Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2024.Doi Number

Optimized UAV-Based Relay Algorithm for Enhanced Emergency Wireless Coverage in Disaster Areas

Deepika Rani Sona[1], A. Visalakshi[2], B. Kalapraveen[3], Senior Member, IEEE, Mohammad Alibakhshikenari[4], Member, IEEE, Bal Virdee[5], Senior Member, IEEE, Zafar Iqbal[6], Lida Kouhalvandi[7], Senior Member, IEEE, Giovanni Pau[8], Senior Member, IEEE, Mekala Manikanta[9], Kakarla Akash Gangireddy[10], Swaroop Dintakurthi, Kondreddy[11], Santhosh Kumar Reddy[12], Ernesto Limiti[13]

[1]School of Electronics Engineering, VIT, Vellore – 632 014, India (E-mail: deepa.drs@gmail.com)
[2]School of computer Science and Engineering, VIT–AP University, Amaravati–522237, India (E-mail: visalakshi.a@vitap.ac.in)
[3]School of Electronics Engineering, VIT–AP University, Amaravati–522237, India (E-mail: kalapraveen.b@vitap.ac.in)
[4]Department of Signal Theory and Communications, Universidad Carlos III de Madrid, 28911 Leganés, Madrid, Spain (E-mail: mohammad.alibakhshikenari@uc3m.es)
[5]Center for Communications Technology, London Metropolitan University, London N7 8DB, United Kingdom (E-mail: b.virdee@londonmet.ac.uk)
[6]Department of General Surgery, College of Medicine, King Saud University, P.O.Box 7805 , Riyadh , 11472, Kingdom of Saudi Arabia (Email: zsyed@ksu.edu.sa)
[7]Department of Electrical and Electronics Engineering, Dogus University, Istanbul 34775, Turkey (E-mail: lida.kouhalvandi@ieee.org)
[8]Faculty of Engineering and Architecture, Kore University of Enna, 94100 Enna, Italy (E-mail: giovanni.pau@unikore.it)
[9]School of Electronics Engineering, VIT, Vellore – 632 014, India (E-mail: mekala.manikanta0910@gmail.com)
[10]School of Electronics Engineering, VIT, Vellore – 632 014, India (E-mail: akashgangireddy31@gmail.com)
[11]School of Electronics Engineering, VIT Vellore – 632 014, India (E-mail: swaroopdintakurthi17@gmail.com)
[12]School of Electronics Engineering, VIT Vellore – 632 014, India (E-mail: santhoshreddy1848@gmail.com)
[13]Electronics Engineering Department, University of Rome “Tor Vergata”, Via del Politecnico 1, 00133 Rome, Italy (e-mail: limiti@ing.uniroma2.it)

Corresponding authors: Kalapraveen B. (e-mail: Kalapraveen.b@vitap.ac.in), Mohammad Alibakhshikenari (e-mail: mohammad.alibakhshikenari@uc3m.es); and Giovanni Pau (e-mail: giovanni.pau@unikore.it)

Dr. Mohammad Alibakhshikenari acknowledges support from the CONEX-Plus programme funded by Universidad Carlos III de Madrid and the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 801538. Also, the authors sincerely appreciate funding from Researchers Supporting Project number (RSPD2024R706), King Saud University, Riyadh, Saudi Arabia.

ABSTRACT In the face of natural disasters, establishing effective communication networks is crucial for coordinating rescue efforts and providing aid. Traditional communication infrastructures are often compromised, leaving affected areas with limited connectivity. This study proposes an optimized UAV-based relay algorithm for enhancing emergency wireless coverage in disaster areas. The algorithm leverages unmanned aerial vehicles (UAVs) as communication relays to extend coverage, enhance communication capabilities, and aid in disaster response. The algorithm consists of several key components. Firstly, it assesses the disaster area using UAV-mounted sensors to identify communication blackspots. It then develops an optimal UAV deployment strategy considering altitude, battery life, and communication range. A robust communication protocol and error correction mechanisms are implemented for seamless data transfer between ground devices and UAVs. Dynamic relay positioning and energy-efficient routing algorithms are developed to adapt to changing conditions and optimize energy consumption. Our simulations show the effectiveness of the algorithm in optimizing path loss, loss probability, and device-to-device (D2D) communication capacity. The algorithm's adaptability to dynamic environmental conditions and its ability to optimize energy consumption make it a valuable tool for disaster response. The proposed algorithm significantly enhances communication capabilities in post-disaster scenarios, enabling more effective coordination of rescue efforts and aid provision. Overall, the optimized UAV-based relay algorithm presents a promising solution for enhancing emergency wireless coverage in disaster areas. Further refinement and real-world testing will help validate its effectiveness and applicability in disaster response scenarios.

INDEX TERMS Communication networks, D2D communication, Disaster areas, Energy-efficient routing, UAV-based relay algorithm.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) have emerged as indispensable tools, particularly in disaster response scenarios, owing to their adaptability and functionality across various applications. Their unique capability to navigate through challenging terrains and access remote areas where conventional communication infrastructure is unavailable or disrupted makes them invaluable assets in post-disaster situations. This strategy aims to incumbrance the capabilities of UAVs by leveraging them as communication relays to extend coverage in disaster-affected regions, thereby enhancing communication capabilities and supporting disaster response efforts [1] –[3]. One pivotal aspect of this initiative is the integration of UAV-mounted sensors for real-time assessment of disaster-affected areas. These sensors are crucial in identifying communication blackspots and facilitating strategic planning for UAV deployment to optimize coverage and connectivity [4]–[6]. By leveraging UAVs, innovative solutions can be devised to address communication challenges and bolster overall disaster mitigation efforts [7].

Furthermore, the proposed scheme emphasizes the development of an algorithm for optimal UAV deployment, considering factors such as altitude, battery life, and communication range. This algorithm, backed by optimization techniques, aims to determine the ideal number of UAVs required to achieve comprehensive coverage, thereby maximizing the effectiveness of the communication network in post-disaster scenarios [8], [9]. Ensuring reliable communication between ground devices and UAVs is another critical aspect of this endeavour, which is addressed by implementing a robust communication protocol. This protocol incorporates error correction mechanisms to mitigate potential disruptions in communication channels, ensuring seamless data transfer even in challenging environments [10]. Moreover, the execution focuses on developing energy-efficient routing algorithms for UAVs during communication relay operations. These algorithms optimize energy consumption by considering variables such as distance, altitude changes, and battery capacity, thereby ensuring sustainable and efficient deployment of UAVs and contributing to the overall effectiveness of the communication network in disaster relief [11], [12].

The proposed work aims to significantly enhance communication capabilities in post-disaster scenarios by addressing these key components. Fig. 1 shows UAV-based relay deployment for enhanced emergency wireless coverage in disaster areas. Unmanned Aerial Vehicles (UAVs), commonly known as drones, are strategically positioned in the disaster zone [13]. The UAVs act as relay stations, extending wireless communication coverage beyond the reach of ground-based infrastructure. The image contrasts the connectivity scenario before and after the UAV deployment. This technology ensures that emergency responders, affected individuals, and relief teams can communicate effectively even in challenging environments. The Optimized UAV-Based Relay Algorithm leverages drones to bridge communication gaps during disasters, providing crucial connectivity for emergency operations. The integration of cutting-edge technologies and methodologies, coupled with a thorough understanding of UAV capabilities and communication dynamics, forms the cornerstone of this initiative, promising transformative Outcomes in disaster management and response [14].

A. RELATED WORK

In recent years, the utilization of UAVs has gathered significant attention across various fields due to their versatility and effectiveness in diverse applications, particularly in disaster response scenarios [15], [16]. The ability of UAVs to navigate challenging terrains and access remote areas inaccessible to traditional communication infrastructure makes them invaluable assets in post-disaster scenarios [17]. This literature review aims to delve into the extensive body of work surrounding UAV-based communication systems and their role in disaster management and recovery efforts, drawing insights from various referenced studies—wireless communications with UAVs present opportunities for versatile communication in disaster scenarios. However, challenges such as signal interference need to be addressed to ensure reliable and uninterrupted communication channels. UAV-Assisted Communication offers efficiency through imitation learning, although it may require substantial training data to optimize performance fully.

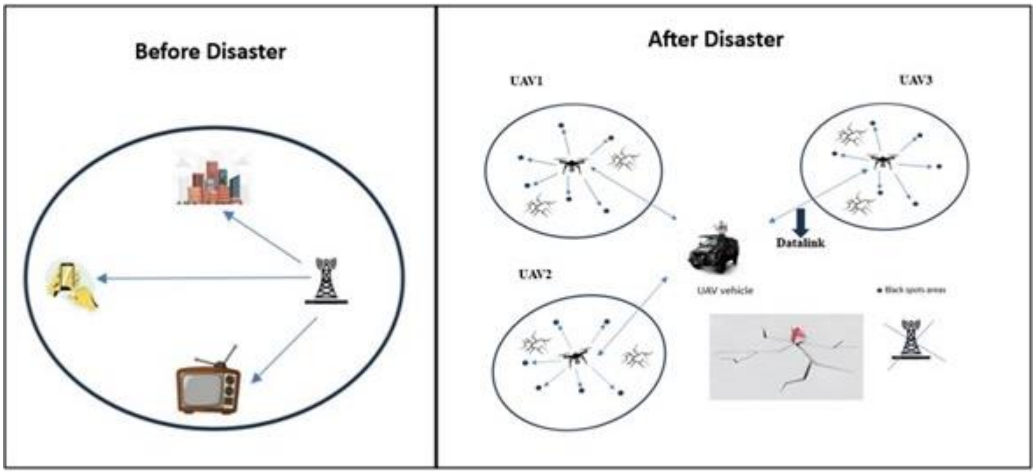

FIGURE 1. **UAV-based relay deployment for enhanced emergency wireless coverage in disaster areas.**

Disaster-resilient emergency Communication emphasizes integrating air-ground cooperation but faces complexities in coordination during large-scale events [18], [19]. 5G Millimeter Wave Communications explore the advantages of high-frequency communication but acknowledge limitations in coverage range under certain scenarios, which are crucial considerations for disaster-affected areas [20]. UAV communication Networks for 5G highlight scalability and adaptability but also note the resource-intensive deployment required. Self-organizing relay Selection focuses on efficient network organization but encounters challenges in dynamic selection processes, particularly in rapidly changing disaster environments [21], [22].Multi-hop and device-to-device (D2D) Communications extend coverage through multi-hop routing but may experience potential interference in crowded areas, impacting communication reliability [23], [24]. Dynamic wireless charging supports continuous operation but faces infrastructure and compatibility challenges that need to be addressed for widespread implementation [25], [26]. The Role of UAVs in Public Safety showcases their potential to enhance emergency communication, albeit with considerations regarding energy consumption and cost-effectiveness. The authors discussed that UAVs for post-disaster communication are pivotal for rapid deployment during recovery phases, although limitations in endurance and payload capacity must be managed for sustained operations [27], [28]. Public Safety Network with D2D emphasizes localized communication for resilience but highlight interference challenges in dense device environments, necessitating robust interference mitigation strategies [29]. D2D Communication in Disaster Management optimizes resource utilization but faces coordination complexities in managing large-scale events. Distributed Clustering for UAV Coverage optimizes coverage through clustering techniques, especially beneficial in dynamic environments requiring adaptable communication strategies discussed in [30].

Optimum UAV Flying Path for D2D Communication optimizes path trajectories for efficient communication, providing real-time adaptability crucial for dynamic disaster scenarios. System Throughput in Heterogeneous Networks emphasizes maximizing network capacity but must address coordination complexities inherent in heterogeneous network environments [31]. UAV Trajectory Optimization optimizes data offloading at cell edges, necessitating real-time trajectory adjustments for seamless communication. UAV-Enabled Wireless Power Transfer optimizes energy usage in power transfer, requiring precision in trajectory design for efficient energy utilization.

Link Characterization for Aerial Wireless Sensor Networks enhances aerial network performance but requires calibration and maintenance to ensure reliability. Energy Trade-off in Ground-to-UAV Communication balances energy consumption but relies on real-time optimization strategies for efficient communication. Joint Trajectory and Communication Design integrate trajectory and communication design but encounter coordination complexities in multi-UAV systems. UAV-Assisted Emergency Networks facilitate rapid response and connectivity in emergencies, emphasizing scalability for effective disaster management. UAV Trajectory Optimization for Data Offloading focuses on efficient data management but requires real-time trajectory adjustments for optimal performance. UAV-Enabled Wireless Power Transfer optimizes energy usage but demands precision in trajectory design for effective power transfer [32]. UAV-Assisted Emergency Networks facilitate rapid response and connectivity in emergencies, emphasizing scalability for effective disaster management. Survey on Energy Optimization Techniques provides a comprehensive overview of optimization methods but acknowledges implementation complexity and adaptation challenges. Throughput Maximization for UAV Systems maximizes data throughput but grapples with trajectory planning and execution complexities [33–35]. Collectively, these background studies contribute valuable insights into the advancements, challenges, and potential solutions in utilizing UAVs for communication, disaster management, and emergency response, highlighting the interdisciplinary nature of UAV-based systems in addressing critical societal needs.

B. CONTRIBUTIONS

This research paper makes several significant contributions to the field of UAV-based relay systems, as outlined below:

- Introduces a novel algorithm for optimizing UAVs as communication relays in disaster areas, focusing on maximizing coverage and enhancing connectivity for effective disaster response.
- Proposes an integrated strategy using UAV-mounted sensors to assess disaster areas in real-time, identifying communication blackspots to inform optimal UAV deployment.
- Develops an algorithm that considers factors like altitude, battery life, and communication range, providing a systematic approach for determining the optimal number and placement of UAVs for comprehensive coverage.
- Devises a robust communication protocol with error correction mechanisms to ensure seamless data transfer between ground devices and UAVs, enhancing the reliability of communication channels in challenging environments.
- Presents energy-efficient routing algorithms for UAVs, optimizing energy consumption through dynamic relay positioning and efficient routing, contributing to sustainable and effective UAV deployment.
- Validates the algorithm's effectiveness through MATLAB simulations, demonstrating improvements in path loss, loss probability, and D2D communication capacity and confirming its adaptability to dynamic conditions.
- Offers a promising solution for enhancing emergency wireless coverage in disaster areas. It addresses key aspects such as sensor deployment, optimal UAV deployment, robust communication protocols, and energy-efficient routing, ultimately aiding disaster management and response efforts.

The rest of this paper is structured as follows: A detailed presentation of the problem formulation and the deployment of sensors on UAVs to assess the size of the disaster area are provided in Section II. In Section III, we provide an instance of the proposed algorithm for using UAVs as communication relays to fill in communication gaps in impacted areas. Simulation results and discussions are presented in Section IV and Section V, respectively. Ultimately, in Section VI, we present our conclusions.

II. METHODOLOGY

Natural disasters often result in widespread communication breakdowns, amplifying the challenges of coordinating rescue and relief efforts. The existing terrestrial communication infrastructure is frequently compromised, leaving affected areas with inadequate connectivity. This disruption has severe consequences, including increased mortality rates due to delayed response and coordination. In response to these challenges, the proposed UAV communication relay algorithm aims to address key issues in disaster-stricken regions. Fig. 2 depicts a scenario where UAVs, commonly known as drones, are deployed in a disaster-affected area. These UAVs play a crucial role in collecting and transmitting data, ensuring that users in the area remain connected. This innovative approach uses UAVs to enhance emergency communication and facilitate efficient disaster relief efforts.

A. CHALLENGES

Communication Blackspots: Traditional communication networks struggle to provide seamless coverage in disaster-affected zones, leading to critical communication blackspots. These blackspots hinder the timely flow of information, impeding emergency response and exacerbating the impact of the disaster.

Optimal Deployment Complexity: Conventional deployment strategies may lack adaptability and optimization, resulting in suboptimal utilization of resources such as UAVs. Factors like altitude, battery life, and communication range need careful consideration to ensure efficient coverage during and after disasters.

Communication Protocol Vulnerabilities: Establishing a reliable communication protocol between ground devices and UAVs in disaster scenarios becomes challenging. Unforeseen disruptions and errors in data transfer can hinder the effectiveness of the UAV communication relay system.

Dynamic Environmental Conditions: Adapting UAV positions in real-time to dynamic environmental conditions poses a significant challenge. Factors like wind speed, geographical features, and variable communication signal strength must be addressed for sustained and effective relay operations.

Energy Consumption Optimization: Inefficient routing algorithms and lack of energy optimization strategies can shorten UAV battery life, limiting their effectiveness in prolonged disaster scenarios. Energy-efficient routing is crucial for extending the duration of UAV-based communication services.

Overall Impact: The identified challenges collectively contribute to increased vulnerability in disaster response efforts. The proposed UAV communication relay algorithm seeks to mitigate these challenges by introducing a comprehensive and adaptive solution, thereby enhancing communication services, reducing response times, and ultimately saving lives in post-disaster scenarios.

Data Collection: The drones are equipped with sensors to collect essential data from the disaster zone. This data could include information about the extent of damage, environmental conditions, and infrastructure status.

Wireless Transmission: Once the data is collected, the UAVs act as communication relays. They transmit signals wirelessly, bridging communication gaps caused by damaged infrastructure or disrupted networks.

Emergency Management: By leveraging this technology, emergency responders, relief teams, and affected individuals can stay connected even in challenging circumstances. The drones provide real-time information, aiding in disaster management and response.

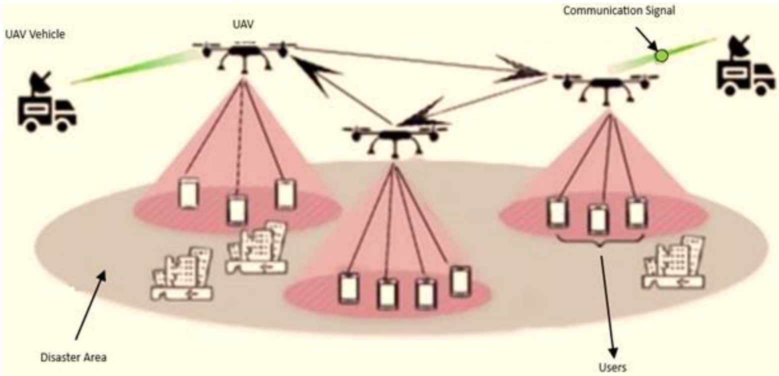

FIGURE 2. **Scenario of data collection and transmission using drones.**

B. NETWORK MODEL

The proposed model in Fig. 3 narrates the deployment of sensors on UAVs to evaluate the extent of the disaster. Which further identifies areas with communication blackspots. The scenario is crucial for understanding communication needs in affected regions. The next step is to determine optimal UAV deployment considering factors like altitude, battery life, and communication range. Strategically position UAVs to cover critical areas. Continuously adjust the UAV positions based on real-time data. Optimize the relay coverage and connectivity. The developed algorithms ensure efficient UAV movement. Energy consumption is minimized while maintaining communication links. This systematic approach leverages UAVs for efficient disaster management, aiding emergency responders.

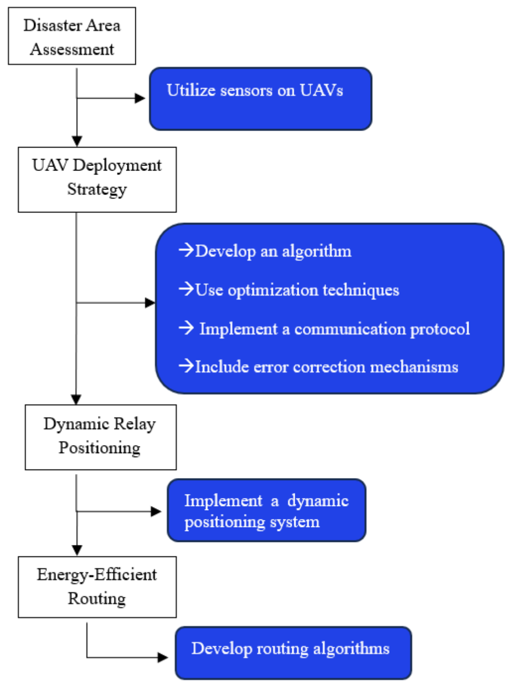

FIGURE 3. **Flow of the proposed model.**

III. PROPOSED UAV-BASED RELAY ALGORITHM

The proposed algorithm involves the deployment of UAVs as communication relays to bridge communication gaps in affected areas. The algorithm focuses on leveraging UAVs as communication relays to address communication challenges in disaster-affected areas. It comprises several key steps to enhance emergency wireless coverage: Firstly, the algorithm begins with a Disaster Area Assessment, where sensors on UAVs are used to evaluate the extent of the disaster and identify areas with communication blackspots. This step is crucial for understanding the communication needs in the affected regions. Next, the algorithm involves developing a UAV Deployment Strategy. This strategy aims to determine the optimal deployment of UAVs by considering factors such as altitude, battery life, and communication range.

Optimization techniques are employed for computing required number of UAVs for efficient coverage, ensuring effective communication support in disaster areas. The third step is the implementation of a Relay Communication Protocol. This protocol facilitates efficient data transfer between ground devices and UAVs. It includes error correction mechanisms to address potential disruptions in communication, ensuring reliable and seamless data transmission. The algorithm also includes a Dynamic Relay Positioning system, allowing UAVs to adapt to changing environmental conditions in real-time. Factors such as wind speed, geographical features, and communication signal strength are considered to optimize UAV positioning, enhancing the overall reliability and effectiveness of the communication network. Lastly, the algorithm focuses on developing Energy-Efficient Routing algorithms. These algorithms aim to optimize the energy consumption of UAVs during communication relay operations. By minimizing energy consumption, the algorithms help extend the operational duration of UAVs, ensuring sustained communication support in disaster scenarios. Overall, the algorithm provides a comprehensive approach to enhance emergency wireless coverage in disaster areas. Integrating these key steps aims to improve communication capabilities, facilitate more effective coordination of rescue efforts, and ultimately contribute to saving lives in post-disaster scenarios.

The two proposed algorithms for an optimized UAV-based relay system for enhanced emergency wireless coverage in disaster areas are presented as follows:

Algorithm 1. UAV Deployment Optimization:

Objective: Minimize path loss and maximize coverage area.
Inputs: area map, population density, terrain data, UAV capabilities.

Step 1: Divide the disaster area into grid cells based on population density and terrain.
    grid_cells = divide_into_grid_cells (area_map, population_density, terrain_data)
Step 2: Calculate the optimal altitude and position for UAV deployment for each grid cell.
    uav_positions = calculate_optimal_positions (grid_cells, uav_capabilities)
Step 3: Deploy UAVs to the calculated positions.
    deploy_uavs (uav_positions)
Step 4: Continuously monitor the coverage and adjust UAV positions as needed based on real-time communication demands.
  while disaster_ongoing:
  monitor_coverage (UAV positions)
  adjust_positions (uav_positions, communication_demands)
end

Algorithm 2. D2D Communication Capacity Optimization Algorithm:

Objective: Maximize D2D communication capacity while minimizing interference.
Inputs: UAV positions, communication range, number of devices.

Start: function optimize D2D Communication (UAV Positions, communication Range, numDevices)
Step 1: Calculate potential D2D communication pairs
    Potential Pairs = calculate Potential Pairs (UAV Positions, communication Range);
Step 2: Assign communication channels to minimize interference
    assign Channels (potential Pairs);
Step 3: Optimize UAV positions for improved D2D communication capacity
    optimize UAV Positions (UAV Positions);
Step 4: Continuously monitor and adjust positions and channels
  while true
  monitor D2D Performance ();
  adjust Positions and Channels ();
end

When integrated into a UAV-based relay system, these algorithms can help enhance Emergency wireless coverage in disaster areas by optimizing UAV deployment and D2D communication capacity.

IV. KEY CALCULATIONS AND INSIGHTS OF THE PROPOSED UAV-BASED RELAY ALGORITHM

The key calculations and insights relevant to the proposed algorithm for UAV-based relay communication in disaster areas are presented in this section. The path loss (*PL*) is calculated based on the distance (*d*) between the transmitter and receiver, the frequency (*f*) of the signal, and a constant factor (*K*) that accounts for environmental factors. The estimated path loss in wireless communication is given by:

$$PL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + K \tag{1}$$

The loss probability (*Ploss*) that represents the likelihood of a packet being lost during transmission is given by:

$$Ploss = 1 - e^{-\lambda d} \tag{2}$$

where λ is the loss rate. The D2D communication capacity (C_{D2D}) that quantifies the maximum achievable data rate for D2D links is given by:

$$C_{D2D} = \log_2(1 + SNR) \tag{3}$$

CD2D is calculated based on the signal-to-noise ratio (SNR), representing the quality of the communication link. The optimal number of UAVs (N_{UAV}) required to ensure efficient coverage of the disaster area is:

$$N_{UAV} = \frac{A_{area}}{A_{coverage}} \tag{4}$$

The energy consumed by for UAV communication relay (E_{relay}) is computed from:

$$E_{relay} = P_{idle} + t_{idle} + P_{comm} \times t_{comm} \tag{5}$$

where P_{idle} and P_{comm} are the power consumed during idle and active communication states respectively. Similarly, t_{idle} and t_{comm} are time durations of idle and active states, respectively. The positions of UAVs are dynamically adjusted based on environmental changes or signal disruptions. Thus, the new position of UAV is updated according to:

$$Position_{new} = Position_{old} + ErrorCorrection \tag{6}$$

Each UAV is flying at an optimal height to achieve maximum coverage. The optimal height is defined as:

$$H_{opt} = \sqrt{\frac{P_{tx} G_{tx}}{P_{rx} G_{rx}}} \tag{7}$$

where, P_{tx} is the transmitting power, G_{tx} is the gain of the transmitting antenna, P_{tx} is the receiving power and G_{tx} is the gain of the receiving antenna. The maximum achievable data rate (R) in the communication link is estimated using the channel bandwidth (W) and the SNR, according to:

$$R = W \times \log_2(1 + SNR) \tag{8}$$

The estimated battery life ($T_{battery}$) of a UAV provides an estimate of how long the UAV can operate before requiring recharging. It is computed according to:

$$T_{battery} = \frac{E_{battery}}{P_{total}} \tag{9}$$

where, $E_{battery}$ is the total energy capacity of the battery, and P_{total} is the total power. The effective communication range (R_{eff}) is the maximum distance over which reliable communication can be established, is computed from:

$$R_{eff} = \sqrt{\frac{P_{tx} G_{tx} \lambda}{P_{rx} G_{rx} (PL)}} \tag{10}$$

V. SIMULATION ANALYSIS

The optimized UAV-based relay algorithm proposed in this research significantly enhances emergency wireless coverage in disaster areas. Extensive simulations provided in this section demonstrate the algorithm's effectiveness in improving communication reliability and coverage range. Table I summarizes the parameters and their descriptions used in the proposed research. Each parameter represents a specific aspect of the simulation.

TABLE I
SIMULATION PARAMETERS

Parameters	**Values**
Software	MATLAB
Number of ground devices	10
Number of UAV'S	3
Number of blackspots	5
Frequency	$[2.4\times10^9, 5\times10^9]$ Hz
Distance	100 meters
Trajectory	$0.01 \times d^2$ meters^2
Relay Density	20 relays/meters^2
Energy Consumption	less
Communication Range	(1 – 100) meters
Efficiency	93%
Loss Probability	Reduced
D2D Communication Capacity	Optimized
Battery Life	Adaptive battery usage
Path Loss, Loss Probability	Affected by user device distance

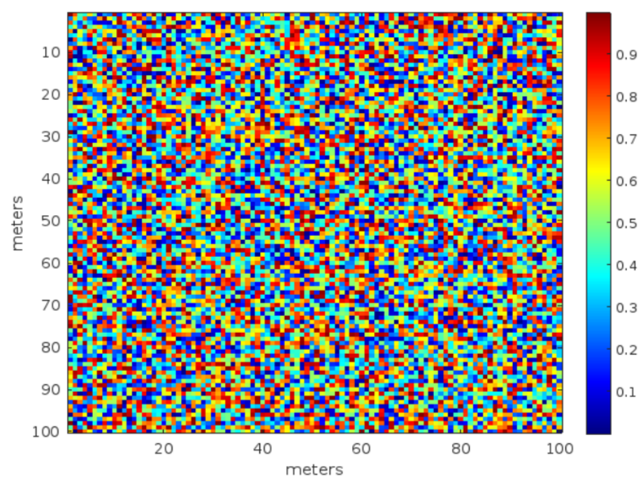

FIGURE 4. Disaster area assessment using sensor data.

Fig. 4 represents sensor data collected during a disaster assessment. The X and Y axes likely correspond to different geographical coordinates or specific areas within the assessed region. The colour intensity in the graph indicates the level of a certain parameter being measured (such as temperature, humidity, etc.). The color bar on the right side ranges from blue (0.1) to red (0.9), representing the magnitude of the measured parameter. Darker red areas indicate higher values (closer to 0.9), while darker blue areas indicate lower values (closer to 0.1). The various colours in between represent intermediate values.

Fig. 5 represents a UAV Deployment Strategy. It is a scatter plot where each blue dot represents a specific location for deploying UAVs. The X and Y axes range from 0 to 100m, likely representing coordinates or areas within a given region.

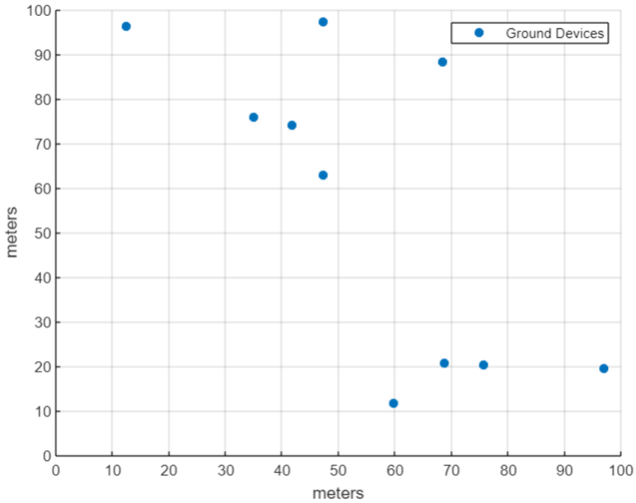

FIGURE 5. **UAV deployment with optimal deployment locations.**

Fig. 6 represents a UAV Deployment Strategy using a communication protocol. It is a random plot where each blue dot represents a specific location for deploying ground devices, and each red dot represents a UAV's location. The X and Y axes range from 0 to 100m, likely representing coordinates or areas within a given region. The dashed lines connect each ground device to every UAV, illustrating potential data transfer paths or communication links.

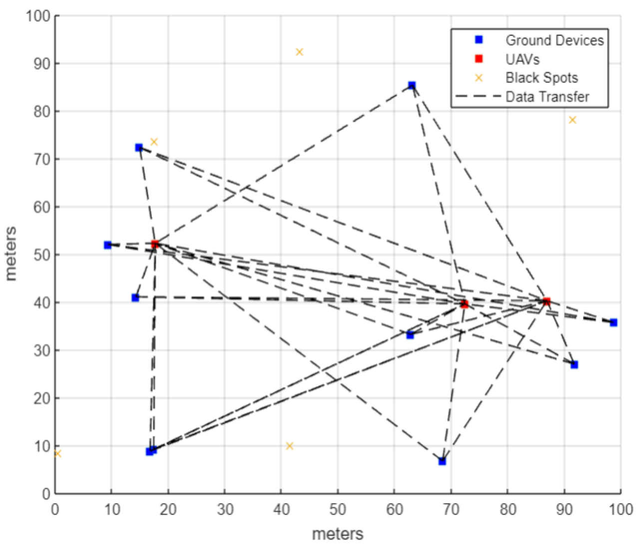

FIGURE 6. **Communication protocol for ground devices, UAVs, and black spots.**

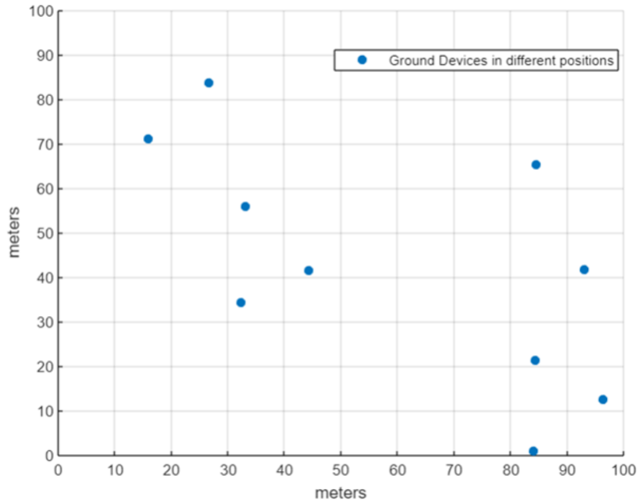

FIGURE 7. **Dynamic relay positioning.**

Fig. 7 represents a dynamic relay positioning strategy for UAVs. It is a scatter plot in which each blue-filled circle represents the position of a UAV on a two-dimensional plane. The X and Y axes range from 0 to 100m, indicating coordinates within a given area. The positions of the UAVs are determined randomly using the code snippet provided. Due to their random assignment, these positions are scattered across the plane without any apparent pattern.

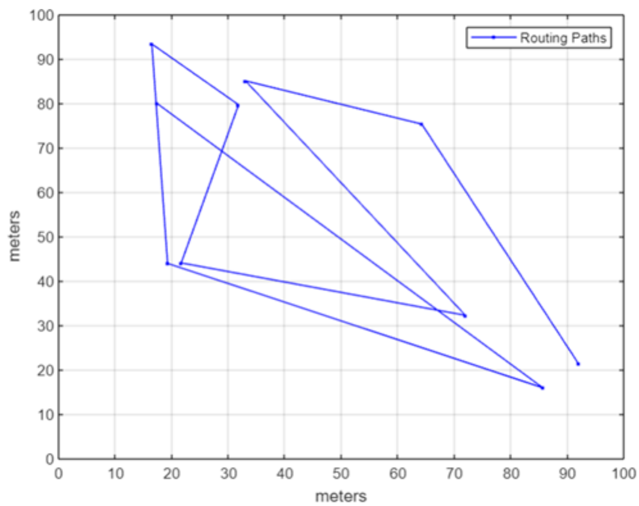

FIGURE 8. **Energy efficient routing paths.**

Fig. 8 represents a scenario related to energy-efficient routing. It visualizes routing paths that connect different points. The X and Y axes range from 0 to 100m, indicating coordinates within a two-dimensional space. The blue lines represent the routing paths connecting various points. Fig. 9 illustrates the scenario for the best energy-efficient routing path and the data transfer between deployed ground devices and UAVs.

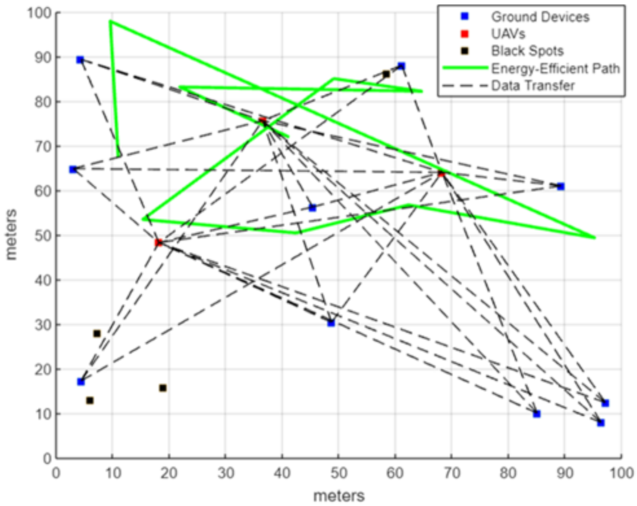

FIGURE 9. **Scenario for the best energy-efficient routing.**

TABLE II
COMPARISON OF PROPOSED SCHEME WITH EXISTING SCHEMES

Aspect	Proposed Method	Reference [34]	Reference [35]
Approach	Utilizes UAVs as communication relays to address communication challenges in disaster-affected areas, focusing on enhancing emergency wireless coverage through a comprehensive approach including disaster area assessment, UAV deployment strategy, relay communication protocol, dynamic relay positioning, and energy-efficient routing.	Examination of energy optimization strategies in cellular networks employing UAVs.	Optimizing data throughput in mobile relaying systems facilitated by UAVs.
Key Techniques	Leveraging UAVs as communication relays, disaster area assessment, UAV deployment optimization, relay communication protocol implementation, dynamic relay positioning, and energy-efficient routing.	Conventional and machine learning approaches for energy optimization	UAV-enabled mobile relaying, emphasizing dynamic trajectory optimization and joint power allocation
Energy Efficiency	The proposed method focuses on optimizing the energy consumption of UAVs for communication relay operations in disaster areas, aiming to extend operational duration and enhance emergency wireless coverage, thus directly addressing energy efficiency in disaster scenarios.	Discusses various energy optimization techniques but no specific comparison	Focuses on maximizing throughput, which indirectly relates to energy efficiency

The scattered distribution of colours suggests that the data points are not following a clear pattern. The graph provides insights into the variation of sensor readings across different locations within the disaster area. The scattered blue dots indicate optimal locations for deploying UAVs. These locations are determined randomly (as per the code snippet provided) and may correspond to areas with specific objectives or coverage requirements. The blue dots represent ground devices, such as sensors, communication nodes, or other devices. The red dots represent UAVs, strategically positioned for communication or data relay. The dashed lines indicate potential communication paths between ground devices and UAVs. This visualization helps plan efficient data transfer scenarios involving UAVs and ground-based devices. The blue dots represent UAV locations, which could be dynamically adjusted based on real-time data, mission requirements, or communication needs. This visualization helps plan efficient relay positioning for data transfer, surveillance, or other tasks involving UAVs . Each blue line represents a route or path that could be taken for data transfer, communication, or other purposes. The randomness in the paths (due to the random data generated) suggests that these routes are dynamically determined or optimized based on specific criteria. Table II presents a comparison of the proposed study with the existing work.

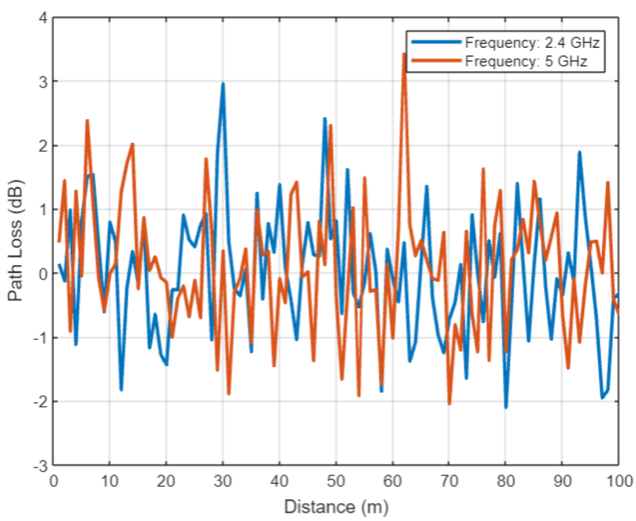

FIGURE 10. **Path loss vs. distance.**

Fig. 10 shows how the signal strength (measured in decibels or dB) decreases as the distance from the transmitter increases. Path loss is affected by various factors, such as the frequency of the signal, the type of terrain, and the presence of obstacles. The graph shows two data sets, one with a smoother curve and one with more variation. This could indicate different environmental conditions or measurement errors. Fig. 11 shows how distance changes the probability of losing a signal (due to interference, noise, or fading). Loss probability is related to path loss, as weaker signals are more likely to be corrupted or undetected. The graph shows two different data sets, one with a higher and one with a lower loss probability. This could indicate different levels of reliability or quality of service.

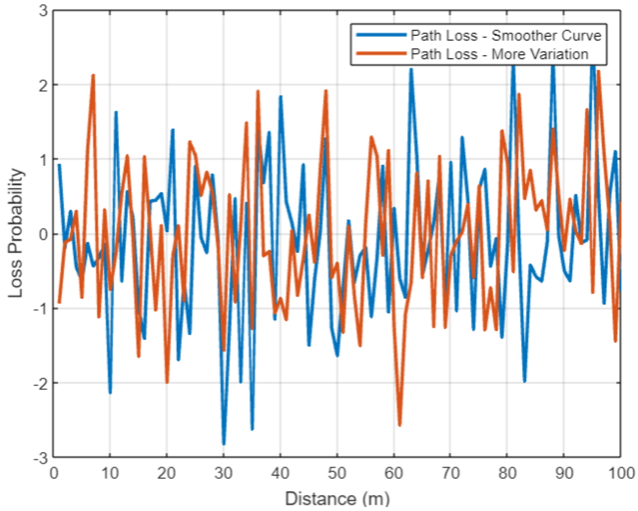

FIGURE 11. **Loss probability vs. distance.**

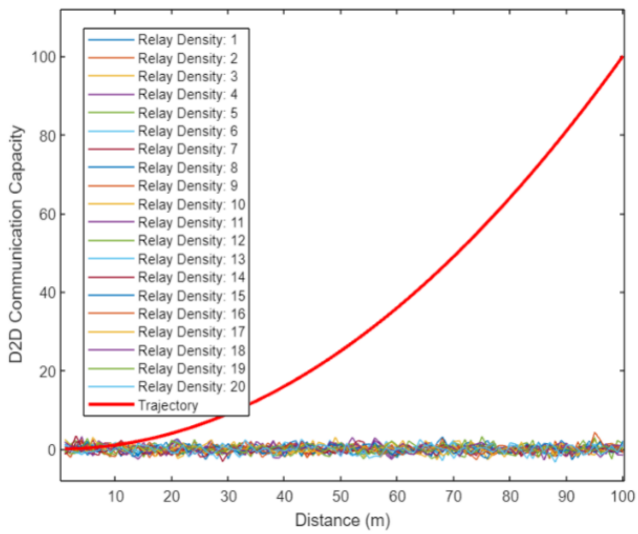

FIGURE 12. **Communication capacity vs. distance vs. trajectory.**

Fig. 12 shows how the amount of data that can be transmitted or received (measured in bits per second or bps) changes with distance. D2D communication capacity is related to both path loss and loss probability, as they affect the SNR and the bit error rate (BER). The graph shows multiple data sets, each representing a different modulation scheme or coding rate. These are techniques that can improve the efficiency or robustness of communication by changing the way the data is defined or encoded. This graph compares the D2D communication capacity between the user device and the optimal relay (UE-Relay) and between the optimal relay and the base station (Relay-BS) over a distance measured in meters. The graph shows that the D2D communication capacity decreases as the distance increases, and that the D2D communication capacity is higher for the Relay-BS link than the UE-Relay link.

Table III describes the importance of relay densities in UAV-based communication networks in disaster areas. It outlines how varying relay densities impact coverage, communication quality, and network efficiency. The table categorizes low to very high relay densities and highlights their effects on coverage, interference, and network capacity. It emphasizes the need for optimal relay density to achieve efficient communication without compromising on interference or network complexity. Overall, the table provides a comprehensive overview of how relay densities are crucial in optimizing communication in disaster scenarios.

TABLE III
RELAY DENSITIES AND THEIR IMPORTANCE

Relay Densities	Importance
1	Low relay density may result in limited coverage and potential communication dead zones.
2	Increasing relay density improves coverage and can help overcome obstacles and signal blockages.
3→9	Optimal relay density balances coverage and interference, ensuring efficient communication.
10	A well-planned relay density can maximize network capacity and minimize signal degradation.
11→20	Very high relay density may lead to increased interference and complexity without added benefit.

Figure 13 shows various trajectory comparisons concerning distance. This trajectory exhibits a gradual increase in height as the distance progresses. It follows a steady, upward path, suggesting a consistent performance or behavior. Trajectory 2 starts at a higher point than Trajectory 1. As the distance increases, it maintains a superior trajectory, reaching a greater height. This trajectory demonstrates efficiency or better performance compared to Trajectory 1.

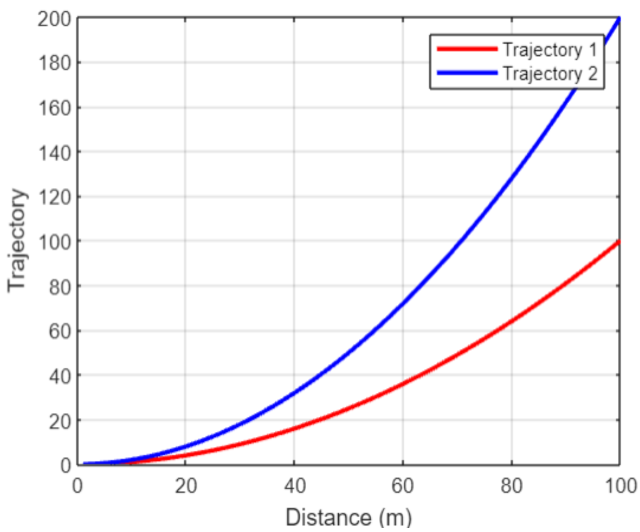

FIGURE 13. Trajectory comparison.

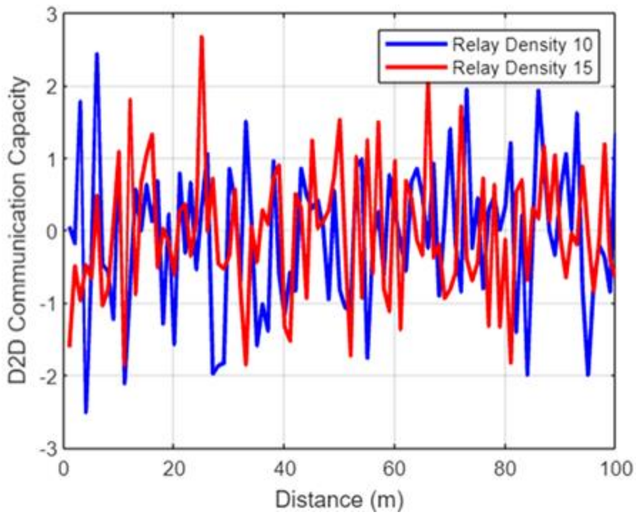

FIGURE 14. D2D communication capacity vs. distance.

Figure 14 illustrates the result of D2D communication capacity versus distance. The blue line on the graph represents relay density 10 with an efficiency of 0.93914. This relay density exhibits fluctuations in D2D communication capacity as the distance increases. At shorter distances, it achieves positive communication capacity, but as the distance grows, it experiences capacity drops. The efficiency factor impacts its overall performance. The red line on the graph corresponds to relay density 15. This relay density operates with an efficiency of 0. 46349. Unlike Relay Density 10, it maintains a more stable communication capacity across varying distances. Its efficiency contributes to consistent performance. Relay density 15 with an efficiency of 0.46349 outperforms relay density 10 (efficiency 0.93914) in terms of stability and reliability in D2D communication capacity.

Table IV presents simulation values for relay density and corresponding energy efficiency in UAV-based communication systems. It illustrates how different relay densities impact energy efficiency, ranging from low to high densities. The values indicate the efficiency of communication networks based on the density of relay nodes. The data showcases variations in energy efficiency across different relay densities, providing insights into optimizing network performance. This information aids in understanding the relationship between relay density and energy efficiency in UAV communication systems.

The proposed model in Fig. 3 narrates the deployment of sensors on UAVs to evaluate the extent of the disaster. Which further identify areas with communication blackspots. The scenario is crucial for understanding communication needs in affected regions. Next step is to determine optimal UAV deployment considering factors like altitude, battery life, and communication range. Strategically position UAVs to cover critical areas. Continuously adjust the UAV positions based on real-time data. Optimize the relay coverage and connectivity. The developed algorithms ensure efficient UAV movement. Energy consumption is minimized while maintaining communication links. This systematic approach leverages UAVs for efficient disaster management, aiding emergency responders and relief efforts.

TABLE IV
ENERGY EFFICIENCY FOR VARIOUS RELAY DENSITIES

Relay Density	Energy Efficiency
1	0.0070367
2	0.89247
3	0.83319
4	0.77517
5	0.78814
6	0.37363
7	0.15231
8	0.35226
9	0.6451
10	0.93914
11	0.093321
12	0.73878
13	0.055267
14	0.75716
15	0.46349
16	0.045004
17	0.84203
18	0.16471
19	0.11507
20	0.27156

VI. DISCUSSIONS

The optimized UAV-based relay algorithm for enhanced emergency wireless coverage in disaster areas presents a promising solution to the challenges faced in establishing communication networks post-disaster. By leveraging UAVs as relays, the algorithm aims to extend coverage, enhance communication capabilities, and aid in disaster response. One of the key strengths of this algorithm lies in its ability to dynamically adjust UAV positioning based on real-time communication demands and environmental factors. This adaptability ensures that the communication network remains effective and efficient, even in challenging terrain and disrupted infrastructure. Moreover, the algorithm's focus on optimizing D2D communication capacity is crucial for improving the overall reliability of the network. By maximizing D2D communication while minimizing interference, the algorithm can enhance the network's performance and coverage area. Furthermore, the algorithm's emphasis on energy-efficient routing is essential for sustainable UAV deployment. The algorithm can prolong UAV flight time and ensure continuous coverage by optimizing energy consumption based on variables such as distance, altitude changes, and battery capacity. Overall, the optimized UAV-based relay algorithm holds great potential for enhancing emergency wireless coverage in disaster areas. Its ability to adapt to changing conditions, optimize D2D communication, and ensure energy efficiency makes it a valuable tool for disaster response and mitigation efforts.

VII. CONCLUSIONS

In conclusion, the utilization of UAVs as communication relays in post-disaster scenarios is not only feasible but also highly effective. The algorithm presented in this strategy offers a systematic approach to deploying UAVs optimally, ensuring maximum coverage while minimizing path loss. By dynamically adapting to changing conditions and implementing energy-efficient routing, this method enhances the overall efficiency of communication networks in disaster-affected areas. The MATLAB implementation provides a valuable starting point for further research and real-world testing. It showcases the potential of UAVs to significantly improve communication coverage, enabling more effective disaster response and recovery efforts. Emergency responders can establish reliable communication networks even in the most challenging post-disaster environments by strategically deploying UAVs based on the proposed algorithm. Moreover, the use of UAVs as communication relays not only improves the efficiency of rescue operations but also enhances the safety of responders. By reducing the reliance on traditional communication infrastructure, which is often compromised during disasters, UAVs can help expedite the delivery of aid and support to affected areas. Overall, this development demonstrates the immense potential of UAVs in disaster management and highlights the importance of continued research and development in this field. By harnessing the capabilities of UAVs, we can significantly enhance our ability to respond to disasters and mitigate their impact on communities.

REFERENCES

[1] Y. Zeng, R. Zhang, and T. J. Lim, "Wireless communications with unmanned aerial vehicles: opportunities and challenges," *IEEE Communications Magazine*, vol. 54, no. 5, pp. 36-42, May 2016, doi: 10.1109/MCOM.2016.7470933.

[2] A. Shamsoshoara, F. Afghah, E. Blasch, J. Ashdown, and M. Bennis, "UAV-Assisted Communication in Remote Disaster Areas Using Imitation Learning," *IEEE Open Journal of the Communications Society*, vol. 2, pp. 738-753, 2021, doi: 10.1109/OJCOMS.2021.3067001.

[3] X. Tang, F. Chen, F. Wang, and Z. Jia, "Disaster-Resilient Emergency Communication With Intelligent Air–Ground Cooperation," *IEEE Internet of Things Journal*, vol. 11, no. 3, pp. 5331-5346, Feb. 2024, doi: 10.1109/JIOT.2023.3305549.

[4] L. Zhang et al., "A Survey on 5G Millimeter Wave Communications for UAV-Assisted Wireless Networks," *IEEE Access*, vol. 7, pp. 117460-117504, 2019, doi: 10.1109/ACCESS.2019.2929241.

[5] N. Salih, A. Jalil, A. Al-Sammarraie, and H. Abdulsahib, "A review on using UAV in wireless communication networks," *Journal of Physics: Conference Series*, vol. 1668, no. 1, p. 012003, 2020.

[6] Y. Li, L. Huang, Y. Yang, and C. Jiang, "A survey on UAV communication networks for 5G and beyond," *IEEE Access*, vol. 7, pp. 11609-11628, 2019.

[7] D. Liu et al., "Self-Organizing Relay Selection in UAV Communication Networks: A Matching Game Perspective," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 102-110, Dec. 2019, doi: 10.1109/MWC.001.1700434.

[8] L. Babun, A. İ. Yürekli, and İ. Güvenç, "Multi-hop and D2D communications for extending coverage in public safety scenarios," in *Proc. IEEE 40th Local Computer Networks Conference Workshops (LCN Workshops)*, Clearwater Beach, FL, USA, 2015, pp. 912-919, doi: 10.1109/LCNW.2015.7365946.

[9] A. Khamitov et al., "Dynamic Wireless Charging of Electric Vehicles: Multi-Channel Modeling," in *Proc. IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, Palermo, Italy, 2018, pp. 1-5, doi: 10.1109/EEEIC.2018.8494211.

[10] S. Shakoor, Z. Kaleem, M. I. Baig, O. Chughtai, T. Q. Duong, and L. D. Nguyen, "Role of UAVs in Public Safety Communications: Energy Efficiency Perspective," *IEEE Access*, vol. 7, pp. 140665-140679, 2019, doi: 10.1109/ACCESS.2019.2942206.

[11] A. Saif, K. Dimyati, K. A. Noordin, N. S. M. Shah, Q. Abdullah, and F. Mukhlif, "Unmanned Aerial Vehicles for Post-Disaster Communication Networks," in *Proc. IEEE 10th International Conference on System Engineering and Technology (ICSET)*, Shah Alam, Malaysia, 2020, pp. 273-277, doi: 10.1109/ICSET51301.2020.9265369.

[12] K. Ali, H. X. Nguyen, P. Shah, Q.-T. Vien, and N. Bhuvanasundaram, "Architecture for public safety network using D2D communication," in *Proc. IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, Doha, Qatar, 2016, pp. 206-211, doi: 10.1109/WCNCW.2016.7552700.

[13] A. Singh, K. Prakash, P. A. Manda, D. R. Sona, and R. R. Das, "Development of an Autonomous UAS for on Air Surveillance and Object Detection: A Real Execution," *Journal of Electrical Engineering & Technology*, vol. 19, no. 1, pp. 723-737, 2023, doi: 10.1007/s42835-023-01573-1.

[14] A. Saif, K. B. Dimyati, K. A. B. Noordin, N. S. M. Shah, S. H. Alsamhi, Q. Abdullah, and N. Farah, "Distributed clustering for user devices under unmanned aerial vehicle coverage area during disaster recovery," *arXiv preprint*, arXiv:2103.07931, 2021.

[15] E. Christy, R. P. Astuti, B. Syihabuddin, B. Narottama, O. Rhesa, and F. Rachmawati, "Optimum UAV flying path for device-to-device communications in disaster area," in *Proc. ICSigSys'16*, Sanur, Indonesia, 2017, pp. 318-322.

[16] V. Annepu, D. R. Sona, C. V. Ravikumar, K. Bagadi, M. Alibakhshikenari, A. A. Althuwayb, B. Alali, C. S. Virdee, G. Pau, I. Dayoub, C. H. See, and F. Falcone, "Review on Unmanned Aerial Vehicle Assisted Sensor Node Localization in Wireless Networks: Soft Computing Approaches," *IEEE Access*, vol. 10, pp. 132875-132894, 2022, doi: 10.1109/ACCESS.2022.3230661.

[17] V. Annepu, A. Rajesh, and K. Bagadi, "Radial basis function-based node localization for unmanned aerial vehicle-assisted 5G wireless sensor networks," *Neural Computing and Applications*, vol. 33, pp. 12333-12346, 2021, doi: 10.1007/s00521-021-05835-9.

[18] V. Annepu and A. Rajesh, "Implementation of an Efficient Artificial Bee Colony Algorithm for Node Localization in Unmanned Aerial Vehicle Assisted Wireless Sensor Networks," *Wireless Personal Communications*, vol. 114, no. 3, pp. 2663-2680, May 2020, doi: 10.1007/s11277-020-07496-8.

[19] Q. Abdullah et al., "Maximizing system throughput in wireless powered sub-6 GHz and millimeter-wave 5G heterogeneous networks," *Telkomnika*, vol. 18, no. 3, pp. 1185-1194, 2020.

[20] M. Silaghi and A. Alqahtan, "Comparing Domains of Application for Electronic Debate Platforms Product Evaluation vs. Commented News," in *Proc. IEEE International Conference on Computational Science and Computational Intelligence (CSCI)*, Las Vegas, NV, USA, 2016, pp. 502-507, doi: 10.1109/CSCI.2016.0101.

[21] K. Mase and H. Okada, "Message communication system using unmanned aerial vehicles under large-scale disaster environments," in *Proc. IEEE 26th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Hong Kong, China, 2015, pp. 2171-2176, doi: 10.1109/PIMRC.2015.7343657.

[22] M. Erdelj and E. Natalizio, "UAV-assisted disaster management: Applications and open issues," in *Proc. IEEE International Conference on Computing, Networking and Communications (ICNC)*, Kauai, HI, USA, 2016, pp. 1-5, doi: 10.1109/ICCNC.2016.7440563.

[23] R. Deng, Z. Jiang, S. Zhou, S. Cui, and Z. Niu, "A Two-Step Learning and Interpolation Method for Location-Based Channel Database Construction," in *Proc. IEEE Global Communications Conference (GLOBECOM)*, Abu Dhabi, United Arab Emirates, 2018, pp. 1-6, doi: 10.1109/GLOCOM.2018.8647393.
[24] H. Menouar, I. Guvenc, K. Akkaya, A. S. Uluagac, A. Kadri, and A. Tuncer, "UAV-Enabled Intelligent Transportation Systems for the Smart City: Applications and Challenges," *IEEE Communications Magazine*, vol. 55, no. 3, pp. 22-28, Mar. 2017, doi: 10.1109/MCOM.2017.1600238CM.
[25] D. R. Sona and K. Bagadi, "Design of an Optimized Social Arithmetic Mean Based Relay Selection Scheme for D2D Cooperative Communication," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 7, pp. 527-531, Oct. 2019, doi: 10.35940/ijitee.J9725.0981119.
[26] D. R. Sona and K. Bagadi, "Development of efficient cell association and resource allocation strategies for heterogeneous D2D communication," *Journal of Advanced Research in Dynamical and Control Systems*, vol. 11, no. 8, pp. 1632-1643, 2019.
[27] N. Zhao et al., "UAV-Assisted Emergency Networks in Disasters," *IEEE Wireless Communications*, vol. 26, no. 1, pp. 45-51, Feb. 2019, doi: 10.1109/MWC.2018.1800160.
[28] F. Cheng et al., "UAV Trajectory Optimization for Data Offloading at the Edge of Multiple Cells," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 7, pp. 6732-6736, July 2018, doi: 10.1109/TVT.2018.2811942.
[29] J. Xu, Y. Zeng, and R. Zhang, "UAV-Enabled Wireless Power Transfer: Trajectory Design and Energy Optimization," *IEEE Transactions on Wireless Communications*, vol. 17, no. 8, pp. 5092-5106, Aug. 2018, doi: 10.1109/TWC.2018.2838134.
[30] N. Ahmed, S. S. Kanhere, and S. Jha, "On the importance of link characterization for aerial wireless sensor networks," *IEEE Communications Magazine*, vol. 54, no. 5, pp. 52-57, May 2016, doi: 10.1109/MCOM.2016.7470935.
[31] D. Yang, Q. Wu, Y. Zeng, and R. Zhang, "Energy Tradeoff in Ground-to-UAV Communication via Trajectory Design," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 7, pp. 6721-6726, July 2018, doi: 10.1109/TVT.2018.2816244.
[32] Q. Wu, Y. Zeng, and R. Zhang, "Joint Trajectory and Communication Design for Multi-UAV Enabled Wireless Networks," *IEEE Transactions on Wireless Communications*, vol. 17, no. 3, pp. 2109-2121, Mar. 2018, doi: 10.1109/TWC.2017.2789293.
[33] Y. Zheng and J. H. L. Hansen, "Unsupervised driving performance assessment using free-positioned smartphones in vehicles," in *Proc. IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, Rio de Janeiro, Brazil, 2016, pp. 1598-1603, doi: 10.1109/ITSC.2016.7795771.
[34] A. Abubakar et al., "A survey on energy optimization techniques in UAV-based cellular networks: from conventional to machine learning approaches," *Drones*, vol. 7, no. 3, p. 214, 2023.
[35] Y. Zeng, R. Zhang, and T. J. Lim, "Throughput Maximization for UAV-Enabled Mobile Relaying Systems," *IEEE Transactions on Communications*, vol. 64, no. 12, pp. 4983-4996, Dec. 2016, doi: 10.1109/TCOMM.2016.2611512.

Deepika Rani Sona – B.Tech, M.E, PhD. Dr. Deepika is a Senior Faculty in the School of Electronics Engineering at VIT University. She has experience of research and development in the field of mobile opportunistic networks, device-to-device communications, network virtualization, energy- efficient wireless networks, future internet, IoT, 5G and machine learning etc. She worked on an Automated Car Parking project at VIT University. She has extensive experience of supervising B.Tech and M.Tech students / projects in D2D, IOT, ML, Robotics and Image Processing.

B. Kalapraveen (Senior Member, IEEE) received the B.E. degree in electronics and communication engineering from Andhra University, India, in 2006, and the M.Tech. degree in electronic systems and communication and the Ph.D. degree in wireless communication from the Department of Electrical Engineering, National Institute of Technology, Rourkela, India, in 2009 and 2014, respectively. He was a Full Professor with the School of Electronics Engineering (SENSE), Vellore Institute of Technology (VIT), Vellore, India, until April 2023. Currently, he is with the School of Electronics Engineering (SENSE), VIT-AP University, Amaravati, Andhra Pradesh, India. His research interests include SDMA, MIMO, OFDM, NOMA, D2D communication, cognitive radio, UAV communication, and artificial intelligence. He has completed six Ph.D. theses under his guidance and is currently guiding three scholars. He is an Academic Editor of Wireless Communication and Mobile Computing and Applied Computational Intelligence and Soft Computing. He also reviews journals like IEEE Access, Wireless Personal Communications, IET Communications, and Telecommunication Systems. He has published over 50 research articles in various refereed international journals, such as IEEE Access, Neural Computing and Applications, Wireless Personal Communication, IET Communication, International Journal of Communication Systems, and Radio Science.

A. Visalakshi received the B. Tech. degree in computer science and engineering from Jawaharlal Nehru Technical University, Kakinada, India, in 2011, the M. Tech. degree in computer science and Technology from Andhra University, Visakhapatnam, India, in 2013, and a Ph.D. degree in computer networks from VIT Vellore, India, in 2020. She was an Assistant Professor at the Department of Computer Engineering, Sri Sivani Institute of Technology, Srikakulam, Andhra Pradesh, from June 2014 to May 2016. Currently, she is an Assistant Professor at the School of Computer Science and Engineering, VIT-AP University, Amaravati, India. Her research interests include wireless networking, artificial intelligence, soft computing techniques, and neural networks.

Mohammad Alibakhshikenari (Member, IEEE) was born in Mazandaran, Iran, in February 1988. He received the Ph.D. degree with European Label in electronics engineering from the University of Rome ''Tor Vergata'', Italy, in February 2020. From the May 2018 to December 2018 he was a Ph.D. Visiting Researcher at the Chalmers University of Technology, Gothenburg, Sweden. His training during this Ph.D. research visit included a research stage in the Swedish Company Gap Waves AB in Gothenburg as well. Since July 2021 he is with the Department of Signal Theory and Communications, Universidad Carlos III de Madrid (uc3m), Spain, as a Principal Investigator of the CONEX (CONnecting EXcellence)-Plus Talent Training Program and Marie Skłodowska-Curie Actions. He was also a Lecturer of the electromagnetic fields and electromagnetic laboratory with the Department of Signal Theory and Communications for academic year 2021–2022 and he received the "Teaching Excellent Acknowledgement" Certificate for the course of electromagnetic fields from the Vice-Rector of studies of uc3m. From December 2022 to May 2023 he spent three industrial and academic research visits in (i) SARAS Technology Ltd Company in Leeds, England; (ii) Edinburgh Napier University in Edinburgh, Scotland; and (iii) University of Bradford in West Yorkshire, England which were defined by CONEX-Plus Talent Training Program and Marie Skłodowska-Curie Actions as his secondment research visit plans. His research interests include electromagnetic systems, antennas and wave-propagations, metamaterials and metasurfaces, sensors, synthetic aperture radars (SAR), 5G and beyond wireless communications, multiple input multiple output (MIMO) systems, RFID tag antennas, substrate integrated waveguides (SIWs), impedance matching circuits, microwave components, millimeter-waves and terahertz integrated circuits, gap waveguide technology, beamforming matrix, and reconfigurable intelligent surfaces (RIS), which led to achieve more than 6000 citations and H-index above 48 reported by Scopus, Google Scholar, and ResearchGate. He was a recipient of the (i) three years Principal Investigator research grant funded by Universidad Carlos III de Madrid and the European Union’s Horizon 2020 Research and Innovation Program under the Marie Skłodowska-Curie Grant started in July 2021, (ii) two years postdoctoral research grant funded by the University of Rome ‘‘Tor Vergata’’ started in November 2019, (iii) three years Ph.D. Scholarship funded by the University of Rome ‘‘Tor Vergata’’ started in November 2016, and (iv) two Young Engineer Awards of the 47th and 48th European Microwave Conference were held in Nuremberg, Germany, in 2017, and in Madrid, Spain, in 2018, respectively. In April 2020 his research article entitled ‘‘High-Gain Metasurface in Polyimide On-Chip Antenna Based on CRLH-TL for Sub Terahertz Integrated Circuits’’ published in Scientific Reports was awarded as the Best Month Paper at the University of Bradford, West Yorkshire, England. He is serving as an Associate Editor for (i) Radio Science, and (ii) IET Journal of Engineering. He also acts as a referee in several highly reputed journals and international conferences.

Bal S. Virdee (SM’08) received the B.Sc. and MPhil degrees in Communications Engineering from the University of Leeds, UK, and his Ph.D. in Electronic Engineering from the University of London, UK. He has worked in industry for various companies including Philips (UK) as an R&D-engineer and Teledyne Defence and Space as a future products developer in RF/microwave communications. He taught at several academic institutions before joining London Metropolitan University, where he is a Senior Professor of Communications Technology in the School of Computing and Digital Media, where he is Head of the Communications Technology Research Center. His research, in collaboration with industry and academia, is in wireless communications encompassing mobile phones to satellite technology. Prof. Virdee has chaired technical sessions at IEEE international conferences and published numerous research papers. He is an Executive Member of IET’s Technical and Professional Network Committee on RF/Microwave-Technology. He is a Fellow of IET and a senior member of IEEE.

Lida Kouhalvandi, IEEE Senior Member and PhD (with honor), joined the Department of Electrical and Electronics Engineering at Dogus University as an Assistant Professor in October 2021 and she took possession of Associate Professor degree in February 2023. She received her PhD in Electronics Engineering in 2021 from the Istanbul Technical University, Istanbul, Turkey. She received her MSc in Electronics Engineering in 2015 from the Istanbul Technical University, Istanbul, Turkey, and her BSc in Electronics Engineering in 2011 from the Azad University of Tabriz, Tabriz, Iran. In recognition of her research, she received the Doctoral Fellowship at Department of Electronics and Telecommunications, Politecnico di Torino, Turin, Italy from 2019 to 2020 and also she joined to Politecnico di Torino, Turin, Italy as a Research Fellowship from February 2021 up to July 2021 and also from May 2022 up to May 2023. Dr. Kouhalvandi’s research interests as a radio frequency and analog engineer are power amplifier, antenna, analog designs, and implantable medical devices. She also has experience in computer-aided designs and optimization algorithms through machine learning. she received 'Best Presentation Award' from EExPolytech-2021: Electrical Engineering and Photonics conference in 2021. Additionally, her PhD thesis was accepted for presentation at the PhD Forum of the 2021 IEEE/ACM Design Automation Conference (DAC 2021) in San Francisco, USA. From the 30th IEEE conference on signal processing and communications applications, she received another 'Best Paper Award' in 2022. She received the 2022 Mojgan Daneshmand Grant from the IEEE Antennas and Propagation Society (AP-S), organized by the IEEE AP-S Young Professionals. Additionally, her PhD thesis was awarded by Istanbul Technical University as the 'Outstanding PhD Thesis' and also from Turkish Electronics Industrialists Association (TESID) as the 'Best Innovation and Creativity PhD Thesis' in 2022.

Giovanni Pau is an Associate Professor at the Faculty of Engineering and Architecture, Kore University of Enna, Italy. Prof. Pau received his Bachelor's degree in Telematic Engineering from the University of Catania, Italy, and both his Master's degree (cum Laude) in Telematic Engineering and Ph.D. from Kore University of Enna, Italy. Prof. Pau is the author/co-author of more than 80 refereed articles published in journals and conference proceedings. He is a Member of the IEEE (Italy Section) and has been involved in several international conferences as a session Co-Chair and Technical Program Committee member. Prof. Pau serves/served as a leading Guest Editor in special issues of several international journals and is an Editorial Board member as Associate Editor of several journals, such as IEEE Access, Wireless Networks (Springer), EURASIP Journal on Wireless Communications and Networking (Springer), Wireless Communications and Mobile Computing (Hindawi), Sensors (MDPI), and Future Internet (MDPI), to name a few. His research interests include Wireless Sensor Networks, Fuzzy Logic Controllers, Intelligent Transportation Systems, Internet of Things, Smart Homes, and Network Security.

Ernesto Limiti (S’87-M’92-SM’17) is a full professor of Electronics in the Engineering Faculty of the University of Roma Tor Vergata since 2002, after being research and teaching assistant (since 1991) and associate professor (since 1998) in the same University. Ernesto Limiti represents University of Roma Tor Vergata in the governing body of the MECSA (Microwave Engineering Center for Space Applications), an inter-universitary center among several Italian Universities. He has been elected to represent the Industrial Engineering sector in the Academic Senate of the University for the period 2007-2010 and 2010-2013. Ernesto Limiti is actually the president of the Consortium “Advanced research and Engineering for Space”, ARES, formed between the University and two companies. Further, he is actually the president of the Laurea and Laurea Magistrale degrees in Electronic Engineering of the University of Roma Tor Vergata. The research activity of Ernesto Limiti is focused on three main lines, all of them belonging to the microwave and millimetre-wave electronics research area. The first one is related to characterisation and modelling for active and passive microwave and millimetre-wave devices. Regarding active devices, the research line is oriented to the small-signal, noise and large signal modelling. Regarding passive devices, equivalent-circuit models have been developed for interacting discontinuities in microstrip, for typical MMIC passive components (MIM capacitors) and to waveguide/coplanar waveguide transitions analysis and design. For active devices, new methodologies have been developed for the noise characterisation and the subsequent modelling, and equivalent-circuit modelling strategies have been implemented both for small and large-signal operating regimes for GaAs, GaN, SiC, Si, InP MESFET/HEMT devices. The second line is related to design methodologies and characterisation methods for low noise circuits. The main focus is on cryogenic amplifiers and devices. Collaborations are currently ongoing with the major radioastronomy institutes all around Europe within the frame of FP6 and FP7 programmes (RadioNet). Finally, the third line is in the analysis methods for nonlinear microwave circuits. In this line, novel analysis methods (Spectral Balance) are developed, together with the stability analysis of the solutions making use of traditional (harmonic balance) approaches. The above research lines have produced more than 250 publications on refereed international journals and presentations within international conferences. Ernesto Limiti acts as a referee of international journals of the microwave and millimetre wave electronics sector and is in the steering committee of international conferences and workshops. He is actively involved in research activities with many research groups, both European and Italian, and he is in tight collaborations with high-tech italian (Selex - SI, Thales Alenia Space, Rheinmetall, Elettronica S.p.A., Space Engineering …) and foreign (OMMIC, Siemens, UMS, …) companies. He contributed, as a researcher and/or as unit responsible, to several National (PRIN MIUR, Madess CNR, Agenzia Spaziale Italiana) and international (ESPRIT COSMIC, Manpower, Edge, Special Action MEPI, ESA, EUROPA, Korrigan, RadioNet FP6 and FP7 …) projects. Regarding teaching activities, Ernesto Limiti teaches, over his istitutional duties in the frame of the Corso di Laurea Magistrale in Ingegneria Elettronica, “Elettronica per lo Spazio” within the Master Course in Sistemi Avanzati di Comunicazione e Navigazione Satellitare. He is a member of the committee of the PhD program in Telecommunications and Microelectronics at the University of Roma Tor Vergata, tutoring an average of four PhD candidates per year.