the coverage range of such UAVs is limited and can be costly. To overcome these challenges, we introduce an innovative Rotational Flying communication drone that features a UAV with a rotational antenna attached to a cellular base station. Our solution expands coverage, saves power, and reduces costs, enabling victims to contact rescue teams and address their situation. With our technology, users can communicate in real-time through video, share aerial footage of affected regions, and engage in asynchronous text chat even when cellular or wireless networks are down. We conducted a thorough analysis of the flying communication server's range of connections, including the user ground-covered distance frequency rate to disperse the network. Our simulation results with a theoretical explanation that validates that coverage expansion, power savings, and low costs can significantly improve emergency communication and provide a network with fewer drones than the existing work.**

***Index Terms*—Drone Base Station; UAVs; Cellular network; Emergency Communication; Disaster.**

I. Introduction

Visual imaging and 3D mapping are instrumental in areas prone to large-scale disasters like earthquakes and flooding. Manned aircraft are typically prohibitively expensive, satellite mapping falls short of high-resolution requirements, and both take too long in emergencies. UAVs have become increasingly popular for air-to-ground communication. It is challenging to collect accurately in emergencies due to the need for coordinated actions by diverse agencies during a disaster. Nonetheless, it is conspicuous that to expand disaster management efficiency, advanced methodologies and technologies are required to theorize systems that build integration of telecommunication devices, remote sensing, and spatial or temporal-oriented databases [1]. Drones can reduce the risks that pilots experience while increasing the effectiveness of firefighting. Unmanned aircraft can fly in reduced visibility and drop fire retardants with greater precision and safety. Drones equipped with communication devices have the added benefit of allowing firefighters on the ground to maintain contact with the command center.

Several technical studies were conducted to address challenges in channel modeling, UAV deployment, trajectory optimization, maximizing coverage area, and resource management. In prior research, UAVs acted as base stations with a single antenna to serve multi-user communications but focused on the velocity vector of UAVs [2]. A range of connectivity for the Flying Communication Server includes Wi-Fi range, video streaming frame rate, and maximum number of concurrent users [3].

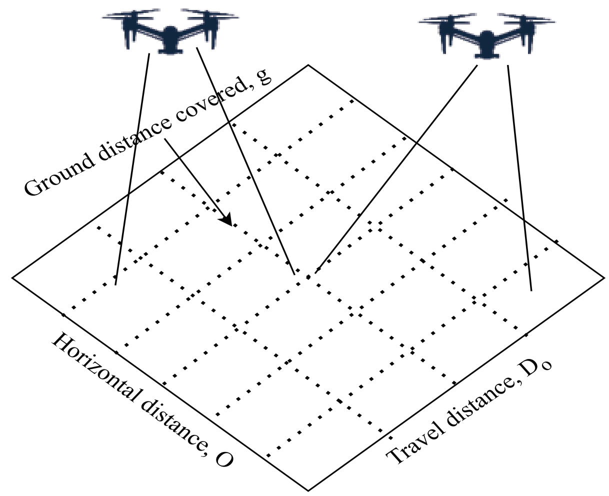

Fig. 1. Large Disaster Affected area L

The drawback of most research is that they work in a single antenna drone cell. Their work was trying to maximize the coverage area network. In disaster areas, we need a communication system and brief contact with the rescue team. If we use the model, we can cover only 50m. The attached camera module is at a 60-degree viewing angle towards the ground [3]. Therefore, they cannot cover large areas on short notice and cheaply.

In our proposed model, we will attach a rotating device to our Drone base station to cover more than 120 degrees, whereas, in other models, it covers only 60 degrees. We reduced the number of drones from 2 to 1, reducing the overall cost by half. The coverage range is more extensive than the previous work in our proposed model. In our work, the drone's height will be reduced from the traditional work to cover more area, but the distance on both sides will be the same.

The main contribution of this paper is,

- We increased the coverage range at a low cost in emergency communication in large disaster areas.
- Our drone will enter the disaster-affected zone and provide network frequency to the affected locals.

This work was supported in part by the US National Science Foundation (NSF) under Grant No. CCSS-2025307 and Lamar University Center for Resiliency (CfR) under Award 23LP02.

- The drone will also take videos and pictures, immediately sent to the rescue teams.
- The reach of connectivity of the flying communication server, such as ground covered distance, frequency rate with low power to distribute network.

II. Literature Review

As a result of the high altitude at which DSCs operate, their air-to-ground channel comprises probabilistic line-of-sight (LoS) and non-line-of-sight (NLoS) links. This, in turn, presents computational challenges when analyzing performance [4]. The wireless backhaul for UAVs is usually capacity-limited and congested. Because UAVs cannot operate for extended periods due to their limited battery life, the author proposed a framework of caching UAV-enabled small-cell networks to offload the data traffic of small-cell base stations (SBSs) [5]. Another study has presented closed-form equations for the urban channel model dependent on height. These equations cover heights up to 40 m and calculate path loss slope and shadowing. The study also compares the calculated results with observed results. Furthermore, a real UAV was used to measure the effects at higher levels, up to 120 m, to see how these effects extend to such heights. This study delves into the impact of site density on interference analysis in urban areas, an area that has previously only been explored in rural scenarios [6]. The problem of designing precoding at cluster DSCs to minimize the transmission power of UABSs and eliminate the intra-cluster interference via performing the modified zero-forcing method and coordinate the inter-cluster interference to achieve our target of reducing transmit power [7]. Autonomous drones can be deployed in disaster areas to provide internet service to affected users. To minimize the distance between the drones and users, the drones need to measure the strength of the received signal and share that information with other nearby drones [8]. The primary aim of optimizing the placement of drones in areas affected by disasters and with limited backhaul communication ranges is to ensure that the maximum number of users are served [9]. Propose a time division hybrid energy harvesting protocol to minimize the average electric energy consumption of a drone-based cellular IoT system to characterize the distribution of machine-type communication gateways in a single cellular coverage [10]. It has investigated the problem of environment-aware deployment of drone base stations that provide wireless connectivity to ground users. Geospatial data is collected, and obstacles that disrupt UAV-to-ground user communications are identified using the Google Earth Engine platform and its image processing functions [11]. The use of drones to re-establish communications in Disaster relief is a concept that has only been tried by a few Groups around the world to date. Using the idea of a git repository, people worldwide who have a phone or know someone who has one can guarantee that people use the aerial MANET to call for help [12]. 3-D continuous movement control of multiple drone cells is formulated to maximize the energy-efficient communication coverage of drone-cell networks while preserving the network connectivity [13]. The coverage probability performance of multiple drone base stations while considering flexible, dynamic changes of this scalable on-the-fly network and the effect of antenna patterns and height-dependent shadowing [14].

Large-scale natural disasters can result in unpredictably high human casualties and damage to man-made infrastructure. This can make it difficult for survivors and search and rescue personnel to communicate, reducing the chances of discovering survivors. As a result, deploying drones outfitted with base stations to operate as temporary small cells is one viable alternative for mobile and adaptive emergency communication networks [15]. While the asset in a radio base station or even a complete mobile core system is well-motivated, numerous practical issues of such drones, which typically carry limited and expensive transportable energy resources, are not adequately considered, such as weight, power consumption, and corresponding flying duration [16]. Multiple Reconfigurable Intelligent Surfaces (RIS) were used with drones because they allow coverage expansion, interference reduction, and energy savings at a cheap deployment cost. In contrast to the typical DBS model, power loss in the extended coverage area has not reduced but instead stayed constant [17]. High data rates, omnipresent services, and flexibility are all promises of future cellular networks. UAV-assisted networks are a promising system design for expanding network coverage and increasing capacity. The system's performance depends heavily on the quality of the backhaul link between the flying node and the ground base station. The aerial flying node's signal strength and interference levels are critical performance criteria for the backhaul connection's quality [18]. A drone fitted with a smartphone main board that establishes a Wi-Fi hotspot network and user equipment, a smartphone capable of making voice-over Wi-Fi calls, make up the drone-based system [19]. Existing cellular outage reporting systems lack sufficient regional granularity and do not give a real-time view of the communication network's status. It measures real-time coverage and quality of service using crowd-sourced data from consumer and first responder phones [20]. Drone-mounted base stations (DBSs) can swiftly restore mobile user (MU) connections in disaster-stricken areas. The access connection data rates between DBSs and MUs are well provided since DBSs may be put near MUs. However, because DBSs are often located distant from remote working base stations, the data rate of the backhaul link between a DBS and the remote working base station may be throttled [21].

III. Proposed Model

A. Motivation

The motivation for this research concerns the climate of Southeastern Texas, where various kinds of disasters like tornadoes, floods, and hurricanes happen every year. When the storms hit, residents are in crisis with communication because their electricity and power supply are lost, and even the rescue teams cannot communicate efficiently. In the proposed work, our drone base station will go to the area where the disaster occurred and provide the network coverage to contact their nearby emergency team, allowing restoration of services in a shorter period and at a lower cost than is currently operating in the more traditional means of ascertaining and fixing outages. In the proposed work, there are three antennas which can cover around 100m.

In Figure 2, the drone has the same distance d, height h, and radius R. The three antennas are attached to the drone's bottom part. The traditional height is h, but in our proposed model, we will reduce the drone's height when the reduced drone height is h_n. The new height is h – h_n. When the drone reaches the h_n point, it can spread its network area and give more coverage, and the distance will be the same d. The radius and distance angle are θ and new angle θ_n new radius Rn. After reducing the drone's height, the radius perimeter will be increased, providing more coverage to the surface area. So, it can provide a cellular network to local people affected by a disaster.

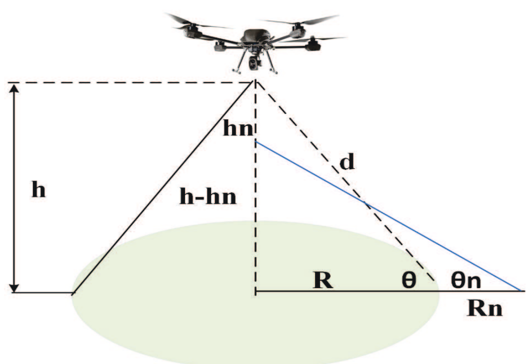

Fig. 2. Rotational Flying cell area 1

In Figure 2, the coverage area will be increased as the radius increases. So, the angle also increased. In this way, it can lower the cost of the whole infrastructure and can provide the system to them in a fleeting time.

B. Hardware Design

Because of the high data rate and cheap monetary cost, wireless local area networks (WLANs) have become a top choice for mobile users (MUs) with the rising popularity of massive data stream mobile apps. However, WLAN management services, such as mobility management and load balancing, may degrade the battery life of mobile devices, which is the most critical aspect of MUs. Unfortunately, few contemporary WLAN systems consider mobile device energy efficiency and management service performance [22]. The drone is designed with three antennas. From each antenna, they will connected to a Wi-Fi device, which will provide a network to the disaster-affected area. Between each antenna, the angle will be 60 degrees. So, the total angle will be a 120-degree area that our proposed drone can cover to provide a network connection. One rotational device is attached at the bottom of the drone, and the antenna with the rotational device can cover omnidirectional. It then improved the idea from Figure 2. The drone can rotate and cover more areas

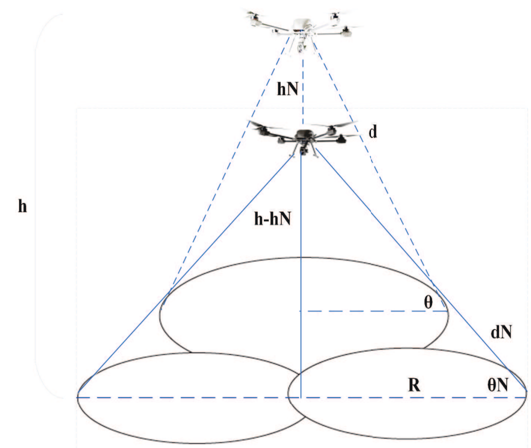

Fig. 3. Rotational Flying cell area 2

as it is attached to the rotational antenna. After reducing the height of the drone, distance d is the same. In Figure 3, two drones are showing each antenna's surface area. The blurred one position is the same as the traditional one's height, which is h. The position of the proposed drone's height decreased by hN. Therefore, the new height will be h-hN. Each antenna's surface area overlapped, so there was no gap between the three antenna's areas. If it is compared with the existing work, the proposed work can provide a network signal to more people in a larger area.

In Figure 3, each of the eclipses has its radius. Therefore, the wider the coverage ranges, the more people can access the network. The frequency rate will also be the same as in the edge point.

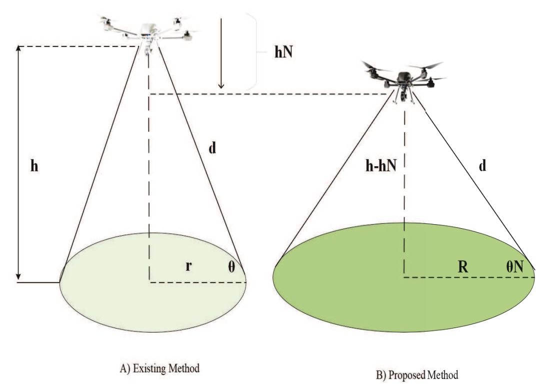

Fig. 4. Rotational Flying cell area 3

Figure 4 compares the previous and proposed models to show the difference from the first appearance of the drone's height. Secondly, the coverage area is increased from the existing model from Figure 4A, calculating the distance d from the radius r and height h. The Pythagoras formula:

$$d = \sqrt{r^2 + h^2} \tag{1}$$

The angle θ can be from height and radius divination with the inverse of a tangent.

$$\theta = tan^{-1}(\frac{h}{r}) \tag{2}$$

The average path loss (PL) for LOS and NLOS links are, respectively,

$$PL_{L}oS(dB) = 20Log(\frac{4\pi f_c d}{c}) + \sigma LoS \tag{3}$$

$$PL_{N}LoS(dB) = 20Log(\frac{4\pi f_c d}{c}) + \sigma NLoS \tag{4}$$

The expression $20\log_{10}\left(\frac{4\pi f d}{c}\right)$ calculates the path loss at distance d for a signal with central frequency f, speed of light c and standard deviation σ.

Now, in the proposed model, the new formula is for the distance of the drone to come from the square of the radius, which is the addition of radius r and new radius rN, and the remaining height will be subtracted from traditional height and new height with square and the whole result will be square root.

$$d = \sqrt{(r + r_N)^2 + (h - h_N)^2} \tag{5}$$

Additionally, now the new angle θ_N,

$$\theta_N = tan^{-1}(\frac{h - h_N}{r + r_N}) \tag{6}$$

From equation 5, we can calculate the distance. In Figure 5, we tried to show a 2D and 3D view to give the entire area range. Figure 5A is the same as the existing method, but 7B is our proposed model. We draw three dash lines for three antennae to clarify how the network range is provided. For each antenna, a range of area is covered, and in the middle of those three surface areas, there is an overlapped area. In this overlapping area, if any user is there, they can use whichever network the user prefers. The edge user gets a signal from their nearby network. As the drone's antenna is rotating, there will be no empty network place where the user will be out of network. Consider the disaster-affected area L shape of size $D_0 * O$ shown in Figure 1. The calculated g covers an area that is less than L. As a result, many drones, N_z, are necessary to cover the whole L.

$$N_z = \frac{D_0}{\sqrt{2}g} \cdot \frac{O}{\sqrt{2}g} \tag{7}$$

Equation 7 calculates the horizontal distance, O, and travel distance, D_0, considering two drones.

C. Protocol Design

In each antenna, the user can get access to their nearby distance antenna. We can demonstrate user distance U(d), distance vector d, time t, antenna A1, A2, and A3.

Rotational Time Division Multiple Access (RTDMA) is a method of digital modulation used for mobile radio and digital cellular communication. RTDMA is a way to divide the limited network available over a radio frequency (RF) cellular channel.

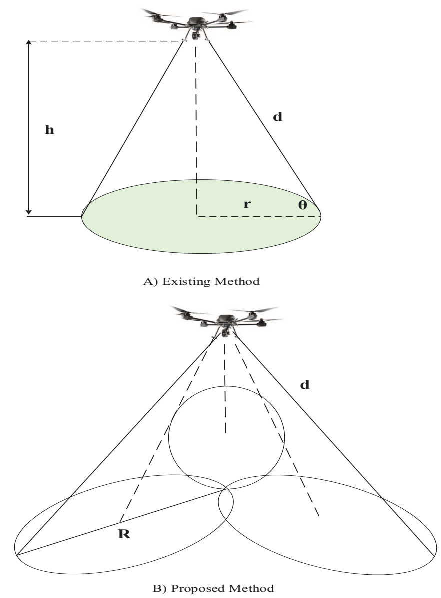

Fig. 5. Rotational Flying cell area 4

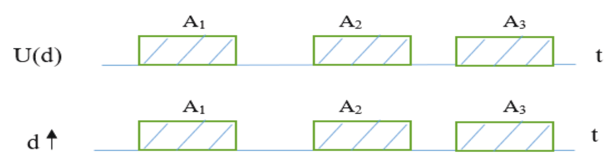

Fig. 6. User distance for antenna

Each user has a selected antenna with a different time slot. RTDMA allows the radio component of a mobile station to listen and broadcast only during its designated time slot. User U1, U2, and U3 have different antennas with the time. As the antenna is rotating, an overlapped area will allow the user to choose the network.

The main application scenario is to serve the area right after the disaster strikes, like after a hurricane, many buildings and facilities are destroyed, and people need to communicate with the outside. If the weather conditions become severe,

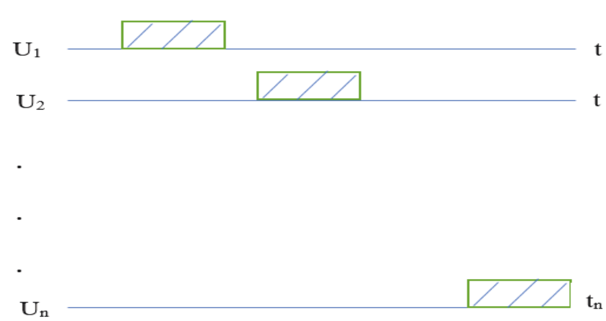

Fig. 7. Multiple user antenna with time

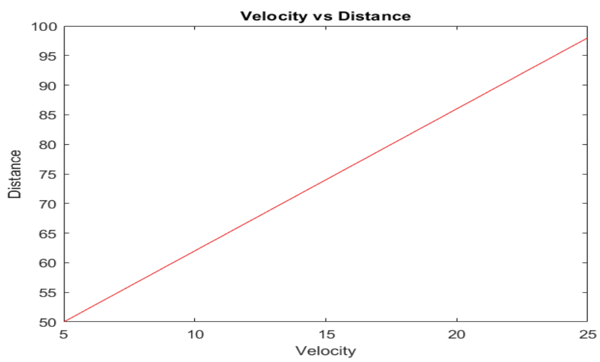

Fig. 8. Distance vs Velocity calculation

we can land the drone on a steady roof or high building instead of flying by changing the antenna installation design. Moreover, we also have a backup drone to take turns for the same serving area so that backup drones can take turns. As we mentioned, we will have multiple drones in single point-of-failure scenarios, but each can cover a larger area with our design. Compared with traditional design, which results in more drones for the same area, they will fail more drones with the same probability. For the system's high user demand and congestion, there are already some apps designed for this scenario that only emergency and text messages or preprocessed images will be collected and sent, so there will be no congestion. Plus, this is the work for mobile app design or emergency protocol design, which is out of the scope of our work.

IV. Simulation

A. Distance vs Velocity calculation

We present our findings on the comparison of distance and velocity of the drone in Figure 8. Our objective was to gather data to support disaster-affected areas. Our simulation results indicate that by increasing the drone's rotational speed, the drone can cover a distance of approximately 100m, which represents a significant improvement from the previous demonstration of 50m.

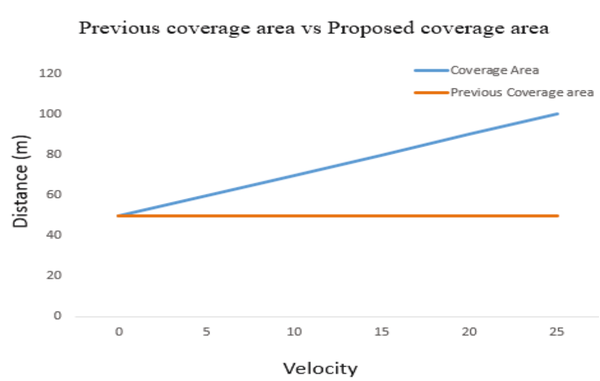

Fig. 9. Comparison of Previous coverage area vs Proposed coverage area

B. Comparison of Previous coverage area vs Proposed coverage area

As depicted in Figure 9, the previous coverage area spanned approximately 50 meters, while the proposed work coverage range nearly doubles that reach to over 100 meters. Figure 9 further highlights the disparity between the existing and proposed coverage areas. Our innovative model not only cuts costs, but also extends network access to more individuals, boasting a survival rate that surpasses that of traditional methods.

As the velocity increases, the overhead also tends to increase. As shown in Figure 10, we have identified the optimal point for both parameters. Specifically, when the velocity is set to 3, we can observe the overhead optimal point.

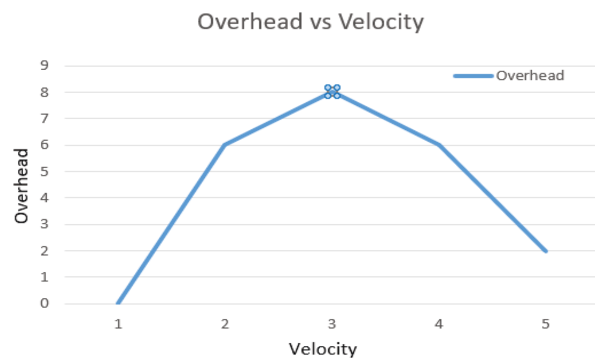

Fig. 10. Relation between Velocity vs Overhead

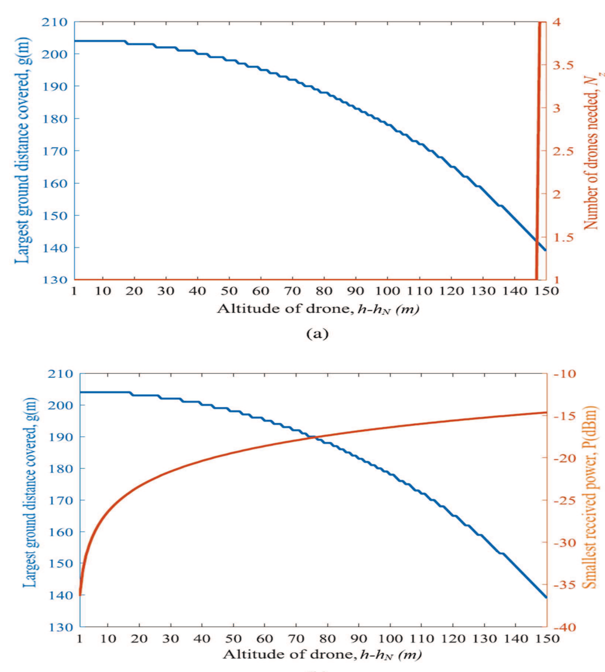

Fig. 11. (a) the smallest power P received as a altitude of $h - h_N$, and (b) number of drones N_z needed as a altitude of $h - h_N$.

C. The Largest Area of Coverage

Figure 11 provides valuable insights into the capabilities of the drone at reduced heights. Specifically, it outlines the maximum ground distance covered, the least received power P, and the number of drones required N_z to cover the entire area L. The drone's ultimate ground distance capacity is 0.5 Gbps.

Figure 11a demonstrates that a drone can cover the disaster-affected area where the reduced height $h - h_N$ is around 146 m. The number of drones is to be expected as they are arranged in a 3-dimensional grid where their number rises exponentially depending on the affected area. If the area is around 200 m, figure 11 shows we will need two drones with overlapping areas when they give coverage. As an illustration, N_z increases from 1 to 2, and the height is more than 142 m because the ground covered distance g is more than 200 m. As our proposed drone can cover around 100 m, it takes two drones to cover 200 m.

Figure 11b displays the power received P, with the region of coverage edge, as the function of $h - h_N$ calculated with the aid of ground distance g. The graph demonstrates that for a height less than 160 m, the power is around -40.4 dBm.

V. Conclusion

We proposed the Rotational Flying Communication Server, a cutting-edge solution equipped with three antennas attached to a unique rotational device located at the bottom of the drone. Each antenna exhibits superior coverage area, and there is an overlapped network area at the center of the three antenna's covered zones. Our drone is designed to provide emergency communication networks to disaster-affected areas, allowing users to record or share videos and pictures, or even text the rescue team, through our wireless cellular network. Our proposed work can cover up to approximately 100m using less power in the affected area, which is almost double that of any previous work.

In our future work, we aim to put our proposed model into practice and compare its simulation results with real-time experimental data to ensure utmost accuracy.

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