UAV-Enabled Disaster Management: Applications, Open Issues, And Challenges

Amina Khan[1], Sumeet Gupta[1], and Sachin Kumar Gupta[1*]

ARTICLE INFO

Article history:
Received: 25 July 2022
Revised: 10 October 2022
Accepted: 15 November 2022

Keywords:
Disaster management
Natural and man-made disaster
Early warning system
Research and rescue
UAV

ABSTRACT

One of the 21st Century's most important innovations has been recognized as Unmanned Aerial Vehicles (UAVs). The accelerated growth of UAVs and their application in several fields open up a new vision for their use in natural and man-made disaster management. In UAV-based disaster management applications, UAV applications not only analyze the region impacted but also support to build a communication network between catastrophe survivors and rescue teams and the nearest mobile networks. The implementation of the UAV program is categorized according to the process of crisis management, and the related work efforts are reviewed along with outstanding research and development issues. In addition to addressing current open research questions and concerns related to UAV for disaster management, this paper provides an overview of the important developments of UAV networks for those applications.The primary purpose of this work is to deliver technical outcomes that can help enhance people's well-being and advance the state of art in developing a robust disaster management system.

1. INTRODUCTION

The incidence level of man-made and natural disasters is a big concern in both developed and emerging parts of the world. The size and scale of the disaster make it very difficult for people to respond and address the crisis immediately [1]. In some situations, it is almost impossible for people to react timely to the catastrophe [2]. At present, attempts are being made to anticipate and foresee the potential occurrence of a disaster to respond effectively to a crisis amid a tragedy, rapidly and accurately assess the impact, remediate, and re-establish normal conditions [3]. This paper emphasizes the need to enhance disaster readiness, outlines a vision to exploit recent developments in UAVs, including Wireless Sensor Networks (WSNs) technology, to boost the capability for network-assisted disaster mitigation, prediction, preparedness, and response.

UAVs or drones are a growing technology with an exponentially increasing ability that provides a vast range of effective solutions in the real world in various smart applications. Owing to the exponential growth in demand for civilian UAVs, the use of civil drones needs to integrate into our daily lives. UAVs are an example of new technology that meets the growing demand for the application because of its diverse implementation potential [4]. The main applications of civil UAVs include inaccessible areas of connectivity, medical services, distributing goods, quarantine areas, emergency communication services, healthcare, data gathering, disaster prediction and recovery, public safety, etc. [5]-[7].

To efficiently carry out complex tasks in real-time, UAV coordination is required in many applications such as monitoring activity, wireless communication across broad areas, disaster recovery, etc. [8]. Smart UAVs are expected to change the communication field and incorporate innovations in disaster management applications to minimize risks and provide cost-effective solutions [6, 8]. In this article, we cover a variety of UAV-based applications for disaster management systems and explore unresolved problems and research concerns.

Due to the significant number of deaths brought on by both natural and human-made disasters that devastate natural resources, cause financial losses, and endanger humans. Therefore, it is crucial to employ an active, straightforward, and affordable strategy to manage and prevent natural and man-made calamity. Recent years have seen a large number of researchers in Mobile Ad-hoc Network (MANET) [9]. Thanks to advancements in networking technologies, users can now interact wirelessly using MANET, an infrastructure-less network that consists of numerous mobile devices connected wirelessly. A number of wireless mobile nodes that are part of the network can autonomously move in any direction. In situations like earthquakes, volcanic eruptions, flooding, and forest fires, MANET can be utilised for rescue and emergency situations [10]. In times of disaster, MANET employs algorithms and

[1]*School of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Kakryal-182320, (Jammu & Kashmir), India.*
**Corresponding author:* Sachin Kumar Gupta; E-mail: sachin.gupta@smvdu.ac.in.

a number of routing protocols that aid in the detection, reduction, and containment of victims and their impacts. WSN was employed by a research team to evaluate forest fire detection technologies. For the purpose of detecting forest fires and other disasters, a number of routing protocols, including Location-Aided Routing (LAR), Optimized Link State Routing (OLSR) and, LAR-Based Reliable Routing Protocol (LARRR), can be utilised. In terms of average throughput, routing overhead, end-to-end delay, packet loss ratio, andpacket delivery ratio,it was discovered that the LARRR protocol performed better than OLSAR and LAR [11].

Over the last few years, several researchers have contributed enormously to UAVs due to their various benefits in the field of disaster management [12, 13] but unable to address unresolved problems and difficult research issues in the field of disaster management. UAVs contribute a lot to civilian and other critical applications, but still, it needs more concentration towards some areas like disaster management. Some of the applications, like disaster management, are very susceptible to delays and require quick emergency services to save the lives of people. The main motivation behind this article is to address some of the open issues and research challenges need in the field of disaster management for providing better connectivity and coverage and also to timely respond to the victims. In this article, the authors try to focus on some of the UAV applications in disaster management and also highlight the most critical open issues and challenges.

The remainder of the paper is laid out as follows: Section 2 discusses the disaster management stage. Section 3 focuses on various UAV-based disaster management applications. Section 4 highlights the open issues for disaster management; section 5 presents the recent challenges and gives future directions; and finally, in section 6 conclusion is drawn.

2. DISASTER MANAGEMENT STAGES

Natural and man-made disasters occur globally every day and signify an important feature that affects the growth of development as well as human life. We must learn about the nature of the disaster, its phases, and its components (such as readiness, catastrophic effect, growth, response, recovery, and prevention)in a position to react to various types of natural and man-made catastrophes and develop feasible methods and techniques for managing disasters.

The most critical thing to be addressed when a disaster happens is the safety of human life. In this respect, the Search and Rescue (SAR) operations must be performed effectively and quickly within the first 72 hours after a disaster occurs. In addition to an international SAR methodology and protocol, the International SAR Advisory Group (INSARAG) sets out set instructions that specify that the teams have to perform their SAR operation [14]. A team manager will be responsible for the task assignment and local decisions, and all team operations shall be coordinated by a supervisor of the situation. A typical SAR task is performed in four main steps: (i) the commander sets up the search region (communication problems between rescue personnel will be minimum if the search area is smaller), (ii) establishment of a command station in the search region, (iii) first responders were split into rescue personnel and scouts, and (iv) scout teams report to the command station their observations and the rescue officers gather information from the command station to see where to take action.

In order to deal withvarious forms of natural catastrophes and to create workable Disaster Management (DM) procedures and approaches, it is crucial to understand what type of catastrophe is, its components, andits phases. The three stages of the Disaster Management System (DMS) are explained in this section. Pre-disaster (before outbreak or coming of catastrophe), intra-disaster (during the disaster), and post-disaster (after the onset of disaster) are the three stages that make up the disaster life process. Throughout the "pre-disaster" stage, UAVs are used to prepare and identify regions that are vulnerable to disasters in order to establish successful measures to lessen the negative effects of both natural and man-made catastrophes. This allows UAVs to gather the necessary data from authorities to establish preparedness and prevention steps that are needed before the breakout of disaster.The "intra-disaster" period applies to the duration of the disaster during which it occurs, and the period begins as the disaster breakout and lasts until it stops. Depending on the duration of the disaster, it can be long-term or short-term. Short-term disasters such as fires, terrorist attacks, and earthquakes last from few minutes to few hours. On the other hand, a long-term disaster such as tsunamis, floods, wildfires, etc., takes place over longer periods and can last up to several days or weeks. A significant amount of destruction has been seen during the "intra-disaster" era; UAV systems should be used to monitor catastrophe progression [15]. Using such monitoring, officials can measure the magnitude/size of catastrophe on the basis of real-time to determine badly impacted areas and thus allocate resources to improve relief operations.Eventually, UAVs can be very useful for post-disaster assessment and in infrastructure damage estimation during the third stage after a catastrophe. Data obtained from the UAV during this stage may be important for the first responders, humanitarian organizations, government agencies, and refugees. In the third stage, UAVs can be utilised in search and rescue activities as well as rehabilitation monitoring. Data collection and analysis can also be documented and analysed for training, research, and educational reasons. Figure 1 presents the role of UAV in different disaster management stages.

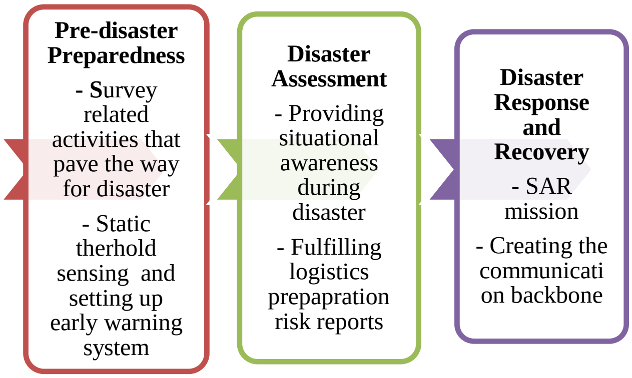

Fig. 1. Role of UAV in Disaster Management Stages.

3. UAV-BASED DISASTER MANAGEMENT APPLICATIONS

The technology of UAVs has the potential to reform the accuracy and efficiency of handling disasters. This section addresses many UAV-aided applications and demonstrates UAV's ability to anticipate, forecast, recover, and handle disaster events, including prediction, tracking, early warning systems, disaster response, surveillance, rescue operations, information collection, and logistics.

3.1 Forecasting, Monitoring, and Early Warning Systems

Early Warning Systems (EWSs), with the advent of telecommunications and sensors, tend to be an exciting choice for the management of disaster to prevent casualties and decrease the financialconsequences of the catastrophe incident. In general, EWSs consist of a slew of environmental change sensors and a network of information communication systems for data transfer to control centres. The functions of an efficient early warning system take care of monitoring, data fusion, risk analysis, and subsequent responses. Recently few researchers proposed a framework for the assessment of worst polluted cities [16] likewise we can also monitor the most predominant location for disasters. UAVs, in combination with WSN, are used to offer a detailed and high-efficiency warning for predicting catastrophe. There are different ways in which UAVs can be used in disaster warnings with WSNs. UAVs can be used to provide connectivity between WSN nodes and decision centers as the data mules or mobile base stations in the air. In this case, information can be transferred to airborne UAVs and retrieved from decision centers, avoiding sending data across several intermediate nodes, thus increasing the reliability and accuracy of data-transmission [17, 18]. The battery-powered node of the WSN network makes energy a key problem in the design, management, and deployment of an EWS. In this situation, UAV can be used as anremote charger to recharge the battery into the draining node.

3.2 Emergency Communication

An essential factor of catastrophe response and recovery is emergency communication. The purpose of emergency communication is to offer communication for the decision-makers, injured people, and disaster rescuers. The effectiveness of disaster management systems, including disaster assessment, search and rescue, and information gathering, is focused on a robust and easy-going communication network. To make wireless communication more efficient, the interoperability of current technologies of wireless communication systems, like Wireless Fidelity (Wi-Fi), ad-hoc networks, cellular networks, and UAV-based aerial base stations, must be improved while the conventional telecommunications network can provide wireless cellular service and high-speed broadband service. They might be destroyed by large-scale man-made or natural disasters, such as base station and cable disruption triggered by an earthquake event, or shutting down power grids in floods. Consequently, the normal means of communication, such as handheld devices, cannot function or may be missing during the disaster. UAV-based approaches were proposed to meet the immediate need for infrastructure-less communication.

Wu et al. [19] suggested a wireless communication network system with a multi-UAV, where every UAV is mounted by an aerial basestation, and it offers the ground users wireless communication. The power consumption and trajectory of UAV are taken into account to accomplish justice among terrestrial users, which results in maximization-minimization problems and solves through successive convex optimization techniques. Similar work is also done in paper [20] for robust communication and trajectory design in the presence of jammers based on multi-UAV enabled wireless networks.

3.3 Search and Rescue Operation

UAVs are known to have tremendous benefits, particularly in search and rescue operations, public safety, and disaster management. Critical infrastructure, like water and power necessities, telecommunication systems, and transport systems, may be completely or partially affected by a natural or man-made disaster such as tsunamis, floods, earthquakes, etc. To support communication services to assist rescue operations requires fast solutions [21]. Disaster response is a time-critical sprint to find and treat the sufferers as soon as possible. In this situation, the main purpose is to save the lives of people. UAVs can deliver catastrophe warnings in time and support to speed up rescue and recovery activities when public network services are affected. UAVs might help disaster responders to accomplish this aim by rapidly scanning large disaster zones employing navigation sensors and built-in cameras to locate possible victims. A variety of key features should be considered to develop effective search and rescue based on UAV systems, including the various environmental hazards in service for the UAV network, energy limitations of UAV systems, and the QoS of UAV data transmission.A differentiated learning environment [22] can be created betweem the SAR team and the victims to reduce the casualities and respond in timely manner.

3.4 Information Gathering by Remote Sensing

The assessment of disaster damage is critical for fast relief measures. Different information is gathered and shared for decision making; thus, for disaster management, information collection or data fusion is necessary. UAV components can be used to spot more details of the catastrophe zones, but with a restricted coverage range. Thus, how to integrate the videos or images captured from multiple sources to create a cohesive model for the disaster scenarios are discussed in articles [23, 24]. For essential real-time applications, the cloud-based solution might not be sufficient. The amount of data that is shared between these devices, however, results in greater bandwidth communication budgets, a loss of mobility, energy restrictions for embedded systems, communication delays, and redundant information [25]. In order to solve these issues, a novel computing paradigm is developed that keeps computation and storage near to the end users, in this case the drones. Fog computing is employed as a middle layer between the cloud and end users to reduce latency, power consumption, scalability, and efficiency. Fog computing addresses the drawbacks of centralised cloud computing by enabling data to be collected, processed, and stored by fog devices [26].

3.5 Logistics

In DM, logistics is one of the most problematic issues. The roads or streets may be obstructed or destroyed during or after a major disaster, and the rescue workers have difficulty reaching the victims and delivering necessary medical treatment. In this situation, UAVs can be used to provide supplies to those in need in disaster-affected regions, including food, medication, and mobile devices.The present civil UAVs could carry a payload up to a few kilograms and could not be a logistically viable solution for repeated demands for emergencies.

In large-scale disaster emergencies, one of the problems is the implementation of a facility site,which mostly depends on choosing the optimum location for the emergency centres. For that,the authors of the research article [27] develop a stochastic Mixed-Integer Nonlinear Programming (MINLP) based on the principle that individuals are evenly spread on the edges of a network. Its goal is to select, from a variety of application locations, the most suitable location for relief delivery centres. The authors aim to build a mathematical model that reduces the overall time of people as well as UAVs over several possible scenarios. Carlsson et al. [28] proposed coordinated logistics consisting of a moving truck and swarm of UAVs. The moving truck carries the packages and is automatically operated. The UAVs pick up the packages from the truck to provide services to the needy. After the successful delivery of the packages, the UAV will return to the truck to collect more packages until all the packages have been supplied. This study examined how the organized system improves the value of logistics facilities. Table 1 provides the summary of different UAV applications, its role, most important challenges and also gives solution.

4. OPEN ISSUES

The involvement of UAVs in disaster management system has numerous research challenges linked to networking as explained below:

4.1 UAV Deployment

Concerning open issues for UAV deployment, new approaches are required to enhance the 3D deployment of UAVs while taking into consideration their specific features. It is necessary to examine how UAVs could be implemented in cooperation with cellular networks, thereby taking into account mutual interference among terrestrial and aerial networks [29]. One more challenge is to mutually optimize bandwidth distribution and 3D positioning for UAV-Base Stations (BSs) to reduce the overall transmission delay of the clients that are aided by UAV-BSs in case of disaster. Also, the deployment of the UAVs should be such that it will provide maximum coverage and connectivity [30].

4.2 Maintaining and Creating UAV-Relay Networks

The relay network created by the UAVs is aerial and requires a high level of resistance to communication failures and interference due to changes in motion or changes in energy levels between the UAVs [31]. A two-round process is required, the first round of centralized identification of optimum relay points (called anchors) that link the disaster areas to the closest radio access network and is headed by a second round of decentralized correction for the period of deployment. The issue of UAV backup assignment at each anchor point is similar to reserve backup channels in the cellular situations, with some significant differences: the capacity of the UAV back-up to act as relay anchor that varies over time based on the changes in energy level; in terms of movement near the anchor site. The handoff procedure itself takes resources; a functional failure will occur by changing the UAV’s role, among others, from relaying to surveying.

Table 1. Summarize the UAV applications and highlight its role, important challenges, and gives solution

UAV applications	Role of UAV	Most importantchallenges	Solutions
Forecasting, Monitoring, and Early Warning Systems	• Provide up-to-date information on the catastrophe. • To foresee catastrophe through environmental monitoring. • To perform information analysis for forecasting and EWSs.	• Reduce energy consumption, offer dependable data transmission, and have accurate estimating skills. • To communicate with minimal latency and high bandwidth for the transfer of video and image streams with excellent quality.	We can use intrusion detection systems like Anomaly-Based Detection,Signature-Based Intrusion Detection, and Rule-Based Intrusion Detection to safeguard UAVs against intrusions.
Emergency Communication	• Make wireless communication easier. • To repair the communication infrastructure that has been damaged or destroyed. • It functions as a fallback for wireless nodes that are broken. • Enable wireless connectivity from a distance. • To encourage contact between rescue teams and catastrophe victims.	• Power efficiency standards. • UAV positioning and flight pattern optimization for enhanced coverage.	To identify hostile UAVs, a combination of two or more novel and effective algorithms, including the elephant herding optimization, the earthworm optimization algorithm, the monarch butterfly optimization, and the moth search algorithm, will be employed.
Search and Rescue Operation	• To locate and save those unfortunate individuals who were injured or trapped during the catastrophe.	• High safety standards, • Quick observation and analysis, • Coordination among the SAR crew.	It's critical that the UAV and SAR team communicate effectivelyto prevent delays in the SAR team's arrival. We can also work together with the SAR team and UAV to collaborate on situational awareness and expedite relief efforts to reduce total casualties.
Information Gathering by Remote Sensing	• To gather data from several sources. • To connect different data systems that can be applied to many DM applications.	• To meet the need for an energy-efficient system, • Effective path planning, • Integration with other systems.	We can determine the UAV's ideal trajectory and utilise various approximation algorithms to minimise data collecting delays.
Logistics	• To provide disaster victims in afflicted areas with relief aid like food, medication, and mobile devices.	• To choose from a variety of selected sites the optimal location for relief delivery centres.	In UAVs, machine learning algorithms can be used to analyse data collected by IoT devices, decide which roads should be closed and the best ways to get to the worst-hit areas, and schedule the delivery of relief supplies to prevent delays in situational awareness and evacuation help.

4.3 UAV Localization

It may be inadequate for UAVs to explore the disaster area autonomously and choose their locations using repeated testing with self-learning techniques given their short flight times and the need for time-bound actions. The authors suggest the usage of partial external inputs to direct the UAVs to create the last hop connection to users and to build a relay network. The last reported information from the cellular database network location and mobile device signals can be leveraged to approximate the number of these impacted individuals and their geographical spread, which calls for a new exchange of signal protocols between networks. The UAV can be guided to high-density locations by strategies such as ant-foraging algorithms, which strengthen the pathways based on the availability or the number of mobile ping requests [32].

4.4 Data Fusion Issues

The UAVs capture images/videos that provide an outline of the circumstances. However, individuals affected can use different social media to exchange images and text messages through the relay UAV network. This provides fine-grained details on the ground that can be fused with high-definition UAV feeds at the control center [33]. The fusion of in-network data with energy constraints within a mobile UAV network has not been fully studied. In addition, the need for fusion of data can affect the UAV network in exciting ways: (i) a more holistic view of the circumstances can take UAVs to different areas; (ii) it can minimize UAV data transfer requirements and thereby save more flight energy. Current channel/source coding from the multimedia sensor network domain is inadequate when the static network topology with separate channel conditions is taken into consideration. Here, both the channel and the topology vary with time.

4.5 Handover Issues

The handover procedure between UAVs will start early when the UAV approaches the indicated location, but this includes the greater effect of a 3-D propagation environment and greater transmission power. Furthermore, the simultaneous moving behavior in air and radio frequency transmissions can also contribute to signal variations due to the Doppler Effect on the incoming UAV. On the other hand, UAVs will position themselves in the air after each other and then start the handover. Nevertheless, there is a trade-off between the benefit of aerial stability with low transmitting power during handover-related communications and the corresponding long time to complete the whole handover procedure [34, 35].

4.6 Coverage and Connectivity

In case of disaster coverage and connectivity plays an important role as most of the terrestrial base station gets destroyed and UAV-BSs provide coverage and connectivity to the ground users [36].Obstacles influence the performance of coverage of UAV-BS for ground users. One main issue is to optimize the maximum UAV-BS coverage by positioning UAV-BSs optimally dependent on the user's positions and obstacles. Generally, the 3-D placement of the UAV-BSs should be defined so that the maximum coverage of the users is possible, given the obstacles and the positions of the ground users in the area [37]. It is particularly helpful as UAVs fly at high-frequency ranges (e.g., at frequencies of millimeters).

4.7 Ensuring Robustness, Network Security, and Privacy

One of the main issues that must be addressed to ensure secure data flow between UAVs and base stations is security [38, 39]. The emphasis should be made on the security of communication to ensure a robust UAV control network and acquisition of information. Malicious attacks are nearly associated with the operation of the UAV network; robust communication protocols thus play a key role. UAVs are used to collect multimedia information regarding the individuals affected by natural or man-made disasters and pose critical questions on the protection of information and trust issues [40]. In reality, UAV-recorded video footage during the disaster contains a recording of sensitive footage such as dead or injured persons, which should be censored automatically, particularly when the media use the footage.

5. RESEARCH CHALLENGES

In this section, some of the major design challenges and considerations of UAV-based disaster management are discussed. Current problems for channel modeling, trajectory optimization, resource management, and network performance are the particular requirements of aerial implementations, taking into account transmission range, delay tolerance, topology changes, performance scalability, mobility issue, and energy constraints. Table 2 gives research directions, open issues, and challengesfor UAV-based wireless networks. Some of the research challenges are as follows:

5.1 Channel Modelling

Different types of channels must be assisted due to the 3D existence of a UAV network. In the case of an aerial system, these links can be either ground-to-air (G2A), air-to-ground (A2G), or air-to-air (A2A). There are some open issues for A2G channel modeling. First of all, more accurate channel models are required, derived from measurements in the real world [41]. UAVs are being widely used as A2A channel modeling as a flying base station, drone-user equipment, and also to support the backhaul. There is a prerequisite for a specific UAV-to-UAV model, which can acquire channel and Doppler Effect time-variation due to the UAV movement. In addition, it is important to define multipath fading in A2A communications, thus taking into account the height of the UAV as well as the movement of the antenna. UAV’s can be designed differently depending on the characteristics of their network, which influence the network-related Quality of Service (QoS) and thus the supportable traffic.

5.2 Trajectory Optimization in UAV

Although the possible mobility of UAVs offers good prospects, it presents new technical problems and challenges. The UAV trajectory must be improved about important performance metrics like delay, spectral efficiency, energy, and throughput. Moreover, the dynamic features and type of UAVs must be taken into consideration in trajectory optimization problems. Whereas a lot of important researches have been conducted on UAV trajectory optimization, some open challenges are still there, which include: (i) UAV trajectory optimization focused on ground user's movement pattern to maximize coverage efficiency (ii) optimization of the trajectory for reliability maximization and latency minimization in wireless UAV based networks (iii) mutual communication, control, trajectory optimization to minimize the fight time of UAVs and (iv) obstacle sensitive trajectory optimization of UAVs taking into account energy consumption of UAV and delay constraint of the user. Finally, it is another open question for cellular-connected UAV-User Equipment (UE) to optimize the trajectory while reducing user's ground interference and being aware of the down-tilt of the antennas in the base stations [19, 42].

5.3 Resource Management

One of the important study concerns in UAV-enabled communication systems is resource management. In general, a framework is required, which handles various resources in a dynamic manner such as energy, bandwidth, transmit power, flight time of UAV, andnumber of UAVs. For example, how to flexibly change the direction of a flying UAV and the transmission power that serves the users on the ground. The main problem, in this case, is to provide optimal mechanisms for the assignment of bandwidths, which can record the impact of UAV's locations, Line-of-Sight (LoS) interference, mobility, and the distribution of ground user's traffic. Furthermore, efficient scheduling technologies have to be designed to minimize interference in the UAV-supported cellular network between aerial and ground base stations. Moreover, in a heterogeneous flying network and terrestrialbase stations, the dynamic spectrum sharing must also be analyzed. Lastly, it is important to design problems for UAV operation to follow acceptable frequency bands (e.g., LTE, Wi-Fi bands) [43, 44].

5.4 Cellular Network Planning with UAVs

Several important problems must be concentrated on planning an effective UAV system. For instance, what is the minimum number of UAVs needed for providing maximum coverage for a known geographic zone that is moderately covered by terrestrial basestations? Resolving such issues is a special concern where there is no normal geometrical form (i.e., square or disk) in the geographical field of interest. The backhaul-conscious implementation of UAVs as the aerial base stations is another design issue. In this situation, the backhaul compatibility of UAVs, as well as the QoS of their user, should be kept in mind when implementing UAV-BS [45, 46].

5.5 Performance Analysis

There are several questions yet to be addressed for performance analysis. For example, it is important to describe the performance completely in terms of coverage and capacity of UAV-based wireless networks, comprising both air and land users and terrestrial base stations [47]. Manageable reactions for the possibility of coverage and spectral efficiency are particularly required in aerial-ground heterogeneous networks. Therefore, basic performance assessments must be carried out to determine the intrinsic trade-offs in UAV networks between energy consumption and spectral efficacy. Another issue is determining the UAV performance in wireless networks while taking into account the UAV mobility. A key analysis of mobile wireless networks includes the identification of temporal and spatial variations in different network performance metrics. For example, the trajectory of UAVs needs to be analyzed in terms of power consumption, latency, and throughput. Finally, it is possible to estimate the effect of complex scheduling on the UAV communication systems performance [48].

5.6 Regulations for Development and Design

Although UAVs acquire their share of national airspace in the country, their deployment must be regulated so that the gains are maximized and the possible damages are minimized. In certain civilian applications, regulation can be a major barrier to UAV deployment. Rules and regulations that are properly designed are realistic. In case of a catastrophe outage, emergency response and rescue measures obey unique acts and guidelines such as disaster mitigation, disaster relief act, etc. [49] to ensure that available services are used efficiently. However, present procedures and regulations are not designed to tackle the use of UAVs in the case of a crisis, and many of them have no guidelines as to how the UAVs are successfully used in disaster management. For example, there are no provisions for necessary characteristics for the dynamic use of UAVs, in particular as part of disaster reduction initiatives such as carrying out infrastructure evaluations and/or study and rescue missions. Table 2 presents research directions, open issues and challenges, and solution and techniques for UAV-based wireless networks.

Table 2. Research directions, open issues and challenges, solution and techniques for UAV-based wireless network

Ref.	Research directions	Open issues and challenges	Solutions and techniques
[29, 30]	UAV Deployment	➢ Deployment of UAVs in coexistence with ground networks. ➢ Energy-efficient deployment. ➢ Mutual 3-D deployment and bandwidth allocation.	➢ Branch and Bound (B&B) algorithm and Received Signal Strength (RSS) algorithm [50].
[41]	Channel Modelling	➢ Small scale fading. ➢ A2G path loss models. ➢ A2A channel modeling.	➢ The most popular models for describing small-scale and large-scalefading, are Rician distribution and log-distance path loss model,respectively [51].
[19, 42]	Trajectory Optimization	➢ Mutual delay and trajectory optimization. ➢ Path planning with reliable communication. ➢ Energy-aware trajectory optimization.	➢ Minimum Time Search (MTS) algorithms based on ant colony optimization [52].
[43, 44, 53]	Resource Management	➢ Flight time and bandwidth optimization. ➢ Spectrum sharing with terrestrial networks. ➢ Multi-dimensional resource management. ➢ Mutual transmit power and trajectory optimization.	➢ Load Prediction Algorithm (LPA) and the UAV-BSs Clustering and Positioning Algorithm (UCPA) [54].
[45, 46]	Cellular Network Planning	➢ UAV optimization. ➢ Cell allocation based on traffic. ➢ Analysis of overheads and signaling. ➢ Cell planning considering backhaul.	➢ Improving antenna design, utilising satellite as a communication system, and boosting transmitter power [55].
[47, 48]	Performance Analysis	➢ Performance analysis considering mobility. ➢ Capturing temporal and spatial correlation. ➢ Analysis of heterogeneous aerial-ground network.	➢ UAV trajectory planning optimization. ➢ The mobility model 3D Brownian motion (BM) and deterministic motion [56].

6. CONCLUSION AND FUTURE DIRECTION

In this article, the first main contribution is given to a comprehensive study on the UAV-enabled disaster management application. It presents the role of UAV in different disaster management phases like forecasting, an EWS, monitoring, emergency communication, disaster response, surveillance, rescue operation, information collection, and logistics. Moreover, it focuses on open issues in terms of disaster management and gives future directions. In addition, it also presents the recent research challenges faced by UAV-based disaster management.The deployment of a UAV-to-UAV collaboration-aided network for the disaster management system across a wide area can be studied in the future.

REFERENCES

[1] Kittipakawat, P., Soralump, S., Sharp, A., Karnjana, J., & Matsuoka, M. (2018). Assessment of Landslide Susceptibility Area using RS and GIS in Krabi. *Greater Mekong Subregion Academic and Research Network International Journal*, *12* (2018) 181 – 188.

[2] Khaing, T. W., Tantanee, S., Pratoomchai, W., &Mahavik, N. (2021). Coupling flood hazard with vulnerability map for flood risk assessment: A case study of Nyaung-U Township in Myanmar. *Greater Mekong Subregion Academic and Research Network International Journal*, *15*, 127-38.

[3] Siripornananon, S., &Visuthismajarn, P. (2016). An Integrated Sustainable Development ModelforEffective Disaster Management Policy of Khlong-U-Taphao Basin in Thailand. *Greater Mekong Subregion Academic and Research Network International Journal*, *10* (2016), 77 – 86.

[4] Mualla, Y., Najjar, A., Daoud, A., Galland, S., Nicolle, C., &Shakshuki, E. (2019). Agent-based simulation of unmanned aerial vehicles in civilian applications: A systematic literature review and research directions. *Future Generation Computer Systems*, *100*, 344-364. https://doi.org/10.1016/j.future.2019.04.051.

[5] Khan, A., Gupta, S., & Gupta, S. K. (2021). Unmanned aerial vehicle-enabled layered architecture based solution for disaster management. *Transactions on Emerging Telecommunications Technologies*, *32*(12), e4370, 1-29. https://doi.org/10.1002/ett.4370.

[6] Zhao, N., Lu, W., Sheng, M., Chen, Y., Tang, J., Yu, F. R., & Wong, K. K. (2019). UAV-assisted emergency networks in disasters. *IEEE Wireless Communications*, *26*(1), 45-51. https://doi.org/10.1109/MWC.2018.1800160.

[7] Ali, K., Nguyen, H. X., Vien, Q. T., Shah, P., & Raza, M. (2020). Deployment of drone-based small cells for public safety communication system. *IEEE Systems Journal*, *14*(2), 2882-2891.

[8] Khan, A., Gupta, S., & Gupta, S. K. (2020). Multi-hazard disaster studies: Monitoring, detection, recovery, and management, based on emerging technologies and optimal techniques. *International journal of disaster risk reduction*, *47*(2020), 101642.

https://doi.org/10.1016/j.ijdrr.2020.101642.

[9] Torres, R., Sandoval, F. A., Enciso, L., & Cueva, S. (2015). Improving lifetime and availability for ad hoc networks to emergency and rescue scenarios. In *New Contributions in Information Systems and Technologies* (pp. 979-989). Springer, Cham. https://doi.org/10.1007/978-3-319-16486-1_97.

[10] Morreale, P., Goncalves, A., & Silva, C. (2015). Mobile ad hoc network communication for disaster recovery. *International Journal of Space-Based and Situated Computing*, *5*(3), 178-186. https://doi.org/10.1504/IJSSC.2015.070949.

[11] AL-Dhief, F. T., Muniyandi, R. C., & Sabri, N. (2016). Performance evaluation of LAR and OLSR routing protocols in forest fire detection using mobile ad-hoc network. *Indian Journal of Science and Technology*, *9*(48). https://doi.org/10.17485/ijst/2016/v9i48/99556.

[12] Mozaffari, M., Saad, W., Bennis, M., Nam, Y. H., &Debbah, M. (2019). A tutorial on UAVs for wireless networks: Applications, challenges, and open problems. *IEEE communications surveys & tutorials*, *21*(3), 2334-2360. https://doi.org/10.1109/COMST.2019.2902862.

[13] Erdelj, M., &Natalizio, E. (2016, February). UAV-assisted disaster management: Applications and open issues. In *2016 international conference on computing, networking and communications (ICNC)* (pp. 1-5). 15- 18 February. Kauai, HI, USA.IEEE.

[14] Okita, Y., Sugita, M., Katsube, T., & Minato, Y. (2018). Capacity building of international search and rescue teams through the classification system: example from Japan Disaster Relief team and INSARAG External Classification and Reclassification. *Journal of Japan Association for Earthquake Engineering*, *18*(6), 6_23-6_40. https://doi.org/10.5610/jaee.18.6_23.

[15] Gencer, E. A. (2013). Natural disasters, urban vulnerability, and risk management: a theoretical overview. *The interplay between urban development, vulnerability, and risk management*, 7-43. https://link.springer.com/chapter/10.1007/978-3-642-29470-9_2

[16] Raheja, S., Obaidat, M. S., Kumar, M., Sadoun, B., & Bhushan, S. (2022). A hybrid MCDM framework and simulation analysis for the assessment of worst polluted cities. *Simulation Modelling Practice and Theory*, *118*, 102540. https://doi.org/10.1016/j.simpat.2022.102540

[17] Erdelj, M., Król, M., &Natalizio, E. (2017). Wireless sensor networks and multi-UAV systems for natural disaster management. *Computer Networks*, *124*, 72-86. https://doi.org/10.1016/j.comnet.2017.05.021.

[18] Popescu, D., Stoican, F., Stamatescu, G., Chenaru, O., &Ichim, L. (2019). A survey of collaborative UAV–WSN systems for efficient monitoring. *Sensors*, *19*(21), 4690. https://doi.org/10.3390/s19214690.

[19] Wu, Q., Zeng, Y., & Zhang, R. (2018). Joint trajectory and communication design for multi-UAV enabled wireless networks. *IEEE Transactions on Wireless Communications*, *17*(3), 2109-2121. https://doi.org/10.1109/TWC.2017.2789293.

[20] Wu, Y., Fan, W., Yang, W., Sun, X., & Guan, X. (2019). Robust trajectory and communication design for multi-UAV enabled wireless networks in the presence of jammers. *IEEE Access*, *8*, 2893-2905. https://doi.org/10.1109/ACCESS.2019.2962534.

[21] Silvagni, M., Tonoli, A., Zenerino, E., &Chiaberge, M. (2017). Multipurpose UAV for search and rescue operations in mountain avalanche events. *Geomatics, Natural Hazards and Risk*, *8*(1), 18-33. https://doi.org/10.1080/19475705.2016.1238852.

[22] Thapliyal, M., Ahuja, N. J., Shankar, A., Cheng, X., & Kumar, M. (2022). A differentiated learning environment in domain model for learning disabled learners. *Journal of Computing in Higher Education*, *34*(1), 60-82. https://doi.org/10.1007/s12528-021-09278-y

[23] Baker, C. A., Rapp, R. R., Elwakil, E., & Zhang, J. (2020). Infrastructure assessment post-disaster: Remotely sensing bridge structural damage by unmanned aerial vehicle in low-light conditions. *Journal of emergency management*, *18*(1), 27-41. https://doi.org/10.5055/JEM.2020.0448.

[24] Chen, Q. J., He, Y. R., He, T. T., & Fu, W. J. (2020). The typhoon disaster analysis emergency response system based on UAV remote sensing technology. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*, 959-965.

[25] Dias, V., Moreira, R., Meira, W., & Guedes, D. (2016, May). Diagnosing performance bottlenecks in massive data parallel programs. In *2016 16th IEEE/ACM international symposium on cluster, cloud and grid computing (CCGrid)* (pp. 273-276).Cartagena Columbia, 16 - 19May, 2016. IEEE. https://doi.org/10.1109/CCGrid.2016.81

[26] Mahmud, R., Kotagiri, R., &Buyya, R. (2018). Fog computing: A taxonomy, survey and future directions. In *Internet of everything* (pp. 103-130). Springer, Singapore. https://doi.org/10.1007/978-981-10-5861-5_5

[27] Golabi, M., Shavarani, S. M., &Izbirak, G. (2017). An edge-based stochastic facility location problem in UAV-supported humanitarian relief logistics: a case study of Tehran earthquake. *Natural Hazards*, *87*(3), 1545-1565. https://doi.org/10.1007/s11069-017-2832-4.

[28] Carlsson, J. G., & Song, S. (2018). Coordinated logistics with a truck and a drone. *Management Science*, *64*(9), 4052-4069. https://doi.org/10.1287/mnsc.2017.2824

[29] Khuwaja, A. A., Zheng, G., Chen, Y., & Feng, W. (2019). Optimum deployment of multiple UAVs for coverage area maximization in the presence of co-channel interference. *IEEE Access*, *7*, 85203-85212. https://doi.org/10.1109/ACCESS.2019.2924720.

[30] Cetinkaya, O., & Merrett, G. V. (2020, May). Efficient deployment of UAV-powered sensors for optimal coverage and connectivity. In *2020 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 1-6). 25-28 May, Seoul, Korea (South), IEEE. https://doi.org/10.1109/WCNC45663.2020.9120738.

[31] Zhong, X., Guo, Y., Li, N., Chen, Y., & Li, S. (2019). Deployment optimization of UAV relay for malfunctioning base station: Model-free approaches. *IEEE Transactions on Vehicular Technology*, *68*(12), 11971-11984. https://doi.org/10.1109/TVT.2019.2947078.

[32] Yao, R., Pakzad, S. N., &Venkitasubramaniam, P. (2017). Compressive sensing based structural damage detection and localization using theoretical and metaheuristic statistics. *Structural Control and Health Monitoring*, *24*(4), e1881. https://doi.org/10.1002/stc.

[33] Ji, H., & Luo, X. (2019). 3D scene reconstruction of landslide topography based on data fusion between laser point cloud and UAV image. *Environmental Earth Sciences*, *78*(17), 1-12. https://doi.org/10.1007/s12665-019-8516-5

[34] Fakhreddine, A., Bettstetter, C., Hayat, S., Muzaffar, R., &Emini, D. (2019, June). Handover challenges for cellular-connected drones. In *Proceedings of the 5th Workshop on Micro Aerial Vehicle Networks, Systems, and Applications* (pp. 9-14), June 21, Seoul, Korea. Association for Computing Machinery. https://doi.org/10.1145/3325421.3329770.

[35] Khan, A., Gupta, S., & Gupta, S. K. (2022). Multi-UAV integrated HetNet for maximum coverage in disaster management. *Journal of Electrical Engineering*, *73*(2), 116-123.

[36] Gupta, A., Sundhan, S., Alsamhi, S. H., & Gupta, S. K. (2020). Review for capacity and coverage improvement in aerially controlled heterogeneous network. *Optical and Wireless Technologies*, 365-376. *Springer Singapore*. https://doi.org/10.1007/978-981-13-6159-3_39.

[37] Lyu, J., & Zhang, R. (2019). Network-connected UAV: 3-D system modeling and coverage performance analysis. *IEEE Internet of Things Journal*, *6*(4), 7048-7060. https://doi.org/10.1109/JIOT.2019.2913887.

[38] Fotouhi, A., Qiang, H., Ding, M., Hassan, M., Giordano, L. G., Garcia-Rodriguez, A., & Yuan, J. (2019). Survey on UAV cellular communications: Practical aspects, standardization advancements, regulation, and security challenges. *IEEE Communications surveys*

& tutorials, *21*(4), 3417-3442. https://doi.org/10.1109/COMST.2019.2906228.

[39] Rashid, A., Sharma, D., Lone, T. A., Gupta, S., & Gupta, S. K. (2019, July). Secure communication in UAV assisted HetNets: a proposed model. In *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage* (pp. 427-440). 18-20 December; Nanjing, China. Springer, Cham. https://doi.org/10.1007/978-3-030-24907-6_32.

[40] Sharma, D., Rashid, A., Gupta, S., & Gupta, S. K. (2019). A functional encryption technique in UAV integrated HetNet: a proposed model. *Int J Simul Syst Sci Technol*, *20*(S1), 7-1. https://doi.org/10.5013/ijssst.a.20.s1.07.

[41] Khawaja, W., Guvenc, I., Matolak, D. W., Fiebig, U. C., & Schneckenburger, N. (2019). A survey of air-to-ground propagation channel modeling for unmanned aerial vehicles. *IEEE Communications Surveys & Tutorials*, *21*(3), 2361-2391. https://doi.org/10.1109/COMST.2019.2915069.

[42] Wang, H., Ren, G., Chen, J., Ding, G., & Yang, Y. (2018). Unmanned aerial vehicle-aided communications: Joint transmit power and trajectory optimization. *IEEE Wireless Communications Letters*, *7*(4), 522-525. https://doi.org/10.1109/LWC.2018.2792435.

[43] Ceran, E. T., Erkilic, T., Uysal-Biyikoglu, E., Girici, T., &Leblebicioglu, K. (2017). Optimal energy allocation policies for a high altitude flying wireless access point. *Transactions on Emerging Telecommunications Technologies*, *28*(4), e3034. https://doi.org/10.1002/ett.3034.

[44] Anton, S. R., & Inman, D. J. (2011, April). Performance modeling of unmanned aerial vehicles with on-board energy harvesting. In *Active and Passive Smart Structures and Integrated Systems 2011* (Vol. 7977, pp. 519-533). SPIE. https://doi.org/10.1117/12.880473.

[45] Van der Bergh, B., Chiumento, A., &Pollin, S. (2016). LTE in the sky: Trading off propagation benefits with interference costs for aerial nodes. *IEEE Communications Magazine*, *54*(5), 44-50. https://doi.org/10.1109/MCOM.2016.7470934.

[46] Khan, A., Gupta, S., & Gupta, S. K. (2022). Emerging UAV technology for disaster detection, mitigation, response, and preparedness. *Journal of Field Robotics*, 1-51. https://doi.org/10.1002/rob.22075.

[47] Alsamhi, S. H., Ma, O., Ansari, M. S., & Gupta, S. K. (2019). Collaboration of drone and internet of public safety things in smart cities: An overview of qos and network performance optimization. *Drones*, *3*(1), 1-18. https://doi.org/10.3390/drones3010013.

[48] Hayajneh, A. M., Zaidi, S. A. R., McLernon, D. C., Di Renzo, M., &Ghogho, M. (2018). Performance analysis of UAV enabled disaster recovery networks: A stochastic geometric framework based on cluster processes. *IEEE Access*, *6*, 26215-26230. https://doi.org/10.1109/ACCESS.2018.2835638.

[49] Relief, R. T. S. D., & Act, E. A. Public Law 93-288, as amended, 42 USC 5121 et seq., and Related Authorities. *United States Code, Title 42, The Public Health and Welfare*. https://doi.org/10.4135/9781452275956.n311.

[50] Masroor, R., Naeem, M., & Ejaz, W. (2021). Efficient deployment of UAVs for disaster management: A multi-criterion optimization approach. *Computer Communications*, *177*, 185-194. https://doi.org/10.1016/j.comcom.2021.07.006

[51] Cui, Z., Guan, K., Briso-Rodríguez, C., Ai, B., Zhong, Z., &Oestges, C. (2020). Channel Modeling for UAV Communications: State of the Art, Case Studies, and Future Directions. *arXiv preprint arXiv:2012.06707*. https://doi.org/10.48550/arXiv.2012.06707

[52] Pérez-Carabaza, S., Scherer, J., Rinner, B., López-Orozco, J. A., &Besada-Portas, E. (2019). UAV trajectory optimization for Minimum Time Search with communication constraints and collision avoidance. *Engineering Applications of Artificial Intelligence*, *85*, 357-371. https://doi.org/10.1016/j.engappai.2019.06.002

[53] Samriya, J. K., Tiwari, R., Cheng, X., Singh, R. K., Shankar, A., & Kumar, M. (2022). Network intrusion detection using ACO-DNN model with DVFS based energy optimization in cloud framework. *Sustainable Computing: Informatics and Systems*, *35*, 100746. https://doi.org/10.1016/j.suscom.2022.100746

[54] Alfaia, R. D., Souto, A. V. D. F., Cardoso, E. H. S., Araújo, J. P. L. D., &Francês, C. R. L. (2022). Resource Management in 5G Networks Assisted by UAV Base Stations: Machine Learning for Overloaded Macrocell Prediction Based on Users' Temporal and Spatial Flow. *Drones*, *6*(6), 145. https://doi.org/10.3390/drones6060145

[55] Kamal, N. M., Sahwee, Z., Hamid, S. A., Norhashim, N., & Lott, N. (2019, November). Cellular network and its relevance for unmanned aerial vehicle application in malaysia. In *IOP Conference Series: Materials Science and Engineering* (Vol. 705, No. 1, p. 012009),21–23 November, Kazimierz Dolny, Poland, IOP Publishing. https://doi.org/10.1088/1757-899X/705/1/012009

[56] Huang, J., Tang, J., Shojaeifard, A., Chen, Z., Hu, J., So, D. K. C., & Wong, K. K. (2021). Drone Mobile Networks: Performance Analysis Under 3D Tractable Mobility Models. *IEEE Access*, *9*, 90555-90567. https://doi.org/10.1109/ACCESS.2021.3089253