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SURVEY ARTICLE

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Emerging UAV technology for disaster detection, mitigation, response, and preparedness

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Abstract

In recent years, Unmanned Aerial Vehicles (UAVs) have gained significant interest in research groups due to the wide range of applications, such as disaster surveillance and monitoring, rescue operations, military, civil, and so forth. UAVs are most often used to fulfill both user's services and requirements such as wireless communication facilities to end-users, as a relay node to extend the coverage of the core network, and so forth. UAVs are versatile in design and can cover larger areas, contrary to the Tethered Balloon and Loon Balloon systems. Generally in any natural or human-made disaster, there is a high potential risk of damage to buildings, transport systems, communication systems, and basic services. During heavy disasters like landslides, forest fires, floods, earthquakes, and so forth, the conventional terrestrial communication system gets destroyed, and people face many problems. In this case, UAVs prove to offer a better solution to provide fast, cost-effective, easy to deploy, and secure wireless communication to the victims. But there are some issues like interference between UAVs and other base stations, coordination between UAVs, Quality of Service requirements, Size, Weight, and Power limitation, delay, coverage, positioning of UAVs, and so forth. This study article mainly highlighted these issues and try to present the recent developments of the state-of-the-art to overcome these issues. In UAV communications, with an increasing emphasis on how UAVs can be integrated with different technologies, such as the Internet of Things, Wireless Sensor Network, Heterogeneous Network, and Cloud computing. The primary aim of this article is to examine how UAVs can assist survivors in floods, earthquakes, tsunamis, or in any natural or human-made disaster situations, either in the present or soon. Also, it focused on various applications of UAVs in disaster management (DM). It underlines the significance of UAVs in DM and their advantages. It also focuses on the various issues and challenges faced by the UAV-based infrastructure and security issues and gives future directions.

KEYWORDS
disaster management system, fog computing, IoT, search and rescue, UAV-communication, UAV-network technologies, UAVs, WSN

1 | INTRODUCTION

The most basic human survival instinct is checked by significant and often unexpected losses of property and life in large natural catastrophes. Several forms of natural catastrophes have resulted in a range of deaths and economic damages, such as climatological (extreme temperatures, wildfire, and droughts), geophysical (heavy rain, tropical storms, sandstorms, and hurricanes), hydrological (floods, debris flows, and flash floods), and so forth (Re, 2015). As per a report (M. R. n. d., 2019), the tsunami of 2004 was the world's most devastating natural disaster over the past four decades. Almost 222,000 people died in the disaster. Similarly, Haiti was the second most deadly disaster in January 2010 and cost around 159,000 lives. Foremost, 316,000 individuals were killed, 30 million injured, and 1.3 million evacuated, according to a report published by the United States Geological Survey (USGS; M. R. n. d., 2019). In Nepal, 7.8-scale earthquake is a common tragedy that takes the lives of 9000 people and wounds of 23,000 (Dangal, 2015). In comparison to the deaths previously mentioned, the rehabilitation process has caused an enormous financial loss in the billions of US dollars spent. Another historical figure states, the tsunami, and earthquake in Japan caused nearly 210 billion US dollars of economic damage in 2011 (M. R. n. d., 2019a). Figure 1 shows the 10 most significant natural disasters worldwide by the death toll from 1980 to 2019 (M. R. n. d., 2019).

It can be seen that if the occurrence of such a catastrophe is not prepared or anticipated, then it led to serious damage to human loss and property (Khan et al., 2020; Thomalla et al., 2006). All feasible approaches are, therefore, necessary to mitigate disaster-related damage. These approaches include the designing of active emergency management programs to enable early relief operations. Nevertheless, the implementation of these measures is often hindered by the fact that policymakers are still poorly informed about the scale of human casualties and infrastructure harm (i.e., power plants, transportation networks, etc.) after a catastrophe. It is primarily because of communications problems and unable to visually evaluate the damage. Initially, before the advancement of the communication system for the early stages of a catastrophe, a conventional manned assessments system was used which was often less effective. Therefore, an improved and effective network-based Disaster Management System (DMS; Erdelj et al., 2017a) is required for forecasting and detecting natural and man-made disaster impacts to deal with time and to decrease the number of deaths and damage to the economy. Aerial disaster management (DM) can be defined as the management and preparedness during a disaster such as coverage and information gathering, resource dispatch and survivor rescue, providing communication, disaster area monitoring, and giving the information of all the activities to the control station to take an appropriate decision. Aerial DM has grown as an important resource to enable authorities to resolve any of these issues and increase their understanding of the situation in case of an emergency. Several technologies are involved in reducing the effects of natural disasters. But Unmanned Aerial Vehicles (UAVs) play a great role in every step of predisaster and postdisaster, like, monitoring, detecting, recovery, and response to reduce the effects of a natural disaster.

Nowadays, UAV technology brings the attention of researchers, scientists, and academicians from all over the world starting from military to other applications, such as commercial, health, private uses, sports, ground target detection (Yuan et al., 2019), smart cities (Gupta et al., 2020; Mohamed et al., 2020) construction, education, entertainment, managing wildfire (Barrado et al., 2010), environment, meteorology (Sun et al., 2019), traffic monitoring (Wang et al., 2019a), astronomy, agriculture, remote sensing (Padró et al., 2019), tacking, rescue and search operation (Kanzaki & Akagi, 2019; Singhal et al., 2021), disaster monitoring (Miyano et al., 2019), disaster relief operation (Sánchez-García et al., 2019), and border surveillance (Al Fayez et al., 2019; Bein et al., 2015). UAVs have illustrated their ability to deal with some of the human beings' most difficult tasks, like, natural catastrophes (38 Ways Drones Will Impact Society: From Fighting War to Forecasting Weather, UAVs Change Everything, 2020). For example, they are used in the wake of Hurricane Katrina (Hurricane Katrina, 2012), typhoon Morakot (Typhoon Morakot, 2012), Hatia earthquake (Haiti earthquake, 2012), L'Aquila

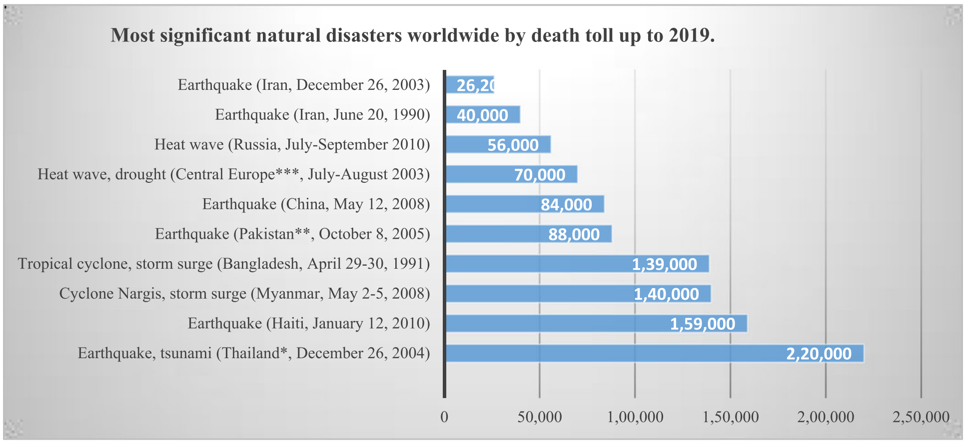

FIGURE 1 The 10 most significant natural disasters worldwide by the death toll from 1980 to 2019 (M. R. n. d., 2019) [Color figure can be viewed at wileyonlinelibrary.com]

earthquake (Adams & Friedland, 2011), and Tohoku earthquake (Tohoku earthquake and tsunami, 2012). UAVs can also provide essential real-time images for disaster areas that can be used to create danger maps. The advantages of UAV systems are multiple: low-cost operation, safe access to dangerous areas, rapid placement, scalable, and flexible deployment to fulfill many assignments that are required in many sectors of society today. UAVs were used in DM to improve disaster response potential, tackle adverse environmental factors, and perform timely rescue operations (Hein et al., 2017). UAVs could provide rescue workers with a bird's eye view of the catastrophe environment, a major feature that is to be considered for an intensive program of DM, including data collection, victim identification, and rescue optimization. Moreover, many UAV systems have been developed to: improve ground network communications (Challita et al., 2019), collect data from the ground-sensor network (Ebrahimi et al., 2018), protect ground communication (Zhang et al., 2019), communicate with ground vehicles (Oubbati et al., 2019), and restore communication in the rough environment (Sharafeddine & Islambouli, 2019). To deliver near-optimal service and fully leverage the capabilities of UAVs, all of these applications must ensure minimum ground reliability. However, there are still several technical challenges and concerns that must be addressed throughout the deployment of UAVs that have yet to be thoroughly researched and resolved. Moreover, several aspects of UAVs, such as their limited battery capacity, great mobility, and ideal deployment, are overlooked. As a result, to solve existing challenges and improve the functioning of applications, a thorough understanding of existing UAV-based solutions is required.

It is important to recognize what type of disaster is, its phases, and its components to respond to different kinds of natural disasters and to develop practicable DM methods and techniques. The process of disaster life consists of three stages: predisaster (before breakout or arrival of disaster), intradisaster (during the disaster), and postdisaster (after the arrival of disaster). A three-stage operating disaster life cycle involving UAVs in the handling of natural and man-made disasters is shown in Figure 2. UAVs can be used, at the predisaster stage, in conjunction with existing warning systems to accurately predict the time and the scope of the outbreak and reduce the cost of disaster-prone economies and materials. According to the Federal Emergency Management Agency, disaster assessment and risk is an overview of various kinds of disasters and the consequences of the danger to identify the related risk as to prepare suitable measures for managing the disaster when it occurs. Such measures are used to reduce community vulnerability and to ensure that informed decisions are taken in time by the authorities and the general public. Hence, disaster prevention approaches are either designed to eliminate potential disasters or to mitigate their adverse effects directly. Since UAVs are capable of flying at a lower altitude to identify local areas of fire ignition at reduced visibility and with a lower risk for pilots as compared with manned aircraft. It also contributes to a decrease in the number of encounters between wildfires and firefighters by using specialized UAVs. Moreover, the UAVs are also used as early warning devices in the monitoring of landslides to locate prone areas and structures (Casagli et al., 2017; Erdelj & Natalizio, 2016). The example above explicitly shows that UAVs can be built into early warning systems for disasters.

During a catastrophe, UAVs are used to identify/locate inaccessible locations by capturing high-resolution real-time photographs that are then used to rapidly create accurate danger maps for the rescuer to determine their condition, establish recovery efforts, and rescue initiatives. For instance, UAVs can be fitted with sensors that measure smoke density, wind speed, and so forth. They can gather data about the combustion rate in an incendiary fire, direction, speed, and so forth, and forecast the imminent creation of this catastrophe. UAVs may also be effective in monitoring wildfire growth and subsequent resident evacuation effectively (Casbeer et al., 2005; Moore, 2013). Monitoring of an active disaster by satellites is applicable, but it may not provide information on the number of casualties, their locations, or the status of relief operations. Dynamic catastrophes, including floods and typhoons, will cause substantial disruption to the power lines and communication towers. This can lead to limited communications among control stations, relief personnel, and survivors. Therefore, large UAVs may be used for temporary connections between control stations and ground teams. Similarly, UAVs of medium size can be used for communications, updates, and alerts by ground teams/survivors (or by local UAV stations using "remote" stations). When a small-scale disaster happens, that is, fire in a building, a medium-sized UAV may

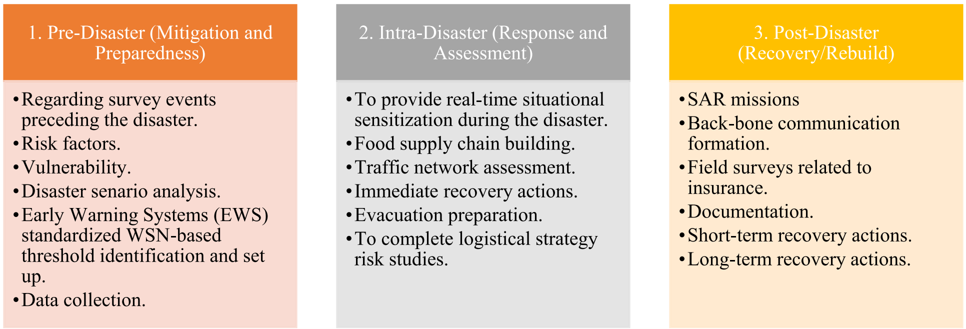

FIGURE 2 Different stages of disaster management based on UAV. SAR, search and rescue; UAV, Unmanned Aerial Vehicle; WSN, Wireless Sensor Network [Color figure can be viewed at wileyonlinelibrary.com]

be used to gather information about the origin of the fire, severity, and degree of fire damage. As UAV operators (controllers) have access to the live streams, the controller can determine how much fire-fighting equipment is required as well as how best spot to position fire-fighters before their first responders arrive at the scene. Moreover, with the help of UAV data, it will allow the first responders to assess fire spread to the adjacent buildings and also the traffic situation there.

In the postdisaster stage, UAVs can also be used in rehabilitation monitoring as well as search and rescue (SAR) operations (Gencer et al., 2013). In addition, documentation and analysis of gathered data can be useful for education, research, and training purposes. Every stage allows the UAVs to perform several tasks, lasts for different times, and has different levels of objectives. In postearthquake situations, UAVs can be used to look for survivors launch SAR work, and gather information on the total number of casualties and the extent of damage in the following period. This can be done using advanced imaging technology to produce three-dimensional (3D) images and virtual structures of these areas that can then serve as a means of creating repair maps. Upon the creation of the repair map, government agencies will conduct recovery missions for high-priority infrastructure. Developing simulated risk networks can help clarify the timeframe for accidents and the infrastructure failure process to mitigate potential losses. Lattanzi and Miller (2017) and Montambault et al. (2010) have explored this dimension, with special application in supply infrastructure, power generation, and transportation. In addition, UAVs will direct refugees to protected places or rescue centers. As a result, using UAVs will minimize the number of first responders to be deployed to the survey at a certain place and time, particularly in a rough environment (i.e., the contamination zones). As demonstrated by Doherty and Rudol (2007) and Goodrich et al. (2008), this will minimize costs and risks related to SAR operations. Several relief operations in the affected areas are needed shortly after a natural disaster. Owing to the shortage of funding and the lack of organized coordination, manpower, and infrastructure, several difficulties are found in this response process. In this sense, de Oliveira Silva et al., 2019) attempts to provide a framework for decision-making to organize the disaster response assistance delivery network using Geographical Information Systems (GISs) and UAV technology.

The need to document the effects of disasters (damaging) and emergency management and learn lessons for improving future disaster response is one of the most significant facets of using UAVs. Since the deployment of UAVs can be done within a few minutes of the disaster, they can record the evolution of disaster (development) and actions of humans as well as the reaction of the disaster. Such “raw” footages are difficult to reproduce with automated experiments (or simulation) and are highly useful for research and education purposes. For example, data gathered from UAVs can contribute to the understanding of disaster behavior, victim reactions, disaster-fighting capacity, and infrastructure structural performance. The investigation team will re-establish a catastrophe site to validate and develop computer models by using data obtained from UAVs. For instance, UAVs have been involved in the postdisaster investigation of nuclear breakdowns, such as air accidents, that is, the Germanwings Flight 9525 crash or the Fukushima Daiichi nuclear disaster (Spranger et al., 2016).

From the above, it can be concluded that UAVs can be a valuable method for emergency relief and infrastructure assessment applications. An emergency communication system is required during any natural disaster, and time plays a critical role in providing information about the victims in real-time to avoid human losses. This paper discusses many recent disasters that successfully utilized UAVs to illustrate the feasibility of using UAVs in different phases of the catastrophe process. Some of the important issues like timely detection, low latency, coordination between UAVs, reliable communication between user and UAV, more coverage and capacity, and so forth, are discussed in this paper. It also discusses the steps needed to successfully integrate UAVs into infrastructure surveillance, risk mitigation, and postincident evaluation applications. Furthermore, it addresses the problems associated with applying UAVs in disaster monitoring, and analysis is raised to tackle the awareness gap.

1.1 | Motivation and principal contribution of the paper

The support of UAVs for various user devices on the ground like UAV-assisted Internet of Things (IoT) networks, UAV-assisted Mobile Ad hoc Networks (MANET), UAV-assisted Wireless Sensor Network (WSN) is recently recognized as the vital element for the success of multiple essential tasks that need substantial improvement with regard to flexibility, network performance, and completion time. Therefore, there is a necessity to define UAV-assisted network architecture which will support the ground user to execute the allocated task effectively (Liu et al., 2018). Yet every assigned task has its problems and challenges (Shakhatreh et al., 2019). For example, UAVs are capable of tracking dangerous conditions and disaster zones (Li et al., 2019), bridging the communication gaps of ground networks (Yuan et al., 2018), and replacing the overloaded or damaged ground Base Stations (BSs; Xilouris et al., 2018). Moreover, a few new issues, including standardization and technical requirements (Li et al., 2019), mobility optimization (Zhang et al., 2017), and privacy and public safety (Vattapparamban et al., 2016), require extra consideration in comparison to current UAV issues. As a result, a vast range of UAV-aided techniques throughout the literature has been suggested to deliver new functionality and simultaneous results, thus addressing the above limitations. This paper's main motivation is to find the critical issues necessary for the timely delivery of messages and provide better wireless communication to the victims and the SAR team. The principal contribution of this article is as follows:

- This paper mainly contributes to data collection through UAVs for various DM scenarios.

- Also, it contributes to UAV-assisted ground communication technologies (such as WSN, IoT, edge, and fog computing) and its coordination for DM.
- Further, it provides a systematic review related to basic UAV-assisted wireless communication for DM.
- Finally, it highlighted the various issues and challenges the UAV faced in disaster scenarios, like, delay, coverage, Quality of Service (QoS) requirements, channel models, UAV positioning, interference problem, and so forth.

The present article mainly focuses on UAV applications related to DMS, that is, how UAV will help in disaster detection, mitigation, response, and preparedness. First, it discusses the present research efforts made in the field of DM for improving its efficiency. Second, it discusses the number of open issues and challenges that remain unresolved. We find it essential to evaluate and concentrate on these issues and problems that considerably increase the effectiveness of catastrophe management systems.

The rest of the paper is outlined as follows: Section 2 presents the reported work in state-of-the-art. Section 3 provides the UAV and its coordination with different technologies, like, WSN, IoT, Edge, and Fog Computing for DM. Section 4 presents a systematic survey of DM applications based on UAVs. Section 5 gives the details related to the network technology and architecture of the UAV. Whereas Section 6 discusses the role of UAV as a relay in providing emergency communication and communication between multi-UAVs. Moreover, Section 7 concentrates on the open research challenges and also gives future directions. Finally, Section 8 concludes the paper. Table 1 presents the list of abbreviations used throughout the article.

2 | REPORTED WORK IN THE STATE-OF-THE-ART

There are currently numerous survey articles in predisaster and post-DM addressing UAV and network function problems. However, the present article of this section is trying to incorporate all components such as preparedness, disastrous impact, response, recovery, development, and mitigation that are required in DM situations into account.

Reynaud and Rasheed (2012) address problems with networking by using all types of aerial vehicles, from balloons and gliders up to satellites. However, significant attempts are required to describe an aerial communications network's function for the successful incorporation of a Low Altitude Platform (LAP)/High Altitude Platform (HAP) in terms of safety and security regulations. In contrast, others present mobile networking with UAVs and detailed analysis of Flying Ad hoc Networks (FANET; Bekmezci et al., 2013; Sahingoz, 2013, 2014). Moreover, these research articles fail to address FANET service qualities that must be enabled to satisfy predefined service performance restrictions, like, jitter, bandwidth, delay packet loss, and so forth. It is a significant technological challenge to establish a robust system for QoS support owing to the hierarchical nature and high mobility of the ad hoc network. In the past two decades, UAV use has been increasingly widespread with developments in computing, camera, connectivity, and networking technology. The focus will shift from the use of a single UAV to the use of many UAVs, which can be combined into teams to accomplish high-level targets. The aim is to move from a single UAV to a multitude of UAVs organized into teams that can collaborate to meet high levels of objectives. UAV-based ad hoc network topology management strategies are focused on Lakew et al. (2020), Nomikos et al. (2020), Park et al. (2019), and Zhao and Braun (2012), while a systematic study on UAVs and their civilian applications are surveyed in Chaturvedi et al. (2019), Hayat et al. (2016), and Mohamed et al. (2020). Zhang et al. (2019a) described the applications, scenarios, challenges, and requirements of Aeronautical Ad hoc Networking (AANETs). It examined emerging and existing airplane communications systems for Air-to-Ground, Air-to-Satellite, and Air-to-Air communications and also for in-cabin communications. This survey looked at the efforts made by the research community to develop AANETs. This paper presents a universal design model for AANETs as well as major technological problems. Moreover, it presents several performance metrics and many sample multi-objective optimization techniques for the design of AANETs. Furthermore, it explored some open issues regarding the implementation of AANETs in real-world aeronautical systems. In the future, the benefits of AANETs will encourage greater research, which will benefit not only aviation but also the broader field of wireless ad hoc networking. AANETs will combine the self-organization of multihop ad hoc networks with the stability and resilience of infrastructure-based networks to create hybrid networking solutions for a variety of aircraft communications applications. The above-discussed research work in the domain only concentrates on UAV-based networks and is lacking to include the system's basic components (such as preparedness, disastrous impact, response, recovery, development, and mitigation) in their studies also does not concentrate on disaster relief situations. Post-DM based on UAV was also discussed by another group of authors but they have either neglect the basic component of the network (such as preparedness, disastrous impact, response, recovery, development, and mitigation) or concentrate on one particular feature, such as the collection of images (Adams & Friedland, 2011; Pi et al., 2020). It only concentrates on a single feature, that is, data acquisition and assessment in case of disaster, whereas all other features like data routing, efficient data processing need to be discussed. The establishment of a consortium of aerial imagery enabled collaborative work among different UAV technology, catastrophic science, and environmental and urban development researchers. Aerial imaging provides data necessary for the interpretation and successful action for technical experts and decision-makers. To provide more precise statistics, however, the aerial imagery data must be checked using ground reality. The workflow of the aerial imagery allows a reliable output of aerial imaging information, which can easily be shared using VEDA, the web-based platform. Ghafoor et al. (2014) discussed post-DM cognitive-radio works. Several aspects are conferred with a demonstration of

TABLE 1 List of abbreviations

ACO	Ant Colony Optimization	MAME	Medium Altitude Medium Endurance
AMP	Agent Mission Planner	MANET	Mobile Ad hoc Networks
ASIMUT	Aid to Situation Management based on Multimodal, MUltilevel acquisition Techniques	MBS	MacroBase Station
ANFIS	Adaptive Network-based Fuzzy Inference System	MD	Mobile Devices
ATC	Air Traffic Control	MEC	Mobile Edge Computing
A2A	Air-to-Air	MG	Minority Games
A2G	Air-to-Ground	MIMO	Multiple Input Multiple Output
BDA	Big Data Analytics	mmWave	Millimeter-Wave
BN	Boundary Nodes	MUSC	Medical University of South Carolina
BS	Base Station	M2M	Machine-to-Machine
B-SMS	Battlefield Soldier Management System	NA	Nearest Assignment
CBBA	Consensus-Based Bundle Algorithm	nDC	Nano Data Centers
CNN	Convolutional Neural Network	NDN	Named Data Networking
CNPC	Control and Non-Payload Communication	NFV	Network Feature Virtualization
DEA	Differential Evolution Algorithm	NOMA	Non-Orthogonal Multiple Access
DIC	Daily Check-In	NURBS	Non-Uniform Rational B-Splines
DM	Disaster Management	OFDMA	Orthogonal Frequency Division Multiple Access
DMS	Disaster Management System	OC	Operative Center
DR-PSLTE	Disaster Resilient-Public Safety Long-Term Evolution	OCU	Operator Control Unit
DSM	Digital Surface Model	OP	Outage Probability
DTN	Delay-Tolerant Network	OSTBC	Orthogonal Space–Time Block Codes
D2D	Device-to-Device	OUDA	Optimum UAV Development Algorithm
eNB	Evolved Node B	PDE	Partial Differential Equation
EMS	Emergency Medical Services	PDF	Probability Density Function
EWS	Early Warning System	PDR	Packet Delivery Ratio
E2E	End-to-End	PL	Path Loss
FANET	Flying Ad hoc Network	PLR	Packet Loss Ratio
FEMA	Federal Energy Management Agency	PRISM	Pictorial Representation of Illness and Self Measure
GA	Genetic Algorithm	PSN	Public Safety Network
GCS	Ground Control Station	PSO	Particle Swarm Optimization

GMP	Global Mission Planner	P2P	Peer-to-Peer
GPS	Global Positioning System	QoL	Quality of Life
GS	Ground Station	QoS	Quality of Service
GU	Graphical User	RFC	Random Forest Classifier
G2A	Ground-to-Air	RSS	Received Signal Strength
HAP	High Altitude Platform	SAR	Search and Rescue
HAS	Harmony Search Algorithm	SDN	Software-Defined Network
HAPF	Hybrid Artificial Potential Field	SIFT	Scale Invariant Feature Transform
HCA	Hill Climbing Algorithm	SNR	Signal to Noise Ratio
HetNet	Heterogeneous Network	SoS	System of System
HLCS	High-Level Coordination Swarm	STOM	Smart Traffic Offloading Mechanism
HVCR	Hierarchical Virtual Communication Ring	SURF	Speed Up Robust Features
IMATISSE	Inundation Monitoring and Alarm Technology in a System of SystEms	SWAP	Size, Weight, and Power
INSARAG	International Search and Rescue Advisory Group	TB	Trajectory Balancing
IoE	Internet of Everything	TETRA	Terrestrial Trunked Radio
IoPST	Internet of Public Safety Things	TR	Transmission Rate
IoT	Internet of Things	TSP	Traveling Salesman Problem
ITU-R	International Telecommunication Union Radiocommunication	UAS	Unmanned Aircraft System
LAP	Low Altitude Platform	UAV	Unmanned Aerial Vehicle
LLS	Low-Level Swarm	USAR	Urban Search and Rescue
LoRa	Long Range	U2I	UAV-to-Infrastructure
LoS	Line of Sight	U2U	UAV-to-UAV
LP	Linear Programming	VTOL	Vertically Take Off and Land
LSAR	Layered Search and Rescue	WoT	Web of Things
LTE	Long-Term Evolution	WPC	Wireless Powered Communication
MALE	Medium Altitude Long Endurance	WSN	Wireless Sensor Network

different industrial initiatives and projects. However, practical and adaptable transmission techniques may be used with high reliability to eliminate connection problems. Moreover, wideband transmitting technologies like Orthogonal Frequency Division Multiple Access, spread spectrum, frequency hopping, and so forth, can be used to improve reliability in a high interference environment. Masroor et al. (2021) studied a UAV-assisted catastrophe situation in which several emergency conditions were used to demonstrate the relevance of installing a UAV in a disaster event. They utilized Integer Linear Optimization Problem to create a model of their constraints and goals. The goal of their optimization challenge is to maximize the number of connections between users and the UAV while ensuring the least amount of user connectivity. The challenge is prolonged to provide a cost-effective deployment solution that takes into account distance and cost. The Branch and Bound (B&B) algorithm was used to solve the problem and maximize the outcomes. They have also presented a low complexity heuristic to demonstrate the usefulness of the given problem.

WSN is an infrastructureless wireless network that is deployed in a large number of wireless sensors in an ad hoc manner that monitors and records the physical conditions of the environment and forwards the collected data to a central location. WSNs can measure environmental conditions, such as temperature, sound, pollution levels, humidity, and wind. WSN has found widespread use in sensing physical parameters for monitoring, prediction, and detection of disasters, like, landslides, forest fires, and earthquakes. Many applications and networking protocols need an appropriate sensor node position because the QoS is dependent on the accuracy of localization. Annepu and Anbazhagan (2020) proposed UAV-aided localization over conventional fixed land anchor locations to improve localization accuracy and decrease implementation costs. In the UAV localization, the UAV flying height was initially optimized, and the least square problem for node localization is proposed using this optimum height. This localization problem has been optimized by the Differential Evolution Algorithm technology. Rashed and Soyturk (2017) discuss multiple mobility models for UAVs, which seek different paths to cover the area of operation, such that a maximum covered node is obtained at the minimum amount of time required by the mobile sink node. It also incorporates a new matrix to devise a tradeoff between maximizing the nodes covered and minimizing the time of operation when selecting the correct mobility model. Erdelj et al. (2017) describe the role of WSN and UAV in natural DM. It focused on the main applications and classified WSN and UAV based on DM phases. In addition to surveying the impacted area, UAV-based DM applications (Erdelj & Natalizio, 2016) also help create the communication network between rescue teams, disaster survivors, and the telecommunications infrastructure that is nearby. Popescu et al. (2019) provide a study on collaborative work on the UAV–WSN system and focus on the multiprotocol hierarchical networking, distributed data processing algorithms, high-level constrained-WSN, and control-UAV. The various fields are also highlighted, such as emergencies, agriculture, homeland security, and the environment. To deal with the harmful consequences of natural disasters, an effective optimization approach was proposed for embedded UAV-assisted relays in WSN (Duong et al., 2019). In embedded UAV–WSN communication, real-time optimization for the monitoring and collection of sensor data is included in this model. Such algorithms are computationally complex, easily implemented, and running fast in milliseconds to solve problems.

IoT and UAV together can potentially improve the performance of the DMS. UAVs are capable of gathering extensive heterogeneous data from areas afflicted by disasters using Fifth-Generation (5G) or Beyond 5G (B5G). Now, this data can be used to gain the appropriate information from the first respondents, such as the detection and recognition of damaged infrastructure and blocked roads and people's state of health living in that region. Ejaz et al. (2020) provide an overview of a different emergency response system based on IoT, UAV, and IoT combined with UAV for a DMS. It proposed an energy-efficient task scheduling algorithm for the collection of data from the ground-IoT network by UAVs. The emphasis is made on designing the UAV's path to reducing energy usage. It also evaluates the essential sign data obtained by UAVs in disaster-affected regions and uses the decision tree algorithm to assess their health risk status. UAV-assisted IoT framework consists of three primary fields of research: (i) IoT ground network, (ii) communication technologies to provide connectivity for ground and aerial, and (iii) data analytics. A comprehensive view of UAV-assisted IoT networks is provided by Ejaz et al. (2019) that can be ubiquitous for aerial and terrestrial users under challenging conditions like wildfire management. The research was undertaken to create an effective ground-IoT network to monitor and detect fire and deliver messages to those who use the system called Named Data Networking architecture. Liu et al. (2018) combined a multihop Device-to-Device (D2D) and UAV–BS to carry out the emergency communication for IoT in catastrophe. The Shortest Path Routing algorithm was considered for a multihop D2D transmission to combine a multihop D2D link with the minimum hops to maximize the wireless UAV range effectively. It helps in saving energy in emergencies from batteries that are constrained on ground devices. Xu et al. (2019) focus on the issues of creating a navigation strategy for UAV disaster relief based on the airborne approach. It develops a lightweight navigation technique employing transfer learning associated with visual recognition. Further, Datta et al. (2018) discuss the possibilities of an integrated IoT and Web of Things platform for UAV services. Cloud technology that handles the video transmission and monitoring of remote-controlled drones in real-time is introduced. From the above research articles, we can conclude that communication protocols between UAVs as well as cluster heads and UAVs can be enhanced to the monitoring center to increase connectivity. In the future, another fascinating research may be the distribution of tasks depending on each cluster's risk factors, which means that we will gather data from UAVs for the first time. After evaluating the data collected, the UAV's route to clusters will be prioritized with high-risk factors.

A holistic and oriented approach covering all facets, including early warning of disaster situations, preparedness, prevention, recovery, and management, is required to reduce losses. Khan et al. (2020a) provide a comprehensive survey of emerging disaster-based approaches and technologies, such as WSN, IoT, UAV, remote sensing, satellite imagery, and artificial intelligence, to tackle challenges related to disaster surveillance, detection, and management. WSNs offer wireless connectivity and sensing, and are considered the key foundation of the IoT network. Hence, WSN's lifespan is the prime concern of the network. For the energy-efficient routing system for WSNs, Biabani et al. (2020) proposed an algorithm for cluster-head selection based on hybrid Particle Swarm Optimization (PSO) and Harmony Search Algorithm for a forest fire. It also designed a multihop PSO-based energy-efficient routing system with modified data packet format and improved tree encoding. Njoku et al. (2020) explore recent research on emerging topics such as project coordination, deployment, and team collaboration and accountability as well as IoT technologies by presenting early warning signals for prevention and preparedness, UAVs for disaster response scenarios, and Big Data Analytics for information collection. However, this article fails in describing various research challenges that are faced during DM, like, coverage, connectivity, mobility, resource allocation, reliability, and so forth. Alsamhi et al. (2019) explore the network performance of the Internet of Public Safety Things and drones to provide these essential facilities in the case of a catastrophe and for the sake of public health and safety. It contributes to enhancing the public security level in smart cities by a joint collaboration between drone technology and wearable smart devices. More research is required to fully understand how IoT can be used effectively to recover catastrophes and improve the overall processes of DM. Sikeridis et al. (2018) propose a system that incorporates UAV support with Wireless Powered Communication techniques to boost further the performance of energy consumption of Non-Orthogonal Multiple Access (NOMA) Public Safety Network. The IoT devices initially make up coalitions by selecting their role (coalition leader or member) in the network based on the principle of Minority Games. The member nodes function subsequently as a stochastic automaton for learning to align themselves with the coalition leader using a reinforcement learning technique.

UAVs can be deployed rapidly whenever needed, making them ideal applicants for assisting terrestrial networks, such as expanding vehicular network connectivity, offloading traffic in cellular networks, reducing D2D network handovers, and creating on-demand wireless communications with ground users in catastrophe circumstances where ground networks are not completely functional. A lot of research has recently been done on this type of deployment. For example, Zhang et al. (2018a) investigated the deployment of multi-UAVs as flying BSs for delivering the on-demand wireless facility to a group of cellular subscribers. Cui et al. (2018) look into ways to improve the worst-case secrecy of a suggested secure communication system that uses UAVs to communicate with ground networks in the existence of ground eavesdroppers. In addition, Yang et al. (2018) proposed a UAV-enabled data gathering system, intending to explore the energy tradeoff issue in UAV-to-ground communications. However, collaborating IoT devices on the ground can be used for public safety but the collaboration of IoT devices on the ground is not useful in disaster scenarios because one can do it only in a normal situation. Whereas in case of natural disasters usually all terrestrial BSs get destroyed so we suggest UAV-mounted BSs that are easy to deploy as compared with ground BSs. Also, UAV–BS can move freely in any direction and can cover large geographical areas, and can move to unreachable places to provide communication to victims.

The smart city's prime aim is to enhance Quality of Life by increasing efficiency, improving infrastructure, efficient use of resources, reducing adverse environmental effects, and discovering health hazards such as radiation and prediction of cancer risk. UAV and fog computing was recently adapted to serve the Internet of Everything (IoE) systems and applications using UAV services to offer the strength and advantages of fog computing and UAV. Al-Khafajiy et al. (2020) present a case study on environmental disaster prediction and recovery plans based on collaborative UAV-Fog computing for IoE-based systems. UAV-Fog computing will support IoE systems in smart cities with versatility, mobility, and quick delivery functionality. UAV-Fog also provides significant benefits over DMS as it allows support for both precatastrophe monitoring, planning, and SAR activities to be used in disaster scenarios. Table 2 gives a summary of the related work and its contribution and limitations.

From the above survey, it is found that several good studies on UAV-based networks have been available, including UAVs as FANETs, UAV-based cellular networks, UAV–WSN networks, UAV–IoT networks, and UAV-based DM. Table 2 presents a brief comparison of the most popular surveys in the literature. Indeed, each survey undergoes rigorous analysis based on numerous factors, including the number of UAV-based applications, the number of comparison studies, the main contributions, and the discussion of future problems. As none of these surveys included all types of UAV-aided applications, it is now time to give a completely up-to-date survey of this key paradigm in a single article. Our contributions are outlined as: This article gives an overview of the UAV aid paradigm as well as in-depth analyses of its primary issues and limitations. It looks at how each system works while also pointing out its key flaws. It gives full comparative research in each category based on key parameters to assist researchers in rapidly grasping the recommended solutions. It wraps off the survey by analyzing the many research challenges, as well as offering some answers and recommending references to meet them. In addition, it highlights some more research challenges from the survey's conclusion.

In this article, the authors try to present the collaborative work between WSN, IoT, and UAV for the DMS. Figure 3 shows the collaboration of WSN, IoT, and UAV for DMS. WSN is a low-power device that is mainly used as a ground sensor for collecting environmental data. The IoT devices do statistical data processing, and distributed algorithms are used as well as fog/edge computing is made. Whereas UAVs perform complex sensing tasks, provide long-distance communication links, and can do trajectory planning and control. Together, these collaborate to carry out real-time query response, real-time data storage, offer reliable communication, provide alternate communication networks, support high-speed data analytics, and fast result generations.

3 | UAV AND ITS COORDINATION WITH DIFFERENT TECHNOLOGIES (WSN, IoT, Edge, Fog, AND Cloud COMPUTING) FOR DM

For some years, UAVs are used in various applications (Alzahrani et al., 2020), as discussed above, and their versatility is demonstrated by UAV's ability to perform complex tasks with low-cost combat and maneuvering flexibility. The operator monitors the location of the vehicle in all situations during a regular mission. However, the operator is liable for only certain tasks while the flight is in a semiautonomous mission, including takeoff and landing of the aircraft are performed autonomously through waypoints by the operator. The trajectory of the aircraft is established on board in a fully autonomous mission, and the operation is conducted without the operator in the vicinity. In this respect, the autonomous aerospace robots are linked to a supervision system (e.g., GS), normally located in the cloud, that is in charge of all high-level processing. The cloud-based solution could be inadequate for critical real-time applications. However, the amount of data that is exchanged between such devices produced higher bandwidth communication costs, lack of mobility, delays in communication, energy limitations for embedded systems, and redundancy of the information (Dias et al., 2016).

TABLE 2 Summary of the related work and its contribution and limitations

Ref. No.	Technology	Highlighted/contributions	Limitations/future direction	Applications
Reynaud and Rasheed (2012)	UAV	• It addresses the problems with networking by using all types of aerial vehicles • It analyzed civil aerial communication networks and described the different aircraft types capable of carrying a communication payload at varying altitudes • It outlined many problems mainly related to aerial network performance and design	• Significant attempts are required to describe an aerial communications network's function for the successful incorporation of a Low Altitude Platform/High Altitude Platform in terms of safety and security regulations	Civilian purpose
Sahingoz (2013), Sahingoz (2014), Bekmezci et al. (2013)	UAV as FANETs	• It presents mobile networking with UAVs and a detailed analysis of FANET • Identify the problems of using UAVs in an ad hoc network as mobile nodes • It focuses on the routing protocols for FANETs	• FANET service qualities must be enabled to satisfy predefined service performance restrictions, like, jitter, bandwidth, delay, packet loss, and so forth • It is a significant technological challenge to establish a robust system for QoS support owing to the hierarchical nature and high mobility of the ad hoc network	Civilian and military
Zhao and Braun (2012), Park et al. (2019), Nomikos et al. (2020), Lakew et al. (2020), Zhang et al. (2019a)	UAV	• It focuses on the UAV-based ad hoc network topology management strategies • It presents an architecture for communication that meets the needs of mobile network applications of 5G • It provides a comprehensive analysis of the current routing protocols for ad hoc flying networks, communication, classification, and application architecture of UAVs	• Routing protocols in FANET should meet the quality of service requirements of applications, such as jitter, bandwidth, packet loss, and delay, which are challenged by multi-UAV complexities such as different network conditions, removal, and addition of UAVs, and high mobility	Commercial and military
Chaturvedi et al. (2019), Mohamed et al. (2020), Hayat et al. (2016)	UAV	• It provides a systematic survey on UAVs and their civilian applications • It gave case examples of drones used in India	• The potential research in the future involves planning and improving effective and productive architecture frameworks, strengthened middleware systems and integration techniques, and better deployment	Military and civilian
Ezequiel et al. (2014)	UAV	• It explores the use of various applications of the remote sensing system based on low-cost UAVs, including infrastructure development monitoring, postdisaster assessment, and environmental protection • It facilitates the acquisition, analysis, postprocessing, sharing, and assessment of aerial imagery using UAVs	• Aerial imaging data must be checked with ground reality to obtain more reliable results • It requires the development of the aerial imaging framework to automate additional processes, including filtering of images and improving the image contrast	Postdisaster assessment, infrastructure development, and environmental management

TABLE 2 (Continued)

Ref. No.	Technology	Highlighted/contributions	Limitations/future direction	Applications
Adams et al. (2011), Pi et al. (2020)	UAV	- It describes a review of the current use of UAVs in the field of disaster monitoring and management for imagery acquisition - It concentrates on one particular feature, such as the collection of images - It enabled the damage measurement and detection of natural disasters in airborne imagery using Convolutional Neural Network models based on past disaster footage	- It only concentrates on a single feature, that is, data acquisition and assessment in case of disaster, whereas all other features like data routing, efficient data processing need to be discussed	Disaster monitoring and management
Ghafoor et al. (2014)	Cognitive radio	- It explores the application of cognitive-communication technology for emergency response networks and shows that it is best suited to address these networks' particular needs	- Practical and adaptable transmission techniques may be used with high reliability to eliminate connection problems - Wideband transmitting technologies like Orthogonal Frequency Division Multiple Access, spread spectrum, frequency hopping, and so forth, can be used to improve reliability in a high interference environment	Disaster response
Masroor et al. (2021)	UAV	- It presents the situational awareness deployment of UAV-based wireless networks in disaster management as a mobile aiding unit - It efficiently places UAVs in emergency circumstances where infrastructure is destroyed and dispersed with features, like, the number of UAVs, cost, and minimum distance	- It does not focus on UAV deployment in the 3D plane - It fails data offloading and multilayer UAV installation	It is used in a disaster situation
Gao et al. (2020), Annepu and Anbazhagan (2020), Rashid et al. (2017), Erdelj et al. (2017), Erdelj & Natalizio (2016), Popescu et al. (2019), Duong et al. (2019)	WSN and UAV	- It designed an integrated data aggregation platform and data sensing node deployment based on a WSN and UAV - It presents UAV-aided localization over conventional fixed land anchor locations to improve localization accuracy and decrease implementation costs - It discusses multiple mobility models for UAVs, which seek different paths to cover the area of operation - It focused on the main applications and classified WSN and UAV based on disaster management phases	- The techniques for motion planning were often much less complicated. Whereas the fundamental problem of optimization can be very complicated, the paths can most frequently be given as a series of segments that connect consecutive path points - It does not focus on coordination and cooperation between WSN and UAV - The latest applications involve numerous large geographically distributed WSN sensor nodes and UAVs beyond the concept of a system	It is used for data aggregation, localization, and mobility models for disasters

(Continues)

TABLE 2 (Continued)

Ref. No.	Technology	Highlighted/contributions	Limitations/future direction	Applications
Ejaz et al. (2020, 2019), Liu et al. (2018), Xu et al. (2019), Datta et al. (2018)	IoT and UAV	• Its emphasis is made on designing UAV's path to reducing energy usage • A ground-IoT network was made to monitor and detect fire and deliver messages to those who use the system called NDN architecture • It combined a multihop D2D and UAV–BS to carry out the emergency communication for IoT in catastrophe • It presents an integrated IoT and WoT platform for UAV services that supports video streaming and monitors commands in real-time	• Communication protocols between UAVs as well as cluster heads and UAVs can be enhanced to the monitoring center to increase connectivity • Another fascinating research may be the distribution of tasks depending on each cluster's risk factors, which means that we will gather data from UAVs for the first time. After evaluating the data collected, the UAV's route to clusters will be prioritized with high-risk factors • It only covers the IoT ground network. Future research is to take into account data analytics and terrestrial and aerial connectivity	It presents an energy-efficient path for UAV, monitoring and detecting, emergency communication, video streaming for disaster management
Khan et al. (2020a), Biabani et al. (2020), Njoku et al. (2020), Alsamhi et al. (2019), Sikeridis et al. (2018), Al-Khafajiy et al. (2020)	WSN, IoT, and UAV	• It explores the network performance of the Internet of IoPST and drones to provide these essential facilities in the case of a catastrophe and for the sake of public health and safety • It presents a case study on environmental disaster prediction and recovery plans based on collaborative UAV-Fog computing for the IoE-based systems • It provides a comprehensive survey of emerging disaster-based approaches and technologies, such as WSN, IoT, UAV, remote sensing, satellite imagery, and artificial intelligence, to tackle disaster surveillance, detection, and management challenges	• To design efficient WSN safety-critical MAC protocols to prevent lengthy delays and extend simulation scenarios, particularly in heterogeneous networks • More research is required to fully understand how IoT can be used effectively to recover catastrophes and improve the overall processes of disaster management	It is used for public safety networks for disaster management

TABLE 2 (Continued)

Ref. No.	Technology	Highlighted/contributions	Limitations/future direction	Applications
Our survey	WSN, IoT, Fog computing, Edge Computing, UAV	• It presents a tutorial overview of recent developments in UAV communications and how UAV integrates with WSN, IoT, Fog, and Edge computing for DMS • It focuses on various applications of UAVs in the DMS • It describes the role of network technologies for UAVs in DMS. • It also highlights the various issues and challenges faced by the UAV and gives the future direction	• In the future, it tries to propose and implement a model integrating with different technologies and analyze the various performance metrics for DM	It is used in disaster mitigation, preparedness, response, and recovery

Abbreviations: 3D, three dimensional; 5G, Fifth-Generation; BS, Base Station; D2D, Device-to-Device; DM, disaster management; DMS, Disaster Management System; FANET, Flying Ad hoc Network; IoE, Internet of Everything; IoPST, Internet of Public Safety Things; IoT, Internet of Things; MAC, Medium access control; NDN, Named Data Networking; QoS, Quality of Service; UAV, Unmanned Aerial Vehicle; WoT, Web of Things; WSN, Wireless Sensor Network.

To mitigate these problems, a new computing model is made to keep storage and computation closer to the end-users that are the drones in this case. To improve power consumption, latency, efficiency, and scalability, fog computing occurs as an intermediate layer between the end-users and the cloud. Fog computing enables data acquisition, data processing, and storage on fog devices to address the shortcomings of centralized cloud computing (Mahmud et al., 2018).

3.1 | Coordination between UAV and WSN

UAVs can be used as data collectors in WSN as they can travel nearer to sensors to gather information from them more effectively (Gong et al., 2018). Wu et al. (2018a) suggest a system for energy-efficient data collection using UAVs. UAVs are positioned over WSNs to reduce the energy usage of ground sensors that are grouped into clusters. Verma et al. (2018) and Verma et al. (2019) suggested the strategy which is the best way for UAVs only to gather data from cluster heads. The trajectory is, however, not specified according to the ground sensors' energy levels. Hence, data gathering is one of the problems in WSN. Besides, ground sensors are grouped in clusters to ensure energy conservation that can produce high overheads during the creation of these groups. Thus, the development of this type of cooperation should take into account the suitable UAV-to-ground channel model (Popescu et al., 2018), implementing a short distance Line of Sight (LoS; Liu et al., 2019), and the trajectory optimization of UAV (Zhan et al., 2018). In the literature, many findings have been made using the principle of UAV–WSN coordination. To ensure that maximum data from each ground sensor is retrieved, Zhan et al. (2017) together tailored the wake-up and sleep cycle for ground sensors and optimized the UAV's trajectory to minimize the consumption of energy effectively and to guarantee the maximum collection of data from each sensor on the ground. Also, it is not realistic, as the authors believe that UAVs fly at the same height. For an emergency, Cao et al. (2017) suggested the collection of data for the WSN cluster based on UAV. This study and its cloud infrastructure take into account the deployment of the terrestrial network and the optimum flight parameters of the UAV. The use of one UAV, however, will adversely affect the effectiveness of the data collection, particularly across a wide range. Figure 4 presents the main contributions to UAV–WSN coordination for DMS. It helps in disaster preparedness, assessment, response, and recovery. In preparedness, we can perform sensing of environmental physical parameters, can do directed surveying with the help of a flight controller, do optimization of WSN data acquisition, and data analysis with help of UAVs as mules. In disaster assessment, we can do situational awareness in real-time, logistics planning of the damaged buildings, acquire WSN environmental data and reconnect the disjoint UAV network. In response and recovery, UAVs can create a communication link, can support the SAR mission, provide medical aid to the victims, and maximize the data provided by WSN to improve the efficiency of SAR executed by UAVs. Figure 5 gives the collaboration between WSN and UAV for the DM system. In Figure 5

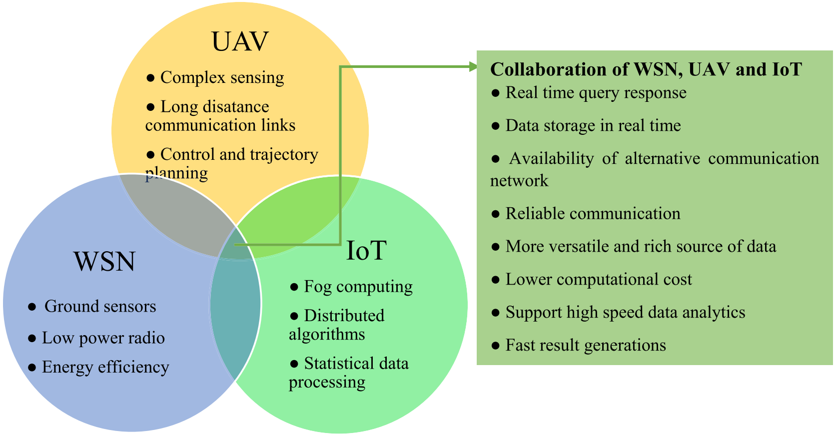

FIGURE 3 Collaboration of WSN, UAV, and IoT for DMS. DMS, Disaster Management System; IoT, Internet of Things; UAV, Unmanned Aerial Vehicle; WSN, Wireless Sensor Network [Color figure can be viewed at wileyonlinelibrary.com]

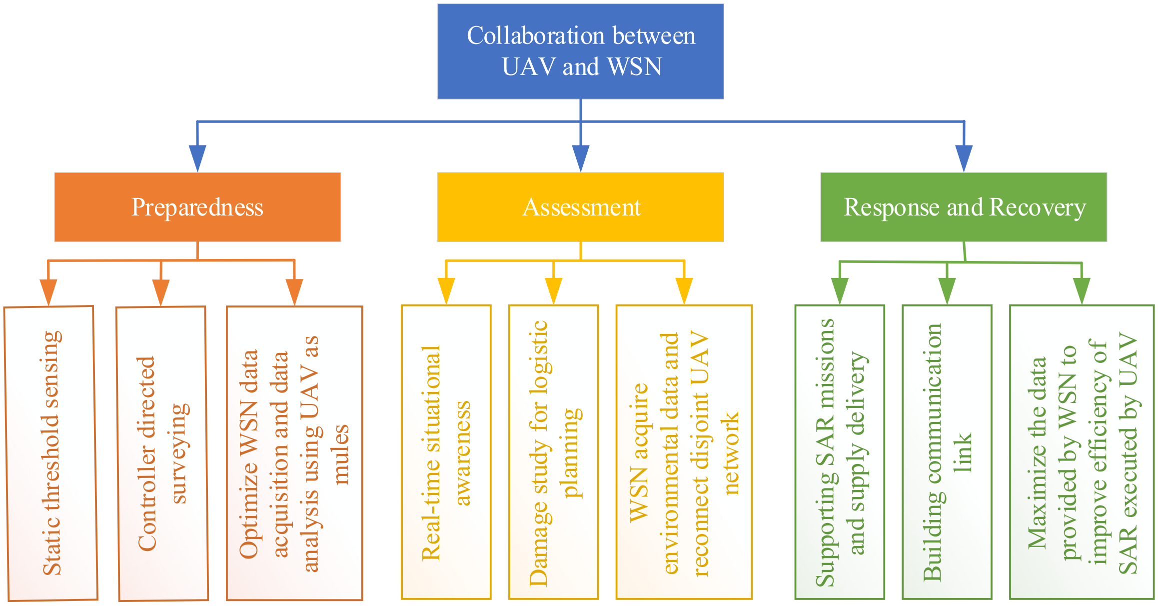

FIGURE 4 Main contributions to UAV–WSN collaboration for DMS. DMS, Disaster Management System; SAR, search and rescue; UAV, Unmanned Aerial Vehicle; WSN, Wireless Sensor Network [Color figure can be viewed at wileyonlinelibrary.com]

WSN is deployed in the disaster zone for sensing the environmental parameters and UAVs are used to collect the sensed data from the WSN which then forwarded the collected data to the BS to take proper action and send the SAR team.

The main idea of this subsection is that several constraints and characteristics, such as induced overhead, UAV density, and energy limits must be evaluated to maximize UAV–WSN data collection. The UAV trajectory must be tuned based on the energy levels of the UAV itself as well as the ground sensors to gather the maximum data. Moreover, to reduce overhead, the ground sensors' wake-up and sleep schedules must be synchronized with the UAV collector's positions rather than with exchanging messages. A significant number of contributions group the ground sensors into clusters, however, the expense of this arrangement in terms of overhead is significant. As a result, dependable clustering solutions must be suggested to limit the degree of induced overhead.

3.2 | Coordination between UAV and IoT

Due to the limited transmission range and energy of the IoT devices, traditional multihop communication techniques can result in both energy loss and poor wireless connections, which leads to a decrease in network life and low data collection rates, respectively (Wu et al., 2018). Therefore, it is necessary to tackle three critical problems effectively: (i) to create suitable locations so that IoT devices can conserve energy efficiently, (ii) to find the wireless and remote rechargeable batteries for IoT devices, and (iii) to provide accurate and secure data collection techniques (Elijah et al., 2018). UAVs are the most appropriate technique to solve these problems by dynamically flying over them. It is used to collect data, transmit data to other IoT modules or BSs over a long distance beyond the communication ranges of such IoT modules, and wirelessly recharge the IoT devices using the harvesting module (Wang et al., 2017). Figure 6 presents the collaboration between IoT and UAV for the DM

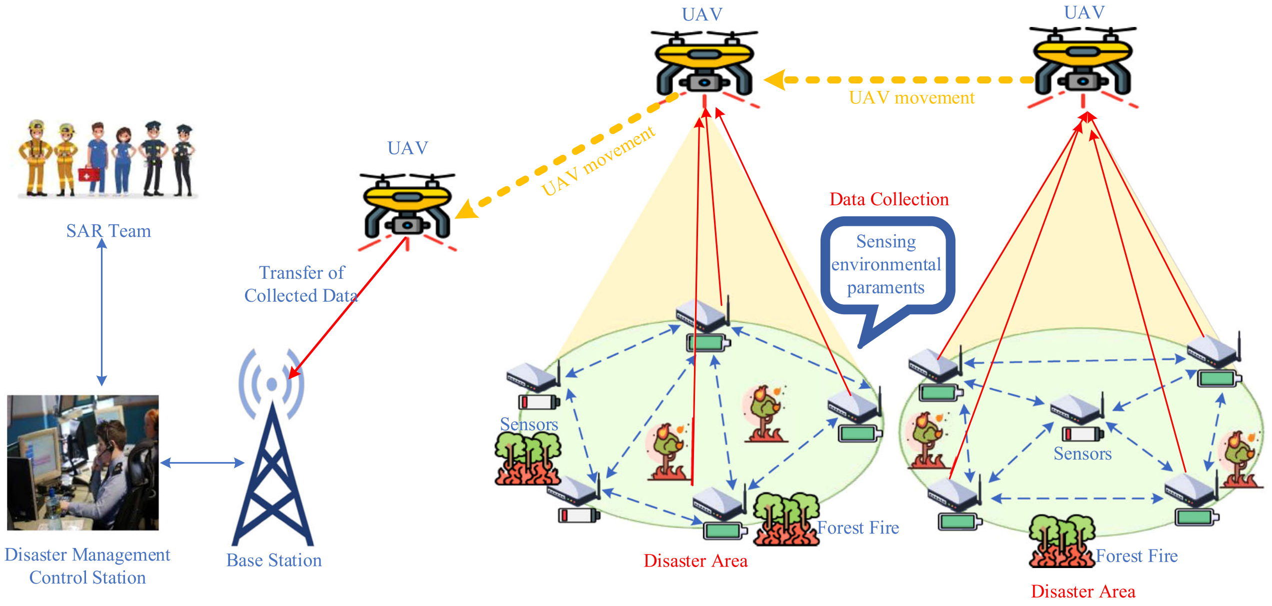

FIGURE 5 UAV and WSN collaboration for DMS. DMS, Disaster Management System; SAR, search and rescue; UAV, Unmanned Aerial Vehicle; WSN, Wireless Sensor Network [Color figure can be viewed at wileyonlinelibrary.com]

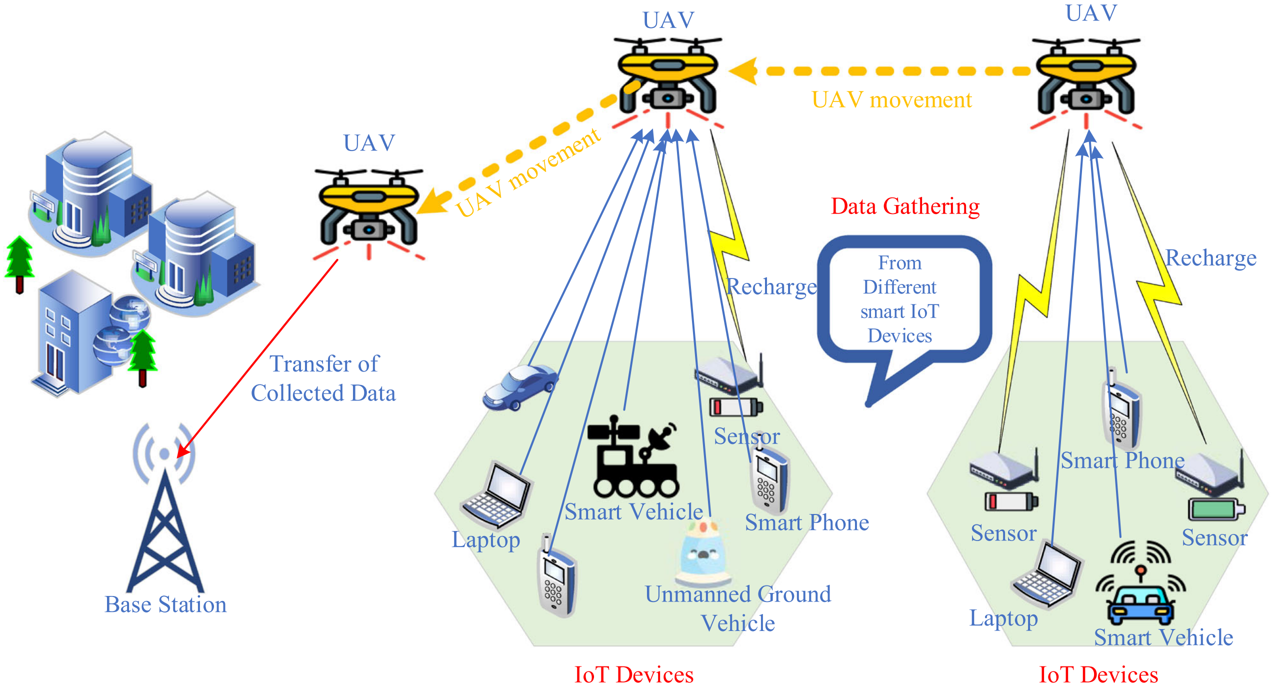

FIGURE 6 UAV and IoT Coordination. IoT, Internet of Things; UAV, Unmanned Aerial Vehicle [Color figure can be viewed at wileyonlinelibrary.com]

system. In Figure 6 UAVs will get data from various IoT devices and then transfer the collected data to the nearest BS. With the help of UAVs, we can monitor the vehicles on the ground, recharge the ground sensors, and communicate with smart devices.

Arabi, Elbiaze et al. (2018) suggested a tradeoff between the transfer of wireless energy and data collection in the IoT environment. They proposed a framework comprised of UAV–BSs with the energy component that servers the IoT ground devices. In turn, IoT applications may use UAV–BSs as energy sources because of their limited energy capacity, while their battery level is below a certain threshold. Also, UAV–BSs gather IoT device data that exceed the defined threshold to send packets with the remaining residual energy. However, it was shown that UAV–BSs are neglected in their energy consumption. To enhance this mission, exhausted IoT modules can be wirelessly recharged, and the data collection by UAVs can also be successful. Arabi et al. (2018) suggested UAV–BSs for recharging all the exhausted IoT ground modules and performing data gathering. The UAV–BS is fitted with a portable recharging kit for energy harvesting. Furthermore, UAV–BS uses IoT device's radio frequency for collecting data and harvesting energy only from those that have ample residual power to send their packets. The UAV route is designed to ensure a minimal journey time and to boost the life of the network. In this study, IoT devices have always been in a wake-up state, thus wasting a lot of resources. Figure 7 presents the main contributions to UAV–IoT coordination for DMS.

Another issue is access congestion in the medium access control (MAC) layer, which causes high power consumption of both sensor devices and UAVs and poor data collection efficiencies due to the characteristics of the extensive connections. This problem is addressed by Pan et al. (2018), which propose a dynamic speed control algorithm for UAVs to adjust the speed of UAVs and efficiently collect data while eliminating the UAV–BS's access congestion. The cellular network facilitates coordination between UAV and ground sensors. Moreover, during the coverage and data collection, UAVs can adjust the ground sensor's speed effectively in conjunction with their distance. Yet this system does not take into account the status of the channel in speed regulation. In a conventional network data gathering, the data packets which need to be transmitted to the BS in a hop-by-hop fashion consume a large amount of energy. UAVs were used in a vulnerable area to travel over the sensed environment to gather data (Goudarzi et al., 2019) to mitigate the energy problem. Due to the movement and flight time constraints, UAVs need to carry out their activities on the smoothest and shortest path. Traveling Salesman Problem can, therefore, be used to schedule the shortest route, while for smoothing the path, Bezier curves can be used to transform flyable paths. The data gathering and ground sensor's residual energy are not taken into consideration as a shortcoming.

The key idea of this subsection is that UAV–IoT data collection demands addressing some issues, including UAV and IoT device energy consumption, wireless battery charge management, and optimal UAV trajectories for data gathering. Determining a near-optimal density of UAVs for data collecting, as well as a reliable data exchange technique between UAVs to other IoT devices placed far away. Since multiple IoT devices can cause interference with other

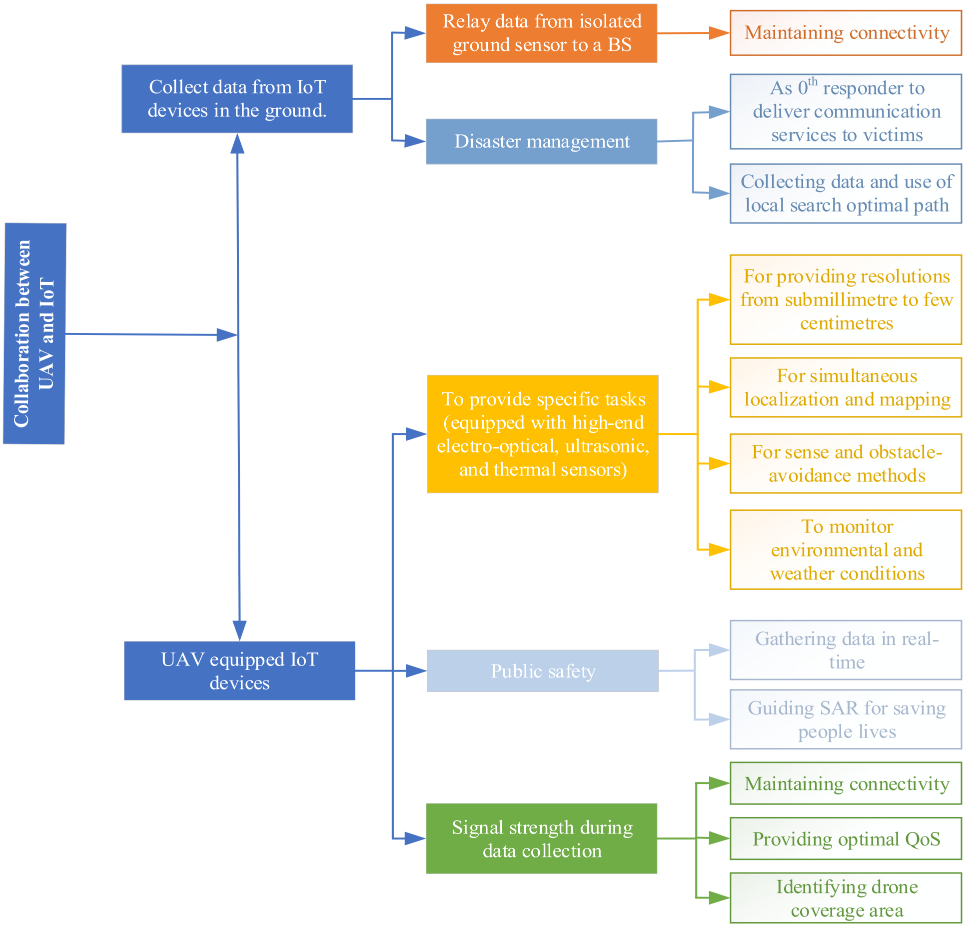

FIGURE 7 Main contributions to UAV–IoT collaboration for DMS. BS, Base Station; DMS, Disaster Management System; IoT, Internet of Things; QoS, Quality of Service; SAR, search and rescue; UAV, Unmanned Aerial Vehicle [Color figure can be viewed at wileyonlinelibrary.com]

IoT devices and UAVs, channel access control must be thoroughly examined.

3.3 | Role of edge computing in UAV for DMS

The computational capabilities of UAVs can be improved in economic and energy-efficient ways if Mobile Edge Computing (MEC) has been implemented to conserve energy for mobile nodes and allow low time computation (Zhang et al., 2018). As UAVs can offload their complex computational functions to terrestrial BSs (i.e., edge network), this aids in improving the UAV's application time and broadening its service horizon. Kalatzis et al. (2018) have proposed an early-fire detection application using UAVs based on the principles of edge and fog computing. This three-layer hierarchical architecture incorporates powerful cloud computing resources, rich fog computing resources, and exploits the UAVs sensing capabilities. The implementation of the Fog computing system shows all these principles have produced fascinating outcomes with the considered situations. However, in the processing load between Fog nodes, an unfair assignment is distinguished. To tackle the limited computational resources, UAV MEC and UAV offloading computing have been researched by Bekkouche et al. (2018) to boost traffic management between UAVs. In the case of a large-scale natural disaster, the evolved Node B (eNB) of the affected region may be devastated, also with huge data traffic at the core network causing congestion. A Smart Traffic Offloading Mechanism (STOM; Chen et al., 2019) was proposed on a vehicular eNB to increase network performance and latency of the disaster-resilient communication system with extreme core network congestion. The STOM can redirect relief worker's traffic flows within the same disaster area based on the concept of MEC to prevent locally based information from entering the core network. Figure 8 presents UAV computing as Edge, Fog, and Cloud nodes. From Figure 8 it can be seen that at ground level UAVs are used to sense the environment, to be remotely controlled, or to send requests. At the edge node it is used for capturing, aggregating, filtering, and encoding the local raw data streams in real-time. And then it is sent for processing at the fog node where it helps in improving dynamism and management of the network. After that, it sent a request message to the cloud node for processing less time-sensitive data and long-term storage. Which in turn give a response to the fog node and further give result to the edge node.

Zhou et al. (2018a) researched the UAV-enabled MEC system to uphold a sustainable offloading task. The system was expected to integrate cloudlet and energy transmitters into UAVs to transfer energy to many Graphical Users (GUs) to perform local computing and task offloading. Under the constraints of the data input sizes and the energy recovery model, an energy-efficient design has been proposed. There are two key advantages: (i) well-regulated energy usage between UAVs and (ii) enhanced computation offloading. Nonetheless, its main downside is to consider the usage of a single UAV to create MEC. Cao et al. (2018) proposed a MEC design in which a cellular ground BS serves UAV for effective computational offloading. Furthermore, this study aims to minimize the mission completion time of UAVs by optimizing the computational offloading, the UAV trajectory, and computational constraint capacity at the ground BS. Nevertheless, during the operation of this system, the power limitations of UAVs are ignored. Zhou et al. (2018) proposed a UAV-enabled MEC wireless powered system. The UAV is used to provide MEC services and energy to the user equipment as it has both the MEC server and the energy transmitter component. The problem of computation rate maximization can be solved by binary as

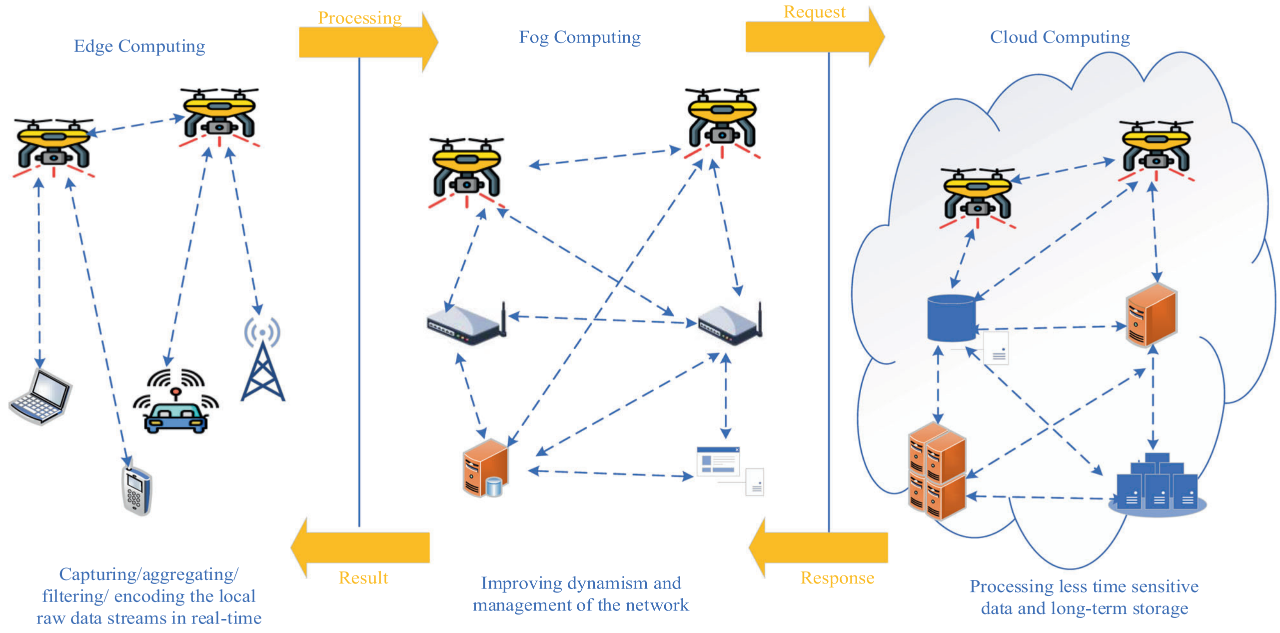

FIGURE 8 UAV computing (Edge, Fog, and Cloud). UAV, Unmanned Aerial Vehicle [Color figure can be viewed at wileyonlinelibrary.com]

well as partial offloading modes using alternating algorithms. As a drawback, UAVs' running time drastically restricts their computer performance.

The major findings from this subsection are to operate as MEC nodes, UAVs must have an effective energy consumption approach and a high processing capability to provide computational offloading possibilities to GUs. The operational duration and density of UAVs pose a significant issue that must be addressed to enhance the overall computational capability of the entire UAV-based network. A balanced distribution in the processing burden must be thoroughly explored.

3.4 | Role of Fog and Cloud computing in UAV for DMS

Cloud Computing (Yu et al., 2018) is a promising approach that provides a cost-effective alternative for processing massive amounts of data in less time. However, there is a round-trip communication delay between users at the edge and cloud servers, as well as caused network congestion, which is handled by some delay-sensitive applications in cases when decision-making and data processing are required immediately. To solve this issue, Fog Computing (Mukherjee et al., 2017) takes advantage of processing resources (e.g., mobile computing devices) brought by end-users at the network's edge. This will make it easier for users to process their data and receive real-time feedback.

Several research papers have been available to define fog computing formally and its corresponding challenges. Dastjerdi and Buyya (2016) and Mouradian et al. (2017) surveyed the issues and benefits of fog computing by presenting an outline of this subject and its characteristics. Likewise, there is a discussion about the emerging trends (Al-Khafajiy et al., 2020; Zahmatkesh & Al-Turjman, 2020), application scenarios (Mohamed et al., 2017), challenges (Mouradian et al., 2017), and security issues (Mukherjee et al., 2017). However, because of an unstable connection, it is not possible to use current fog platforms in distant regions. Architecture is needed to incorporate fog computing in practical applications to accomplish the objectives suggested. Sharma et al. (2017a) introduce a fog architecture of the Software-Defined Network (SDN), which is flexible for programmatic network control. The devices should have a flexible self-organizing mechanism in this network to facilitate fog node insertion. There are some other problems like delay and power consumption relevant to the application of fog. Atapattu et al. (2020) introduce a three-layer IoT fog cloud computing architecture to reduce the delay in each layer. This study determines the power allocation and optimum workload at each layer. The main aim is to reduce the per layer maximum delay with individual power limits (including transmission delay and data processing delay). The algorithm proposed is dependent on an alternative method of optimization, which provides close to optimal performance with substantially lower complexity. Moreover, Yousefpour et al. (2017) presented an architecture to reduce the delay in services. This study proposes a fog node policy that covers the queue-length and multiple request forms with varying processing times.

In our proposed model, we are going to deal with latency and power constraint problems mainly. In the literature, latency is demonstrated in somewhat different ways. The latency in Arkian et al. (2017) is determined by adding the time needed for data transfer between nodes, processing time, and the time involved with coordinating services between nodes. Some of the factors like communication delay in inter-UAVs, the average network transmission errors, and the time needed to cluster data in fog are considered by Deng et al. (2015) and Wang et al. (2020). Power consumption is another factor that needs to be analyzed. Jalali et al. (2016) provide a framework for studying power usage of nano Data Centers (nDC) and propose time-based energy consumption models for the unshared network as well as flow-based models for shared network equipment. This study provides a model for evaluating the energy usage of cloud and fog nodes in the network activity to determine their tradeoffs. In this model, fog computing is considered a data center that provides end-users with preloaded content. The model examined the problem of saving energy on cloud servers, despite positive results. The problem limitation in this paper is optimizing energy consumption in fog devices to prolong the flight time of UAVs.

The fog computing system is an emerging architecture for delivering IoT with computing, control, storage, and networking. Mobile Devices (MDs) can use the fog computing system to download their data or costly computing tasks in the fog node nearby instead of in the remote cloud. While the offload will decrease the MD's power usage, it may also result in higher latency, including time between communication between MDs and fog/cloud servers, as well as waiting and server runtime. Therefore, it is of research significance on how to manage energy consumption and delay efficiency. It is also necessary to decide how a cost model for MDs will benefit from cloud and fog services based on power usage. Liu et al. (2017) analyzed data forwarding energy consumption. The model of the fog device is regarded as an unlimited source of power supply that is not suitable for an embedded program. So, the current model can be upgraded with existing models that minimize the delay while keeping the optimum power consumption at the fog level.

He et al. (2018) suggested two techniques to facilitate the security of UAVs to safeguard UAVs serving as Fog nodes from Global Positioning System (GPS) spoofing. The first technique makes use of the UAV's monocular camera and Inertial Measurement Unit (IMU) to identify GPS spoofing. The second strategy employs an image localization method to enable UAV independent return through error reduction. The limitation of this approach is the centralized structure, which uses one UAV and only one BS. Various IoT applications can benefit from UAVs functioning as fog nodes, which can improve network performance metrics. For example, Mohamed et al. (2017) presented a project in which UAVs were used as mobile fog nodes to better service applications of IoT in an urban city. This study delivers fog computing capabilities, flexibility, mobility, and dynamically provisioned features to help IoT applications in many locations and various situations. The complexity of Fog computing used in this project can be regarded as one of its major flaws. Chen, Chen, You et al. (2016) presented an intelligent monitoring system in metropolitan areas based on the Fog computing model to circumvent the complexity problem. Later this model is employed to get real-time processing in applications, like, traffic-tracking and decision-making. Similarly, Chen, Chen, Song et al. (2016) presented a monitoring system based on fog computing for transportation monitoring. However, with a single tracking algorithm, this system can monitor vehicles and their speeds in real-time. This system's monitoring capabilities, however, are restricted to one vehicle.

Many studies have so far concentrated on embedding cloud computing into UAVs to improve network processing speed and storage. Jeong et al. (2017) proposed a mobile cloud computing system based on UAVs. This system examines UAV path planning for energy efficiency and offers computation offloading to ground mobile stations with limited computing power. This method, however, does not support interference or mobility among GUs. Jeong et al. (2017a) suggest a similar approach in which they used a UAV-based moving cloudlet, where UAVs are outfitted with a computer processor offload that allows computation to be offloaded to MDs on the ground. However, the goal of this study is to reduce MDs' energy consumption by improving bit allocation for uplink and downlink communication in the presence of a specified UAV path. This is inconvenient because it ignores the joint optimization of local computing and offloading.

The major findings from this subsection are that UAVs can serve as Fog nodes, which work together to complete processing jobs and improve network performance metrics. However, we have identified a centralized aspect in many of these contributions by using a single UAV functioning as a Fog node. UAVs can be employed as a cloud platform, performing storing operations and processing to outpace the limited capacity of GUs and assist them on a long-term basis. Several challenges are recognized based on the type of the applications for which UAVs are used, such as UAV density, the complexity of cloud and fog computing, and the limited capacity of UAV resources. Table 3 gives the summary of UAV coordination with WSN, IoT, and UAV computing.

4 | DATA COLLECTION THROUGH UAVS FOR VARIOUS DM SCENARIOS

In this section, classification in DM of UAV-assisted systems is based on the purpose of the specific set of applications. For example, systemic analysis, hazard modeling, environmental monitoring, and early warning system design frameworks are clustered together, as their common objective is to forecast, predict, and foresee a catastrophe event. UAV-assisted applications in DM that are taken into account in this study are the following: (a) monitoring, forecast, and early warning systems, (b) disaster information fusion and sharing, (c) situational awareness, logistics, and evacuation support, (d) damage assessment, (e) standalone communication system, (f) SAR missions, (g) coverage area and media coverage, (h) medical and health emergency, and (i) infrastructure reconstruction.

4.1 | Monitoring, forecasting, and early warning systems

This subsection deals with the usage of UAVs where structural and environmental monitoring, predictive research, and early warning systems are aimed at forecasting the catastrophe. During the mitigation and planning stages of the DM process, the goal is to predict and anticipate the natural disaster. Wang et al. (2019) proposed a rapid UAV remote sensing image stitching system based on Speed Up Robust Features description. This approach was applied to fast image stitching by UAV remote sensing to achieve high-quality UAV remote sensing images for automated and simple splicing. This method's stitching rate is much faster than that of the algorithm Scale Invariant Feature Transform. Thuy et al. (2020) presented a Cloud-based 3D data modeling, data processing, and technical framework (collectively referred to as “KKC 3-D cloud”) and the uses of the derived 3D data, along with an emergency aid solution and building progress monitoring with stereo-image acquisition auxiliary camera sensors by using UAVs as a source for processing 3D data. KKC 3D cloud is a 3D data processing service that uses motion structure to generate adaptive and accurate geospatial data sets in a fully automated way, such as georeferenced imagery, 3D meshes, and 3D-point clouds. Deep learning is a modern tool for identifying events based on aerial photographs. Kamilaris and Prenafeta-Boldú (2018) presented the state-of-the-artwork surrounding the use of disaster detection, profound learning techniques. In identifying disasters with high precision, they illustrate the capability of this technique through a fairly straightforward deep learning model. The results have shown the accuracy of 91%, based on a data set of 544 images (with disaster images, such as collapsed buildings, earthquakes, floods, fires, tsunamis, and nondisaster scenes), which indicates that deep learning, together with UAVs with camera sensors, can anticipate a disaster with high accuracy. Sherstjuk et al. (2018) presented the tactical forest fire-fighting detection and monitoring system based on remote sensing, UAV, and image processing. It defined a system with its general parameters and options, and also the system's functions, activities, and architecture are taken into account. It presented the image processing and remote sensing algorithms, which provided a means of data integration into a DSS in real-time.

Feng et al. (2015) suggested a program for flood control using data from a UAV fleet. To track flooding areas, high-resolution images captured from crafts must be analyzed. To accomplish this goal, the system carries out several phases: (i) collection and preprocessing of UAV data, (ii) texture analysis and feature selection, (iii) classification of images, and (iv) accuracy assessment. They classify the regions using the Random Forest Classifier to achieve a high degree of precision (87.3%). Popescu et al. (2015) proposed a similar approach. A methodology was proposed by authors for

TABLE 3 Summary of UAV coordination with WSN, IoT, and UAV computing

References	Mobility and density of UAV	Environment	Type of ground nodes	Highlights/objectives	Advantages	Limitations
Coordination between WSN and UAV						
Zhan et al. (2018)	Mobile/ single-UAV	Large region	Multiple-sensors	Reduce energy consumption by optimizing the UAV's wake-up routine and trajectory	Significant energy was saved by both the sensors and the UAV while ensuring that the maximum amount of data is collected from each sensor	The altitudes of UAVs should be kept at the same height
Wu et al. (2018a)	Mobile/ single-UAV	Dangerous region	Multiple-sensors	Using a UAV as a data mule to gather data in a clustered WSN to reduce the amount of energy spent by sensors	Reduced the time it takes for data to be collected and the amount of energy used by sensors	The UAV's trajectory is not optimized based on sensor energy levels
Cao et al. (2017)	Mobile/ single-UAV	Catastrophe region	Multiple-sensors	Cloud infrastructures are being used to process and save a significant amount of gathered data	Minimized the data collecting time, UAV and sensor's energy consumption, and flight time	Only one UAV in a large area is allowed
Coordination between UAV and IoT						
Arabi, Elbiaze et al. (2018)	Mobile/ single-UAV	Island	IoT devices	Data collection and charging for IoT devices that have run out of power	When adopting the low battery principle, there was a greater advantage in terms of the data collection and recharging tradeoff	It was not taken into account the circumstance where the UAV's remaining energy is low
Arabi, Sabir et al. (2018)	Mobile/ single-UAV	Harsh environment	IoT devices	Recharging exhausted IoT devices and guaranteeing data gathering efficiency	Under various scheduling policies, the system performed well in terms of energy recharging and data collection	IoT devices are always on and do not sleep while collecting data, wasting a significant amount of energy
Pan et al. (2018)	Mobile/ single-UAV	Harsh environment	IoT sensors	Enhancing the efficiency of data collection while minimizing congestion during channel access	Efficient and accurate data collection was provided, and there were no congestion issues	The channel status was not taken into account while determining speed control
Goudari et al. (2019)	Mobile/ multiple-UAVs	City area	Multiple-sensors	Increasing data collecting speed while reducing energy consumption and boosting the delivery ratio	Reduced energy consumption significantly and successfully guided UAVs to their ultimate destinations	Data collecting time and ground-sensor energy are not taken into account
Edge CompUting						
Kalatzis et al. (2018)	Mobile/ multiple-UAVs	Forest region	Single base station	Handle the difficulties given by the early identification of forest fires use case	Among the evaluated cases, the Fog computing principle produced the best-balanced outcomes	The processing burden is not distributed evenly among Fog nodes
He et al. (2018)	Mobile/ single-UAV	Not defined	Single base station	Employing UAVs in a noncontrolled environment	MEC technology is being used to improve UAV traffic management	Only one UAV can be operated at a time

TABLE 3 (Continued)

References	Mobility and density of UAV	Environment	Type of ground nodes	Highlights/objectives	Advantages	Limitations
Zhou et al. (2018a)	Static/ Single-UAV	Not defined	Multiple IoT devices	Improving the processing capability of IoT devices as well as their operational time	The allocation of resources has improved significantly	The UAV's operational time limits its processing performance
Cao et al. (2018)	Mobile/ single-UAV	Not defined	Multiple base stations	Computational responsibilities are being delegated to some BSs on the ground	There was a significant performance improvement, in terms of task completion time	The UAV's energy consumption is not taken into account
Zhou et al. (2018)	Static/ Single-UAV	Not defined	Multiple graphical users	Using wireless power transfer ideas and MEC technology to overcome GUs' restricted processing capabilities	UAVs' computation offloading has been improved, and their energy consumption has been reduced	MEC is performed using a single UAV
Fog and Cloud Computing						
He et al. (2018)	Mobile/ single-UAV	Airport region	Single base station	To facilitate the security of UAVs to safeguard UAVs serving as Fog nodes from GPS spoofing	Its ability to detect GPS spoofing has been demonstrated	A single UAV was used in conjunction with centralized infrastructure
Mohamed et al. (2017)	Mobile/ multiple UAV	Industrial region	Multiple base station/ sensors	Using fog computing and UAVs to support various IoT applications	Localization services, effective communication, and low latency were provided	The proposed Fog principle has a complicated architecture
Chen, Chen, You et al. (2016)	Mobile/ single-UAV	Urban region	Multiple fog nodes	Fog computing is used to process real-time monitoring data	Can handle many monitoring targets without the need for a sophisticated algorithm	The system's efficiency was severely hampered by the usage of a single UAV
Chen, Chen, Song et al. (2016)	Mobile/ single-UAV	Urban region	Multiple base station/fog nodes	Fog computing-based urban monitoring solution	A suspected vehicle was promptly identified and traced	Only one moving object was tracked
Jeong et al. (2017)	Mobile/ single-UAV	Infrastructure less region	Multiple graphical users	Providing chances to graphical users for computational offloading, utilizing UAV-based cloud computing	To save GU energy, the bit allocation, and cloudlet trajectory were optimized	Did not support interference or mobility among graphical users
Jeong et al. (2017a)	Mobile/ single-UAV	Not defined	Single graphical users	Using a UAV-based cloud computing system to provide offloading options to the graphical user	The GU's energy usage and compute performance have been improved The GU's energy usage and computing performance have been improved	Both the combined local computation and offloading optimization were overlooked

Abbreviations: BS, Base Station; GPS, Global Positioning System; GU, Graphical User; IoT, Internet of Things; UAV, Unmanned Aerial Vehicle; WSN, Wireless Sensor Network.

segmentation, localization, detection, and scale measuring of flooded regions from aerial UAV images. The methodology is based on the analysis of texture features and the sliding box method. The evaluation process takes into consideration the degree of results gained from false negative and false positive cases during feature selection. The system evaluation indicates a 98.87% accuracy rate. Farfaglia et al. (2015) proposed an Advance System to Monitor the Territory, an inquiry initiative aimed to establish a System of System exploiting multi-Unmanned Aerial System (UAS) for monitoring civilian activities. The research in this project used Medium Altitude Medium Endurance for strategic missions and specified target monitoring at lower altitudes with higher deployability for shorter ranges. Also, Medium Altitude Long Endurance is used for long-range surveillance over a prolonged period.

4.2 | Disaster information fusion and sharing

Although data fusion is crucial and beneficial in all stages of DM, the assessment stage has its most significant impact. The aim of data fusion and the sharing of knowledge is to integrate different available sources of information and/or to build a bridge between various IT systems used in other DM applications. For example, Kumar et al. (2004) put forward a first response system that focuses on the usage of mobile independent agents in emergency locations, which incorporates data fusion. They envisage a program to be introduced for rescue services to collect information about an uncertain area and raise awareness of the situation. Several hazardous and environmental material detection sensors will be mounted on all robots to allow them to build a map of unsafe areas.

Mosterman et al. (2014) proposed an experimental framework that uses cyberspace to control and coordinate multi heterogeneous vehicles and carry out complex logistical operations during automated humanitarian tasks. The program addresses demand and information about the condition of the infrastructure. During deployment or design, the flexible architecture enables vehicles to be added to the fleet at any period. Bartoli et al. (2015) proposed a novel emergency management platform that incorporates heterogeneous elements such as intelligent data collection and analysis systems, messaging, social networks, and WSN for smart public safety systems. Rosalie et al. (2016) present the Aid to SItuation Management based on MUltimodal, MUltiUAVs, Multilevel acquisition Techniques project. It is comprised of a multiple-fleet of UAVs to involve networking, communication, and positioning features for catastrophe relief situations. The system contains three major components: (i) Ground Control Station (GCS)—the core component which is accountable for all the data processing, receiving, and controlling; (ii) High-Level Coordination Swarm made up of fixed-wing UAVs; (iii) Low-Level Swarm made up of multirotor UAVs. Each vehicle is fitted with a Wi-Fi communication module to communicate directly with its neighbors.

Paulino et al. (2018) proposed the Adaptive Network-based Fuzzy Inference System for data fusion application, which can improve the precise location of such networks. Ji and Luo (2019) proposed an optimized model method that fuses high-resolution images taken from UAVs with laser point clouds for landslide topography. The UAV system is ideal for landslide emergency response due to its relatively high performance and wide coverage range. The use of Partial Differential Equation based on the UAV images and the laser point cloud integrates through-hole repair technology with a Non-Uniform Rational B-Splines technique to quickly recreate a 3D environment. You (2020) proposed an automated, UAV-based mission-driven perception and fusion architecture that can enable demand-oriented data processing and automatic collection of information in line with application information requirements. It focuses on various daunting techniques, including avoidance and joint perception, splitting and automated flocking, and cooperative monitoring and detection. Vallejo et al. (2020) proposed the creation of a multiagent architecture that allows a network comprised of smart agents to track hazardous situations and assist human personnel in the decision-making process. Such areas, which have been identified in advance, are distinguished by a range of priorities that are important in terms of aerial monitoring and surveillance.

4.3 | Situational awareness, logistics, and evacuation support

The aim of logistics and situational awareness is to collect data during the disaster period, particularly concerning the movement of disaster-threatened persons and the rescue teams in the disaster zone. Figure 9 presents the components of situational awareness in disaster situations. In Figure 9, UAV provides the state of the environment to make a proper decision and take quick action. The framework is based on both mobile and static sensors and tackles the challenges posed by the collection of sensor data, routing, tracking responder's activity, and mobility problems (Erman et al., 2008). Erdelj et al. (2017a) examine the general configuration of the multi-UAV and WSN systems required for an assessment of different types of catastrophe, as well as the obstacles to be solved by such a system. The Inundation Monitoring and Alarm Technology in a System of SystEms project aims at combining the multi-UAV and WSN systems into a novel crowdsensing model, in which mobile phone users supply the collected mobile data to improve the WSN, thus increasing the amount of information available for situational awareness.

Belbachir et al. (2015) emphasize forest fire detection by UAVs. Vehicles in these situations work on an unfamiliar terrain to establish an adaptive coverage mapping approach. To predict distance from the forest fire, authors concentrate on strengthening the role of the localizing population through the decision-making approach focused on a temperature-dependent probabilistic model. According to the status of the forest-fire information, the UAVs attempt to refine their trajectories utilizing a map that is modified at each point of the exploration. Luo et al. (2015) develop a disaster-sensing UAV-cloud system. A UAV fleet is being used to capture footage from a risky

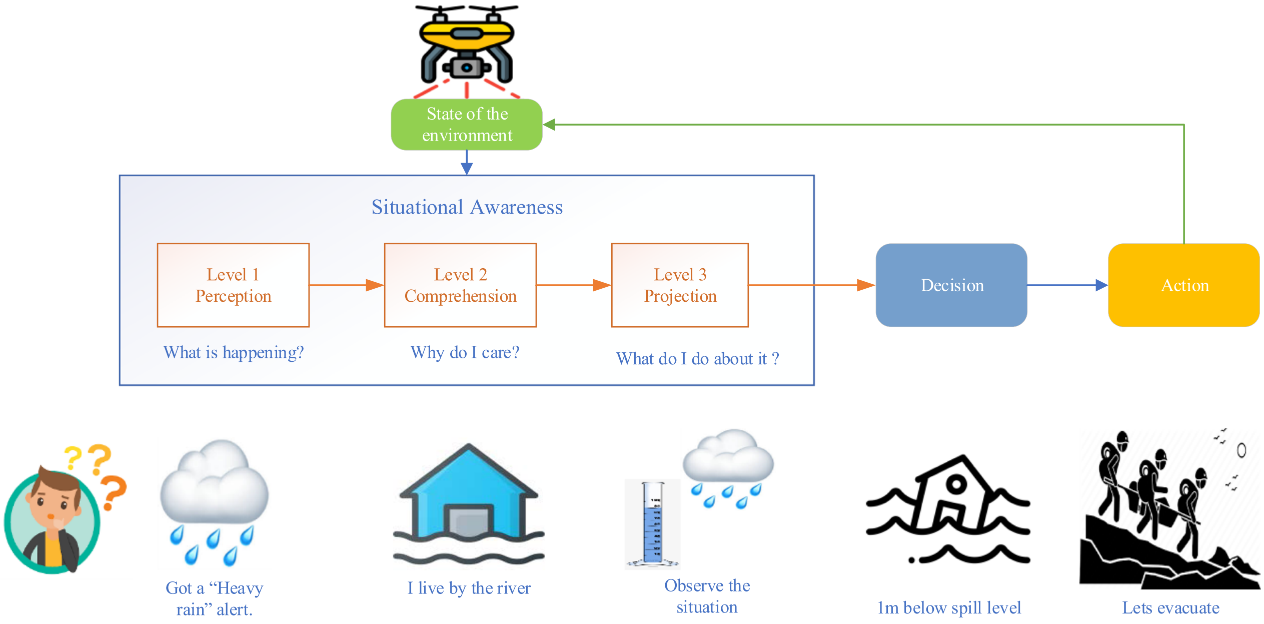

FIGURE 9 Presents the components of situational awareness [Color figure can be viewed at wileyonlinelibrary.com]

area. The authors recommend utilizing the preprocessing photos of drones to minimize the amount of data transmitted, taking into consideration the context information. The system integrates data processing and offloading, data scheduling, assessing network measurement, and video acquisition. The data are then sent to the server and analyzed by the cloud module. Sood (2020) proposed a Fog–Cloud-centered cyber–physical framework based on IoT that prioritizes and provides prompt emergency assistance to the evacuation of terrified people. In this case, Fog computing is used to diagnose the Panic Health Status of stranded persons in real-time and to quickly supply them with curative and diagnostic warnings. The Fog layer DNA is used to reduce Fog-to-Cloud data traffic and to improve the fog layer energy efficiency. Preparedness for crises is a crucial element in public recovery in the case of adversity. People who are well prepared for emergencies and disasters are generally believed to cope well and to suffer less injury. In this context, a new visual instrument was used to measure individually significant evaluations and emotions (the Pictorial Representation of Illness and Self-Measure) by Bodas (2020). It was used to test Israeli hazard experiences of emergencies.

4.4 | Damage assessment

In cases of a catastrophe, it is essential to use various methods, including systemic UAV video inspection and health monitoring, to determine the extent of the damage to the people. In this sense, Kruijff et al. explain the deployment of two major earthquakes in the Emilia-Romagna region in Northern Italy in collaboration with the Italian National fire corps participating in a postdisaster examination in July 2012 (NIFTi project; Kruijff et al., 2012). The team used a heterogeneous network comprised of desktop computers, monitors, and laptops. On the rescue robots, ROS7 was mounted, transmitting data to an Operator Control Unit (OCU) over a 2.4 GHz Wi-Fi network. For 3D laser range data analysis (point clouds) as well as for the OCU and visualization, off-board computers were used. In this project it uses two different UAV systems; NIFTi Company developed the first one fitted with a range-finder Hokuyo UTM-30LX, IMU module, a pressure sensor-based altimeter, and a sonar, GPS module, 3D magnetic compass, a webcam looking ahead and down, the 1.6 GHz Intel Atom onboard computer with 10–15 min operating time. The second UAV was designed with eight high-power engines and was capable of moving up to 2 kg of payload. The camera had a high-performance video signal transmitter (5.8 GHz, 1.5 W), Intel i7 2.6 GHz onboard computer, and ASUS Xtion Pro instead of the laser scanner. The authors identify the UAV team, which included the UAV operator, a UAV task expert who has been monitoring UAV video feeds, leading the UAV operator to the mission targets, the UAV team safeguarding the UAV security commander. As a UAV operates, there are so many details to manage that can be carried out safely by one person, ranging from sensor details to device and network monitoring. The outcome of the project is the cognitive overload experienced by UGV controllers and UAVs, which supports work into automated systems for damage assessment.

Robinson and Lauf (2013) highlighted the key obstacles to incorporating aerial sensing and assessment of fault-tolerant and effective deployment of joint autonomous aircraft to enhance operational performance and reliability. Each aircraft is fitted with an Ardupilot control board to enable autonomous navigation. The authors mentioned that they defined an initial potential communication range of around 350 m by using the Gumstix Overo boards and their optimized wireless communication hardware. Ezequiel et al.

(2014) explore the use of remote-control-UAV systems for low-cost, infrastructure development monitoring, environmental management, and postdisaster assessment. The findings indicate that the incorporation of aerial surveys, field assessments, and the exchange of information paves the way for an efficient decision-making support network. Further, there is considerable interest in using a small UAV system that is capable of collecting information on aerial disaster assessment (Wada et al., 2015). Each UAV contains handheld optical sensors and image transfer modules created by the authors. A craft carries out an autoflight along the way, knowing its position after the takeoff. A video of the target region can be received, sent to the server, and exchanged via the Internet with its users. UAVs may be used as radiation detectors, communication relays, and nondisaster monitoring with external hardware, such as environmental monitoring using external hardware.

Lim et al. (2016) introduce a two-phase mathematical model for a practical assessment of damage to the power network using UAVs. The first phase presents a two-stage stochastic integer optimization model for damage assessment, where it defines the appropriate UAV locations before severe weather events occur. The second phase is meant for changing the UAV locations if needed when updated information draws nearer to the predicted time of arrival of extreme weather. Kakooei and Baleghi (2017) introduce a new paradigm based on the image processing techniques and design environment to maximize the benefits of multiple technologies and eliminate disadvantages. A façade is perceived in oblique UAV images by the fusion of vertical and oblique images with environmental information and geometrical transformation. In comparison to roof-only damage assessment, the new adaptive fusion system resulted in an improved measurement of damage scales. Calantropio et al. (2018) present a semiautomatic solution, founded on the combined understanding of the Digital Surface Model, 3D model navigation, and orthoimagery that has provided an encouraging outcome. It supported the integration of a UAV-based large-scale imaging approach into the recommended protocols and operational workflows for DM emergency response. Mavroulis et al. (2019) integrated UAV and GIS web applications for rapid postearthquake damage assessment and consider a methodological framework European Macroseismic Scale-1998 for drawing isoseismal map. Pi et al. (2021) provided a method of implementing the impacts and extent of catastrophic aerial (helicopter and UAV) images (through transfer learning), preparation, validation, and testing of two Convolutional Neural Network (CNN) architectures, namely, Pyramid Scene Parsing Network and Mask-RCNN.

4.5 | Standalone communication system

The most important function during DM is dedicated to autonomous communication systems aimed at repairing the destroyed or damaged communication infrastructure during the catastrophe. Throughout the disaster response process, its use is most important, whereas the functional, standalone communication system also can be used during the recovery phase. Bupe et al. (2015) suggest a fully autonomous framework for the use of UAVs as the first stage catastrophe recovery communication network for the relief of large areas. They provide an automation algorithm for monitoring the deployment and placement of UAVs, using a conventional cell network architecture using seven cell clusters, with Micro Air Vehicle Link protocol as a hexagonal model. The algorithm follows the clustering relying on centralized management of UAV cells by awarding super-nodes to higher-level UAVs. The framework selects super-nodes individually based on weighted variables and makes modifications to the total amount of UAVs in the framework dynamically. Sánchez-García et al. (2016) aim to deliver a connection between rescue workers and victims of disasters using a group of UAVs. In a situation of an urban catastrophe, authors first incorporate a practical mobility model for victims. The model suggests an adaptive approach, which allows UAVs, by the combination of Jaccard distance and artificial intelligence algorithms, to allow the operational improvements in a catastrophe scenario. Finally, a distinction was made between several local search intelligence computational algorithms like simulated annealing, mountain climbing, and random walk for the greatest strategic UAV movements. Krug et al. (2014) tailor their approach to the Delay-Tolerant Network (DTN) situations for MANET. The framework assumes that Boundary Nodes are used to connect MANETS and drones that are deployed as data ferries using different protocols. In these situations, the authors discuss the issue of global name resolution. Saha et al. (2015) propose a four-tier architecture that enables the transmission of messages within disconnected shelters. Tier-one is made up of tablets and user phones, which share information as DTN nodes. Data are then obtained from each shelter by laptops with greater capacity for storage at tier-two. At tier-three, UAV mobile vehicles transfer data between tier-two devices. Due to the large disaster areas, the system integrates towers with long-range Wi-Fi by aggregating multiple shelters and tier-two devices to improve performance.

Kaleem et al. (2019) proposed a three-layer Disaster-Resilient Public Safety-LTE (DR-PSLTE) architecture. This architecture comprises an SDN layer to offer central control, a UAV cloudlet layer that facilitates edge networking or emergency communication connectivity, and a radio access layer. It is scalable and incorporates the advantages of SDNs and edge computing to satisfy the latency demands of various PS-LTE networks effectively. Compared with traditional distributed computing architecture, this architecture DR-PSLTE eliminates the delay by 20%. Reina et al. (2018) recommend that drones can be used as zeroth responders for interacting with victims in the event of a disaster. The zeroth response aims to reach before the first response in the disaster scenario. Their movements and deployment are divided into two phases. The first stage uses a Genetic Algorithm to identify the best drone positions based on certain previously collected information from the catastrophe situation. The second stage involves the adjustment of positions to disaster conditions and the exploration of new areas to identify more victims. In the second stage, a local searching algorithm like Hill

Climbing Algorithm is used. It examined the proposed approach under different circumstances in virtual rural catastrophe situations with 125 static victims. Mohamed et al. (2020) focus on the use of UAVs in disaster situations for providing emergency communication as well as many other applications of UAVs. An advanced WSN-based emergency management system (Bai et al., 2010) is introduced to facilitate contact between disaster victims and rescue teams. A similar approach, which is based on the fact that the UAV network serves as a backbone of a disaster-sensitive communication network, is suggested by Carli et al. (2014), Dalmasso et al. (2012), Fujiwara and Watanabe (2005), Marinho et al. (2013), Morgenthaler et al. (2012), Nelson et al. (2011), and Tuna et al. (2012). Minh et al. (2014) proposed a new architecture that expands the Internet connectivity to disaster victims using MDs from surviving access points. It is available on request with wireless virtualization on MDs to establish virtual access points.

4.6 | SAR missions

When a tragedy occurs, saving human lives is the most critical problem to be solved. In this case, SAR efforts have to be carried out fast and efficiently, with the first 72 h following the incident reaching the most critical time of day. The International Search and Rescue Advisory Group (INSARAG) offers the SAR methodology and protocol internationally and publishes a set of guidelines that indicates that the SAR process must be carried out by teams (INSARAG, 2020). A team leader shall be responsible for task selection and strategic assessments, while all the activities of the team are overseen by the head of the event. A typical SAR operation will take place in four key steps: (1) the commander sets up the search area (a wider search area minimizes communication problems with the rescuers), (2) establishes a search center, (3) the first reporters are split into search and relief officers, and (4) search teams will tell the command station of their findings, and the rescuers will collect information from them. Nourbakhsh et al. (2005) established the urban SAR architecture and methods to interact with real-world and simulation-based analysis. They made a sensor fusion algorithm and sensor software for efficient victim identification that allows the aggregation of sensor readings on several robots from different sensors. Pogkas et al. (2007) developed a similar low-cost ad hoc sensor network for disaster relief applications. They offer a SAR team a quick and reliable tool to gather information about the location of individuals in a collapsed building. They also combine a power-aware routing strategy and a low-power mode algorithm to achieve an energy-efficient system. Tuna et al. (2014) present a new method in developing a WSN for the use of autonomous mobile robots to detect human existence in disasters. The system offers various benefits over a human-assisted system, including total independent implementation, flexibility, and collective knowledge. The achievement of these potential benefits, on the other hand, relies significantly on the communication and coordination capability of the suggested system. There were findings that legal and weather limitations constrained where, when, and who could fly UAVs. The advantages of UAVs for dangerous tracking, but not for SAR or emergency intervention, have been demonstrated due to regulatory constraints, and environmental and local capacities.

Most of the current paper addresses UAV operations in searching wide remote areas (Clark et al., 2018); furthermore, it is important to address existing literature-related problems and to suit potential approaches based on the current literature analysis to establish a consistent UAS application technique in the Urban Search and Rescue. Karma et al. (2015) also address the problems and advantages of a field trial in SAR operation in case of a forest fire. The most important survival factor was “time-to-rescue” (and later “time-to-operative”; Statheropoulos et al., 2015). Today, most of the searches carried out by animal rescuers and the number of staff involved have a vital effect on the victim's chances of being identified. UAS technology will improve “time-to-rescue” by making the victim more effective and faster. This can be accomplished by the use of sophisticated sensors mounted on UAS systems and covering larger areas in a limited time (Lakamp, 2016). Improved visual capabilities would also provide a clearer understanding of circumstances, which could be needed for the safety of rescue teams (Mariusz et al., 2018) UAS will provide reliable and effective logistics assistance as well as visual capability. Alotaibi et al. (2019) investigated a SAR system consisting of multiple UAVs to find a maximum number of people in minimum time using a Layered Search and Rescue (LSAR) algorithm. The LSAR method comprises two phases: (i) a preprocess environment partitioning phase that samples the catastrophe region, and (ii) the SAR phase where the cloud server coordinated the SAR process. Whereas, the density of the survivors is one of the significant factors that limit the efficacy of the LSAR algorithm, namely, to detect the catastrophe area where the majority of the survivors are located. Therefore, the best realistic effects in real-life applications are given using image processing technologies for these purposes. Miyano et al. (2019) propose a multi-UAV search scheduling approach from the user-centric viewpoint that takes both the data transmission time and processing time of acquired data into consideration. Moreover, when casualties arise in the ocean or air transportation, it usually required combined military and civilian efforts to conduct SAR operations to find the region where the incident occurred in the search for life and the aircraft. Ferrari and Chen (2020) explore the planning problem of an ad hoc fleet to conduct high seas search missions as a resource assignment concern. It provides variations in the target role of binary integer programming as a solution to various features of an aerial SAR activity, including the expiry time from an announced emergency, target data, and the type of SAR operation.

4.7 | Coverage area and media coverage

The UAVs may help provide audiences with information on a timely basis (unlike providing emergency teams with situational awareness). The conventional communication network may get disrupted in a catastrophe. In this situation, UAVs may be used to fill the coverage gap. Small cells using drones are tested to maximize postdisaster coverage gaps in a cellular network (Hayajneh et al., 2018). The authors have suggested a clustered deployment of small drone cells in the disaster-hit region. The position of the UAV-mounted BS is configured to increase the coverage and throughput performance (Merwaday et al., 2016). Lin et al. (2019) explore the energy-saving path for the UAV to support as many users as possible with minimal energy resources in postdisaster communication. Liu et al. (2019a) suggested an emergency coordination NOMA distributed system using UAVs. The channel distribution, floating time, and power expenditure in UAVs can be optimized together to increase the exposure and total ratio of IoT systems in areas impacted by a catastrophe. Liu and Ansari (2018a) developed a UAV-mounted BS for the disaster rescue operation to enable Machine-to-Machine communication between wearable human IoT devices. A resource management program is introduced to boost the energy efficiency and user scheduling of UAV-mounted BSs.

Sharma et al. (2017b) presented an intelligent solution for efficient and accurate positioning of the UAVs on the demand areas contributing to enhanced coverage and capacity of the wireless networks. The suggested solution uses entropy methods and prioritywise supremacy to tackle the two problems, namely, the cooperative problem of UAV allocation and the decision problem of MacroBase Station. Finally, network negotiations are decided by these solutions to precisely map the UAVs into the desired areas to improve the network parameters significantly. Alsamhi et al. (2018) proposed a Tethered Balloon technology to provide a large disaster coverage area. Consequently, SAR teams thus earn a high priority and improve their efficiency in the specific service area substantially. The Tethered Balloon suggested refers to all hazards except for storms. The Tethered Balloon is constantly explored as a simple solution to improve the efficiency of emergency health rescues, facilities, and services in the disaster area. High QoS support in delivering communication services to save lives for the rescue and recovery teams during or after the tragedy is the most critical prerequisite. The problem of capacity, coverage range, and intercellular interference is of greater concern to cellular networks with the emerging 5G infrastructure and the BS on UAVs. Cileo et al. (2017) used the deterministic approach to evaluate these issues by using the data collected from a commercial program for wireless electromagnetic wave propagation. The above-mentioned parameters are evaluated by adjusting the received power threshold.

4.8 | Medical and health emergency

In medical applications, cooperation and collaboration between various departments are important for overall coordination and viable development. Accessibility to critical resources for life care and emergency is an essential concern for all city residents, anywhere and at any moment. For example, a UAV is used to carry the defibrillator and medical supplies to a cardiovascular patient to immediately resuscitate the cardiopulmonary system (RT-Russia, 2014). Another example is UAVs that could operate in remote or congested areas as ambulances. The use of UAVs to provide ambulatory care and critical life support devices, and emergency supplies for these conditions will speed up responses and reduce the costs of these facilities for remote areas. Qiu et al. (2020) explore the problems of effective cooperation and collaboration between public information platforms, relevant institutions, and deployment of public health and health promotions in China. Dayananda et al. (2017) use UAVs with robotic arms and onboard sensors to provide medical treatment. The authors discussed, in particular, the situation of cardiac arrest and proposed a method to cope with such a medical tragedy. Winders et al. (2020), in their study, extensively examine the existing proof of the effectiveness of first-aid approaches to mitigate and manage the mental health consequences of responding to a catastrophe. Cho et al. (2008) monitored the health of soldiers using wearable sensors and UAVs on the battlefield. The aim is to provide medical assistance effectively to save the lives of the soldiers. Similar work is done by Erdelj et al. (2017a) to provide critical medical supplies using UAVs in disaster-affected areas with destroyed and damaged transport infrastructure. Bailey et al. (2020) continued the improvement of the Medical University of South Carolina Health Daily Check-In (DCI) as a contact tool that has culminated in an organization that is more accessible and operationally sensitive. To ensure maximum efficiency, the DCI offers an understanding of the coordination mechanism for emergency communication services, effective exchange of information, and optimal transparency. The DCI has developed as a medium of communication in emergency response, with the various incidents posing particular problems.

Catastrophe-induced disruption is related to a higher risk of conditions of both mental and physical wellbeing. Jang et al. (2020) aim to consider (1) the extent and frequency of natural catastrophes, the population affected, and mortality through evaluating surveillance information examined in the data basis of Emergencies, and (2) the health consequences through a systematic analysis of previous studies (1975–2017), which recorded mental and physical health results and epidemiological measures of the relationship of populations displaced by the natural catastrophe in Southeast Asia. Researchers and decision-makers must apply more tools for avoiding and reducing health effects, following the Sendai Framework for Disaster Risk Reduction 2015–2030. In the immediate diagnosis, recovery, and relocation for patients in the prehospital, Emergency Medical Services (EMS) are of vital significance. To strengthen these procedures, the Israel National EMS company has formed a strong and special voluntary network of specialized telecommunication approaches (Dadon et al., 2020). Telecommunications policy covers handheld push-to-talk, pagers, and advanced software applications for smartphones. They are controlled and handled by a central monitoring and control center. These procedures should be tailored to enhance emergency prehospital service at both the technological and organizational levels.

Moreover, from the initially announced epidemic of coronavirus (COVID-19) in China, which is now propagated all around the world,

TABLE 4 Summarize the UAV applications and highlight their functions, critical issues, and potential risks

UAV Applications	UAV Functions	Most critical issues	Potential risks	Solutions
Monitoring, forecasting, and EWS	• Provide real-time information about the disaster • To predict disaster by environmental monitoring • To do information analysis for early warning systems and forecasting	• To provide reliable data transmission • Minimize energy consumption • Accurate estimation capabilities • To have low latency and high bandwidth communication for transferring high-quality images and video streams	• In general, low risk; but, face likely hacking and manipulation of events if security is not good enough	• We can deploy Intrusion Detection Systems to protect UAVs against intruders, such as Rule-Based Intrusion Detection, Signature-Based Intrusion Detection, Anomaly Based Detection
Disaster information fusion and sharing	• To combine different sources of information • To bridge various information systems that can be used in many DM applications	• Efficient path planning • To achieve the requirement of an energy-efficient system • Integration with other systems	• It has risks associated with high delays in the collection of critical information and fusion that lead to further delays in decision-making	• To reduce delays in the collection of data we can find out an optimal trajectory for UAV and we can use different approximation algorithms
Situational awareness, logistics, and evacuation support	• To collect information on the migration and the emergency teams in the disaster area, in particular, of people affected by the tragedy • To deliver relief services, such as medicine, food, and mobile devices, to the victims of the disaster-affected areas	• To deploy a facility site, which is mainly based on the selection of the best site for the emergency centers • To determine the best place of relief delivery centers among a range of applicant locations	• The risk of delay in situational awareness and evacuation support may result in more casualties and human losses	• We can do a collaborate with UAV edge intelligence and SAR with an ad hoc network that allows disaster operation teams to obtain situational awareness, carry out triage relief efforts to limit overall damage, and avoid the highest risk zones based on the mapping of the infrastructure. Also, to minimize delay in situational awareness and evacuation support machine-learning techniques can be used in UAVs to analyze the data collected by IoT devices and make appropriate decisions regarding which roads need to be closed and the best paths to reach the most destroyed areas, and plan the delivery of relief supplies
Damage assessment	• To assess the scale of damage • To provide transportation of instrumentation, power sources, and onboard computing devices without substantially altering the flight property of aircraft	• To implement collaborative autonomous fault-tolerant aircraft and efficient deployments to enhance operational reliability and performance	• The larger the vulnerability to an unknown and unstructured situation, the higher the probability of its failure because of potential obstacles along its path	• The vulnerability to an unknown and unstructured situation can be mitigated by retrieval of building characteristics through UAV image segmentation and machine learning algorithms such as a Support Vector Machine Learning algorithm to classify the delineated buildings

(Continues)

TABLE 4 (Continued)

UAV Applications	UAV Functions	Most critical issues	Potential risks	Solutions
Standalone Communication System	• Facilitate wireless communication • To restore the destroyed or damaged infrastructure of communication • It works as a backup for defective wireless nodes • Enable remote wireless connectivity • To promote intercommunication between victims of disasters and rescue teams	• UAV positioning and flying pattern optimization for improved coverage • Power efficiency criteria	• Some safe operations and security problems may generally arise with low risk	• A combination of two or more new and optimal algorithms such as earthworm optimization algorithm, moth search algorithm, monarch butterfly optimization, and elephant herding optimization will be used to identify malicious UAVs
Search and rescue missions	• To find and rescue people who are unfortunate, who have been trapped or injured during the disaster	• Fast observation and analysis • High safety requirements • Coordination between the SAR team	• The risk of delay in the arrival of the search and rescue team may result in more causalities	• To avoid delay in the arrival of the SAR team proper communication between the SAR team and UAV is required also we can collaborate with the UAV and SAR team that allows SAR operation teams to obtain situational awareness and carry out triage relief efforts to limit overall causalities
Coverage area and media coverage	• To provide timely information about the ongoing disaster	• To establish standards for the usage of UAVs in disaster regions • To incorporate images and videos from different outlets (including media organizations, private owners of UAVs, experts of UAVs)	• To follow the guidelines for the transmission and publication of captured knowledge in real-time	• According to the guidelines, drone operators will need to obtain a Unique Identification Number (UIN) for their UAV and security clearance from the Ministry of Home Affairs (MHA) before they can get their drone in the air. At the multilateral level, the International Civil Aviation Organization (ICAO) is the lead platform for framing rules of the road for drone operations (Rajagopalan & Krishna, 2018)
Medical and health emergency	• To provide medical facilities to emergency patients • Act like rescue vehicles and ambulances for remote locations	• To have high standards for protection, safety, and reliability • To minimize the high cost of development, production, and maintenance, mainly for UAV ambulances	• The risk of misuse of the medical products supplied • In cases of crash or malfunction of aircraft, there is always the risk of people	• In such cases, we can use systems that can send an acknowledgment message to the sender. If the acknowledgment is not received within a certain period then another UAV will be sent to the victim

TABLE 4 (Continued)

UAV Applications	UAV Functions	Most critical issues	Potential risks	Solutions
Infrastructure reconstruction	• Gather infrastructure data (e.g., images and scans) • Analyze the gathered data to find challenges and locate problems	• To provide accurate and fast observation and analysis • High storage requirements for image and video streaming for inspection • To have efficient, reliable communication with control centers at low latency and with high bandwidth. To integrate with other computational tools for more analysis	• Faulty sensing or transmission of sensed data in some cases leads to inadequate analysis • Inspected infrastructure can cause any destruction due to some accidents	• For faulty sensing, we can use an AI mechanism to detect the false data which will help in proper analysis of the sensed data

Abbreviations: AI, artificial intelligence; DM, disaster management; EWS, Early Warning System; IoT, Internet of Things; SAR, search and rescue; UAV, Unmanned Aerial Vehicle.

Medtech firms are designing robotics and drones to help counter it and offer treatment and take care of others who are quarantined or maintain social isolation (Bernard, 2020). In this case, Robot-supported telemedicine helps doctors to connect remotely, save time, and helps infectious patients to remain at their places. Robots can not only interact with people who are quarantined by a coronavirus, but they also obtain vital knowledge from patients and help doctors to manage patients. As robots are resistant to infection, the task of raising the number of robots for medical supplies in the healthcare environments was taken up by technology companies, such as JD.com and others. Robots are also important for the distribution of essential goods to people who purchase and buy online and are in house quarantine. Similar emergency services can also be provided by UAVs when incidents occur in towns, which hinder or delay ground transport.

4.9 | Infrastructure reconstruction

The use of a UAV network could facilitate inspection processes and improve reconstruction efficiency and accuracy. UAVs or drones reflect a scientific and engineering frontier that is supposed to have a profound influence on many fields of technology. The use of high-quality optical cameras in Greece following natural disasters for infrastructure investigation in 2015/2016 reveals four case histories: a dam collapse leading to underwater floods and consequent downstream flood near the village of Elassona, a bridge breakdown resulting from a bridge jet near the village of Kalampaka as well as a broken pier and landslides triggered by an earthquake of 6.5 magnitudes in Lefkada Island on November 17, 2015 (Zekkos et al., 2016). Wu et al. (2018b) recommended the synthesis to identify and determine the safety status of civil facilities, including pavements and bridges, of the most sophisticated computer systems in the area of profound computing and UAV. The UAV with infrared thermography camera and high-resolution camera gathers a vast amount of imagery data from the target infrastructure, which is used as inputs for the classification and condition evaluation of specialized deep neural networks. Liu et al. (2020) proposed a new image-based crack assessment approach using UAV and a 3D reconstruction scene for the bridge piers. This methodology corrects both geometry distortion and perspective distortion by using nonflat structural surfaces and understanding crack localization. The corrected crack structures are formed in the original 3D form and in real-time, and after correction, the crack width is precisely determined. Baker et al. (2020) proposed the planned flight that gives an overview of how road and bridge tests are to be carried out to test the path's feasibility for the recovery and response process in a major flood situation. Reliable postcatastrophe bridge evaluations minimize the risk of catastrophic collapse and intensify much more complicated rehabilitation with the potential for more losses. During the low light, visual details supplied by UAV remote sensing help prepare a main and alternate pathway for specific reactions and those wanting to evacuate more quickly. In future studies, the knowledge given from this initial analysis is

TABLE 5 A comparative tabular study: WSN, IoT, and UAV-based disaster management applications and solutions

Reference		Technology			Disaster management stages		UAV applications										
Reference	Year	WSN	IoT	UAV	Preparedness	Assessment	Response and recovery	Monitoring, forecast, and EWS	Information fusion and sharing	Damage assessment	Situational awareness and logistics	Standalone communication	SAR mission	Coverage area and media coverage	Medical and health emergency	Infrastructure reconstruction	Natural hazard
Wang et al. (2019)	2018			●		●		●		●							–
Thuy et al. (2020)	2020			●		●	●	●									–
Kamilaris and Prenafeta-Boldú (2018)	2018			●	●			●									Earthquake, flood, and so forth
Sherstjuk et al. (2018)	2018			●	●			●									Forest fire
Feng et al. (2015)	2015			●	●	●		●		●	●						Flood
Popescu et al. (2015)	2015			●	●	●		●		●	●						Flood
Farfaglia et al. (2015)	2015			●				●	●		●						Flood, earth-quake
Kumar et al. (2004)	2004	●		●		●			●	●							Fire fighting
Mosterman et al. (2014)	2014	●		●			●		●								–
Bartoli et al. (2015)	2015	●			●		●		●								–
Rosalie et al. (2016)	2016			●			●		●		●						–
Paulino et al. (2018)	2018			●	●				●		●						–
Ji and Luo (2019)	2019			●		●			●								Landslide
You (2020)	2020		●	●		●			●								–
Vallejo et al. (2020)	2020		●	●		●			●								–
Erman et al. (2008)	2008	●		●		●					●						–

TABLE 5 (Continued)

Reference		Technology			Disaster management stages		UAV applications										
Reference	Year	WSN	IoT	UAV	Preparedness	Assessment	Response and recovery	Monitoring, forecast, and EWS	Information fusion and sharing	Damage assessment	Situational awareness and logistics	Standalone communication	SAR mission	Coverage area and media coverage	Medical and health emergency	Infrastructure reconstruction	Natural hazard
Erdelj et al. (2017a)	2017	•		•		•					•				•		–
Belbachir et al. (2015)	2015			•		•					•						Forest fire
Luo et al. (2015)	2015			•		•					•						Oil spill, flooding
Sood (2020)	2020		•	•		•					•						–
Bodas (2020)	2020		•	•	•						•						Earthquake
Kruijff et al. (2012)	2012			•			•			•			•				Earthquake
Robinson and Lauf (2013)	2013			•			•			•		•	•				–
Ezequiel et al. (2014)	2014			•		•				•							Typhoon
Wada et al. (2015)	2015			•		•				•							–
Lim et al. (2016)	2016			•		•				•							–
Kakooei and Baleghi (2017)	2017			•		•				•							Earthquake
Calantropio et al. (2018)	2018			•			•			•							–
Mavroulis et al. (2019)	2019			•		•				•							Earthquake
Pi et al. (2021)	2021			•		•				•							Flooding
Bupe et al. (2015)	2015			•			•					•					Hurricane
Sanchez-García et al. (2016)	2016			•			•					•					–
Krug et al. (2014)	2014	•					•					•					–
Saha et al. (2015)	2015			•			•					•					–

(Continues)

TABLE 5 (Continued)

Reference		Technology			Disaster management stages		UAV applications										
Reference	Year	WSN	IoT	UAV	Preparedness	Assessment	Response and recovery	Monitoring, forecast, and EWS	Information fusion and sharing	Damage assessment	Situational awareness and logistics	Standalone communication	SAR mission	Coverage area and media coverage	Medical and health emergency	Infrastructure reconstruction	Natural hazard
Kaleem et al. (2019)	2019			•			•					•					–
Reina et al. (2018)	2018		•	•		•	•					•	•				–
Mohamed et al. (2020)	2018		•	•				•				•	•				–
Carli et al. (2014)	2014	•					•					•					–
Dalmasso et al. (2012)	2012			•			•					•					–
Fujiwara and Watanabe (2005)	2005	•					•					•					–
Marinho et al. (2013)	2013			•			•					•					–
Morgenthaler et al. (2012)	2012			•			•					•					–
Nelson et al. (2011)	2011	•					•					•					Earthquake, hurricane
Tuna et al. (2012)	2012	•		•			•					•					–
Minh et al. (2014)	2014	•		•			•					•					Earthquake
Nourbakhsh et al. (2005)	2005	•		•			•						•				–
Pogkas et al. (2007)	2007	•				•	•						•				–
Tuna et al. (2014)	2014	•		•			•						•				–
Clark et al. (2018)	2018			•			•						•				–
Karma et al. (2015)	2015			•			•						•				Forest fire
Statheropoulos et al. (2015)	2015			•			•						•				–

TABLE 5 (Continued)

Reference		Technology			Disaster management stages		UAV applications										
Reference	Year	WSN	IoT	UAV	Preparedness	Assessment	Response and recovery	Monitoring, forecast, and EWS	Information fusion and sharing	Damage assessment	Situational awareness and logistics	Standalone communication	SAR mission	Coverage area and media coverage	Medical and health emergency	Infrastructure reconstruction	Natural hazard
Lakamp (2016)	2016			•			•						•				–
Mariusz et al. (2018)	2018			•			•						•				Earthquake
Alotaibi et al. (2019)	2019		•	•			•						•				–
Miyano et al. (2019)	2019		•	•			•						•				
Ferrari and Chen (2020)	2020			•			•						•				Ocean accidents
Hayajneh et al. (2018)	2018			•			•							•			–
Merwaday et al. (2016)	2016			•			•							•			Earthquake
Lin et al. (2019)	2019			•			•							•			–
Liu et al. (2019a)	2019		•	•			•							•			–
Liu et al. (2018)	2018			•			•						•	•			–
Lagazo et al. (2018)	2018			•	•				•					•			–
Alsamhi et al. (2018)	2018			•	•		•							•			–
Cileo et al. (2017)	2017			•			•							•			–
RT-Russia (2014)	2014			•			•								•		Heart attack
Qiu et al. (2020)	2020						•								•		–
Dayananda et al. (2017)	2017			•			•								•		Heart attack
Winders et al. (2020)	2020						•								•		–
Cho et al. (2008)	2008	•		•			•								•		Battlefield
Bailey et al. (2020)	2020				•		•								•		Flood

(Continues)

TABLE 5 (Continued)

Reference		Technology			Disaster management stages		UAV applications										
Reference	Year	WSN	IoT	UAV	Preparedness	Assessment	Response and recovery	Monitoring, forecast, and EWS	Information fusion and sharing	Damage assessment	Situational awareness and logistics	Standalone communication	SAR mission	Coverage area and media coverage	Medical and health emergency	Infrastructure reconstruction	Natural hazard
Jang et al. (2020)	2020				•		•								•		–
Dadon et al. (2020)	2020						•								•		–
Bernard (2020)	2020			•			•								•		COVID-19
Zekkos et al. (2016)	2016			•			•									•	Landslide
Wu et al. (2018)	2018			•			•									•	–
Liu et al. (2020)	2020		•	•			•									•	–
Baker et al. (2020)	2020			•			•									•	Hurricane

Abbreviations: EWS, Early Warning System; IoT, Internet of Things; SAR, search and rescue; UAV, Unmanned Aerial Vehicle; WSN, Wireless Sensor Network.

focused on, and the semiautonomous review of crucial bridge components such as the planned flight path for the optimum fight route is being integrated. Table 4 gives a summary of UAV applications and highlights their functions, critical issues, and potential risks. Table 5 presents a comparative tabular study of WSN, IoT, and UAV-based DM applications and solutions.

5 | UAV-BASED NETWORK TECHNOLOGY AND ARCHITECTURE FOR DM

The performance of UAV implementation in functional settings depends mainly on networking technologies. In this segment, we concentrate on UAV DM and response networking technologies. First of all, we implement the unified network architecture that incorporates 802.11 Wi-Fi, 2G/3G/4G, UAV ad hoc, and satellite networks (Gupta et al., 2015). A detailed discussion and analysis will be carried out of key networking components with the emphasis on whether current technologies can fulfill the UAV DM performance. Figure 10 shows a unified network model based on UAVs for DM. Figure 10, which consists of a satellite-aided GPS network, UAV ad hoc network, Wi-Fi network, and 2G/3G/4G cellular network, illustrates a universal UAV-based DM network architecture. UAVs link with the GPS satellite network on the top layer, equipped with an onboard GPS receiver that regularly supplies information on location and times. The data are essential for UAVs to conduct DM activities safely and correctly. Some of the examples contain Google Loon: Google balloons at 18 km above the ground level at high altitudes, providing Internet services and cellular networks for rural and remote areas (Tiwari, 2016). Balloons at high altitudes provide an efficient means of communication between UAVs and ground stations and among UAVs within a wide geographical region in the case of DM. The EU ABSOLUTE, which produces a hybrid Helikite (kite-ballon), easily deploys 4G communication in case of an emergency (Chandrasekharan et al., 2016), which is another example.

There are two types of network connectivity, namely, infrastructure-based and infrastructureless (ad hoc network) connectivity. Each node, for example, for infrastructure-based network connectivity, Wi-Fi access point, or Long-Term Evolution (LTE) eNode BS can communicate effectively with aerial UAVs and therefore form a framework of a star topology network system within which the UAV has placed in the middle of the star network. The ground station will communicate indirectly via UAV with others using this topology. It is found that connectivity to infrastructure-based networks has the advantages of quick installation, stable channel requirements, and configuration, while restriction of bandwidth and coverage is indicated where high-definition videos are needed to be transmitted for disaster recovery and analysis in the broad areas. For this problem, one solution is to install the versatile high-altitude UAV that covers large areas, gathers valuable information, stores them on board,

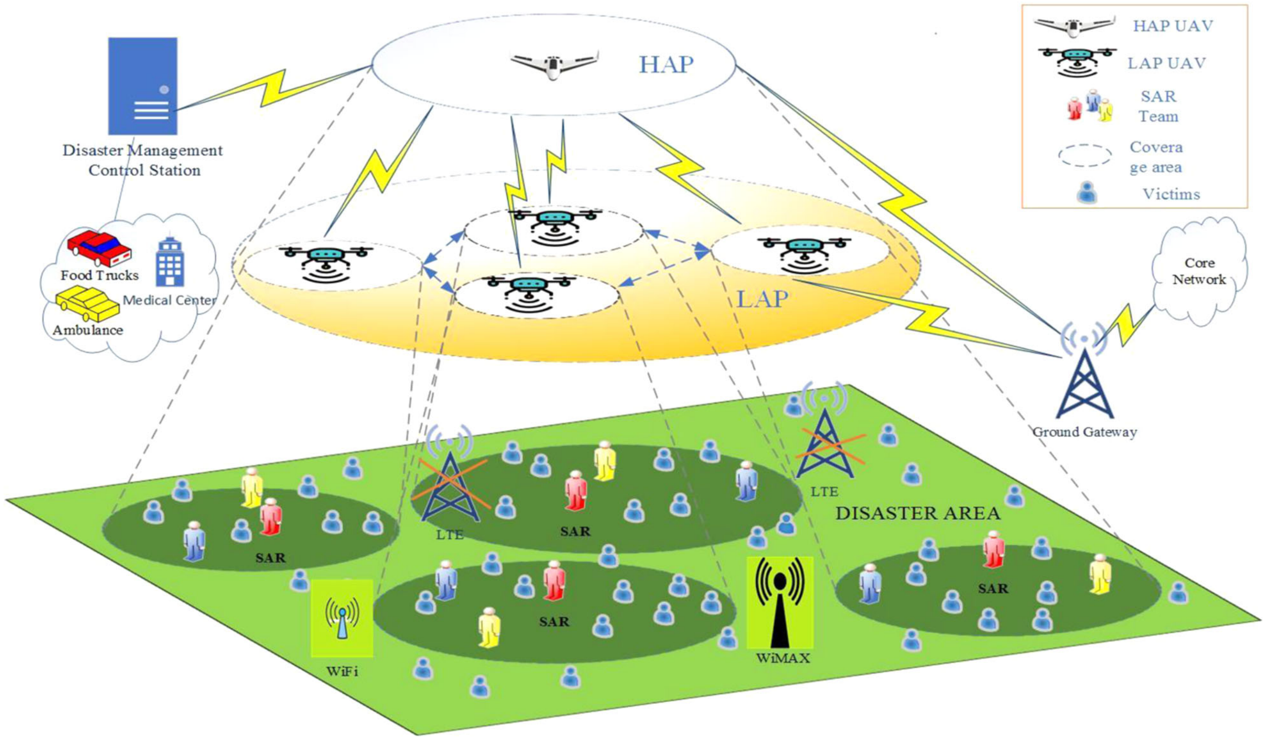

FIGURE 10 UAV-based unified network architecture for the disaster management system. HAP, High Altitude Platform; LAP, Low Altitude Platform; LTE, Long-Term Evolution; SAR, search and rescue; UAV, Unmanned Aerial Vehicle [Color figure can be viewed at wileyonlinelibrary.com]

and when UAVs return, it discharges them at the ground station or shares information in real-time with eNode ground stations.

In Figure 10, it is shown, an ad hoc aerial network consists of several low-cost small UAVs. Small UAVs may fly at lower altitudes and perform tasks in a distributed way for DM. They do not need a particular launch system and can start and land in different fields, which makes them ideally suited for disaster situations. However, a team of small UAVs will meet on-demand service at the best level during a major disaster case. But when multiple UAVs are essentially used in catastrophe situations, a variety of daunting problems arise. For example, small UAVs have limited power, computation, communications, and sensing capabilities. They cannot fly in the air for a long time, and it is difficult to keep communication links reliable and secure. Further research efforts are therefore necessary to achieve high-performance, secure UAV-based ad hoc networks.

Many advancements in UAV technology have been taken place that includes storage, memory, communication capabilities, and improved onboard processing. As a result, UAVs are being used more and more in many applications. Nevertheless, these UAVs must have the ability to connect effectively with each other through UAV-to-UAV communication and current networking infrastructures through UAV-to-Infrastructure communication to take full benefit of their services. Jawhar et al. (2017) describe the services, functions, and necessities of the UAV-based communication systems. They also describe the networking architectures, underlying mechanisms, data traffic specifications, and detail the various techniques and protocols that can be deployed at specific networking layers and UAV communication links. Wang et al. (2016) underlined the benefits of building a four-layer network architecture and a multi-UAV network. The advantages and disadvantages of prevailing protocol architectures were also studied, as well as an outline of the related gateway-selection concerns. They described two distributed gateway-selection techniques, one for small multi-UAV networks and the other for tiny multi-UAV networks. Finally, they looked at the stability of networked multi-UAV systems and suggested some future research topics.

It should be noted, according to the disaster scenarios and networking infrastructure that is accessible in the affected region, a UAV-based DMS should select the best form of connectivity. UAVs can also be linked to the BS if the 2G/3G/4G/5G cellular networks operate well. Alternatively, ad hoc communication can be established to convey information gathered by UAVs in a multihop manner to GCSs. Table 6 gives a summary of different wireless communication technologies and their characteristics for the DMS using UAVs (Luo et al., 2019; Ullah et al., 2019).

With the help of 5G and B5G mobile networks, UAVs are becoming increasingly important. UAVs have all the ability to fulfill the ever-growing mobile data needs of mobile networks and offer universal access to wireless devices of different types. Yet, the model of UAV assistance confronts many challenges and critical problems. The network management of existing UAV-support systems is complicated, time-consuming, and performed manually, thus creating

TABLE 6 Summarize different wireless communication technologies and their characteristics for the DMS using UAVs

Features	Wi-Fi	GPS	UMTS	LTE	LTE-A	5G	6G
Frequency band	2.4 GHz, 5.2 GHz	1176–1576 MHz	700–2600 MHz	700–2690 MHz	450 MHz–4.99 GHz	57.05–64 GHz	73 GHz, 140 GHz, and 1–10 THz
Channel width	20 MHz	2 MHz	5 MHz	1.4, 3, 5, 10, 15, 20 MHz	Up to 100 MHz	2.16 GHz	Up to 3 THz
Range	Up to 100 m	3–5 m	Up to 10 km	Up to 30 km	Up to 30 km	50 m	10 m
Latency	10 ms	10ms	20–80 ms	10 ms	–	1 ms	<0.1 ms
QoS support	Enhanced distributed channel access	-	Bearer selection	QoS Class Identifier (QCI) and bearer traffic allocation	QCI and bearer traffic allocation	QoS Flow Identifier (QFI)	Massive Broad Bandwidth Machine Type (mBBMT)
Bit rate	6–54 Mbps	50 Mbps	2 Mbps	Up to 300 Mbps	Up to 1 Gbps	Up to 4 Gbps	~1 Tbps
Broadcast/ multicast support	Broadcast	Broadcast	Multimedia Broadcast Multicast Service (MBMS)	eMBMS	eMBMS	eMBMS	Further-enhanced Mobile Broadband (FeMBB)
Coverage	Intermittent	Ubiquitous	Ubiquitous	Ubiquitous	Ubiquitous	Ubiquitous	Ubiquitous
Mobility support	Low	Extremely high	High	Very high (350 km/h)	Very high (up to 350 km/h)	Ultrahigh (up to 500 km/h)	Ultrahigh (up to 1000 km/h)
Market potential	High	High	High	Potentially high	Potentially high	Potentially high	Potentially very high
UAV support	Yes	Yes	Potential	Potential	Potential	Potential	Potential

Abbreviations: DMS, Disaster Management System; GPS, Global Positioning System; LTE, Long-Term Evolution; LTE-A, Long-Term Evolution Advanced; QoS, Quality of Service; UAV, Unmanned Aerial Vehicle; UMTS, Universal Mobile Telecommunications Service.

a variety of interoperability problems. To solve all of these problems efficiently, Oubbati et al. (2020) provide the characteristics of two promising technologies, that is, SDN and Network Feature Virtualization (NFV), that allow UAV support in the coming generation of mobile networks to be handled and improve efficiency. The first technology is SDN, which uses a controller to segregate the control plane from the data plane. The data plane distributes packets to the most appropriate interfaces, whereas the control plane executes logical operations and makes all essential decisions regarding network protocol management. The separation of these two planes enables traffic to be routed intelligently and to make the best use of network resources. The second technology is NVF, which allows service providers to create many separate virtual systems while accessing physical resources. The cost of Operational Expenditure and Capital Expenditure can be significantly reduced using NFV. Furthermore, it helps reduce the time it takes to bring network services and new applications to market. For great flexibility and maximum customizability, NFV uses the concepts of network slicing and subnet isolation. This technology will be critical for enabling QoS in UAV networks for a variety of applications.

6 | UAV FOR PROVIDING COMMUNICATION IN DISASTER SITUATIONS

Communication and networking are other important aspects of UAV systems in a disaster situation. This study includes such areas as the requirements for reliability, mobility, autonomy, delay, and bandwidth. UAV platforms have different communication and networking demands, depending on their applications (Frew & Brown, 2008, 2009; Saleem et al., 2015). This includes delay-tolerant networking (Henkel & Brown, 2006), communication with commands and controls (Richards et al., 2002), and mobility support. Close-to-fly, versatile, and affordable wireless networks composed of small UAVs provide the on-the-fly communication tools to synchronize rescue teams in the event of natural as well as man-made catastrophes and to assist survivors promptly through self-managed ad hoc Wi-Fi networks (Rosati et al., 2015). UAVs can be used as communication relays in places where communication networks have been disrupted as a result of natural events such as landslides, earthquakes, forest fires, flooding, or man-made incidents, such as military attacks, bomb blasts, and so forth. UAVs can be used for communication between UAVs and ground users as well as between multi-UAVs.

An important parameter of UAVs is that it is constrained by the power–weight ratios. During emergency communication, UAVs are equipped with communication nodes such as equipment needed for the missions, like, radar, cameras, and actuators. Due to weight and space limits, increasing the number of batteries is not a viable solution. Recent improvements in battery technologies permit marginally improving the endurance for roughly 90 min utilizing Lithium-Polymer (LiPo) batteries (Verstraete et al., 2012). To extend the endurance of UAVs, extra power sources must be used to offset battery limitations while staying within space and weight constraints. Due to its quasi-instantaneous refueling and high specific energy, a fuel cell appears to be a promising contender in this case. Its energy density can be up to five times that of LiPo batteries, resulting in a significant boost in hybrid-UAV endurance (Kim & Kwon, 2012). It is worth mentioning that the majority of electrical UAVs in the market use a fuel cell as their primary power source. A supercapacitor can also help with the power supply process because of its quick comeback to peak power and high power density needed in UAV unexpected movements and takeoff. Solar cells can be carried and solar energy can be used by fixed-wing UAVs. With the use of a storage device, fuel consumption can be lowered (Shiau et al., 2009), resulting in greatly increased endurance. As a result, hybridizing the power supply system by combining two or more power sources appears to be the greatest solution for ensuring a long endurance for a UAV. The structure of the power supply system, on the other hand, is critical. Indeed, it is dependent not only on the characteristics of the power sources but also on the requirements of the UAV mission. In the area of battery-powered UAV systems, new technologies such as tethering, laser-beam inflight recharging, and swapping are being considered.

Moreover, UAV is like an end effector, it only matters what the mission is for this end effector. Whereas, the problem of energy optimization is hardly hampered by the UAV's weight that restricts onboard computation capability for real-time optimization, as well as the fact that embedded processors must be provided, reducing endurance. Therefore, off-board computation might be regarded as a trend in this sense, as it allows many limitations of onboard computation to be overcome. Indeed, recent research has suggested predicting the energy consumption of UAVs based on a priori knowledge of the planned mission (profile, maneuvering actions, duration, etc.; Abeywickrama et al., 2018; Prasetia et al., 2019).

6.1 | UAV as flying BS for public safety in DMS

During a wide-scale natural disaster and unexpected event, the existing terrestrial communication networks can be disrupted or even destroyed completely and, therefore, significantly overloaded (Gomez et al., 2015). In these situations, communication between the first responders and SAR operations is important for the safety of the public. Therefore, a reliable, fast, and capable system of urgent communication is required to ensure successful public safety communications. In this respect, FirstNet was set up in the United States to develop a national and high-speed wireless broadband network for communications in public safety. Public security scenarios may include LTE 4G, Wi-Fi, satellite communication, and public security systems, such as Terrestrial Trunked Radio and APCO25 (Baldini et al., 2013). Future broadband wireless technology is also included. Nevertheless, these systems cannot provide low latency, versatility, and rapid environmental adaptation during natural disasters. In this case, a promising alternative to allow fast, scalable, and reliable wireless communication under the public safety scenario was the use of UAV-based air networks (Merwaday & Guvenc, 2015). Deruyck et al. (2018) proposed an emergency aid method for the use of UAVs for large-scale disaster scenarios. For UAVs, it is possible to bring and float femtocell BSs to their designated position. They introduced this method in the middle of Ghent, Belgium, in a practical disaster scenario. In addition, they also proposed the prediction model based on the intervention period and user coverage for the number of drones required.

Since UAVs do not need a very complex and costly network (e.g., cables), they can fly and change positions quickly in emergency conditions to provide on-demand communications to ground users. And they can create public safety communications networks on-demand due to their unique characteristics, like, fast reconfiguration, flexible deployment, and mobile in nature. UAVs, for example, can be used as aerial mobile BSs to provide broadband access to regions with degraded terrestrial wireless infrastructure. In addition, moving UAVs can continuously travel into a particular area in a minimum time frame to provide maximum coverage. The usage of UAV-mounted BSs can, therefore, be a suitable solution to provide ubiquitous and quick public safety connectivity.

The placement of UAV–BS has an impact on both the capacity of the backhaul link and the QoS of the user in the access connection. The UAV–BS should be situated as near to the hotspot region as possible to meet user QoS requirements and enhance access connection throughput. On the other hand, moving the UAV–BS closer to the hotspot region widens the gap between the Free Space Optical (FSO) transmitter and receiver. As the distance between the transmitter and receiver grows, the received power decreases, reducing the capacity of the backhaul link. As a result, the UAV–BS should be appropriately positioned to meet user QoS needs while also providing ample capacity in the backhaul link to handle the traffic accumulated in the access link. The resource allocation strategy specifies how much power and bandwidth each user should receive from the UAV–BS. Because the 3D location of the UAV–BS determines each user's path loss (PL), a different UAV–BS placement strategy will result in a different resource allocation scheme. The UAV–BS's 3D location must be repositioned due to a revised resource allocation technique. As a result, the UAV–BS's location and the policy for allocating resources should be examined together. Zhang and Ansari (2020) in their work propose a Cyclic Iterative UAV–BS placEment and Resource allocation (CIDER) algorithm for maximizing access link throughput while meeting user QoS needs in a hotspot region. They recommend deploying UAV–BS in a hotspot area to service customers, with FSO serving as the backhaul link, and studying FSO channel modeling. Under the constraints of user QoS needs and limited available resources, they evaluate both the users' resource allocation strategy and the UAV–BS's 3D position.

6.2 | UAV as a relay for communication

In recent years, UAVs have received great importance as communication relays, and a great deal of work has been done in this field. The current IoT technology is susceptible to natural catastrophes and cannot deliver secure services to users in disaster zones in emergencies. UAV plays a vital role in emergency IoT deployment

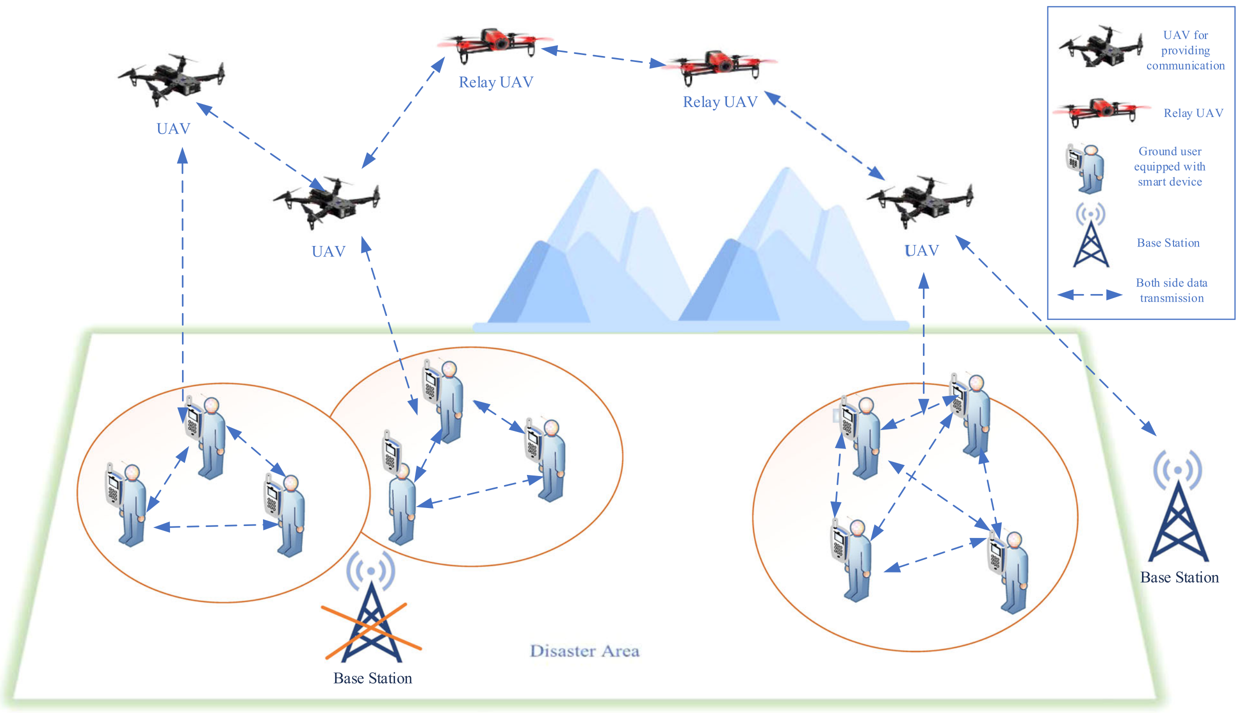

FIGURE 11 UAV-based relay network to provide wireless communication in the disaster-affected area. UAV, Unmanned Aerial Vehicle [Color figure can be viewed at wileyonlinelibrary.com]

because of their rapid deployment and versatile maneuverability. It can be deployed quickly as an aerial relay to improve communication capability significantly within disaster regions by effective UAV trajectory design. Na et al. (2020) designed the UAV-relay communication model for multiuser data transmission. When the disruption in the connection between the user zone and BS happens, BS can transfer information first to the UAV and then send it to users. The model suggests a combined UAV trajectory and power assignment system. The aim is to optimize the downlink achieved by optimizing the UAV and BS/UAV power trajectories subject to information causal constraints and UAV mobility. Figure 11 represents the UAV-based relay network to provide wireless communication in the disaster-affected area. In case of any area where human reachability is not feasible like in a war zone, hilly region, disaster zone, and so forth. UAV-based relay network is used to offer wireless communication and also help for providing extended coverage. In Figure 11 UAVs and the SAR team are equipped with smart devices that have transceiver capability for transferring data in both directions. As UAVs have a limited power supply which restricts the range of data transmission, in such case multi-UAV-based relay network is used to transmit the sensed data to the ground station in a multihop manner.

Ullah et al. (2017) offered an Optimum UAV Deployment Algorithm for fast deployment of the UAV to provide an optimal location for bridging communication between ground nodes and providing the participating ground stations with the best communications facilities. The algorithms operate in such a way that the UAV flies to the disaster area and begins to deliver beacon messages regularly. When nodes receive the beacon alert, they return their ID together with their GPS positions to the UAV in response. The distance between the participating ground nodes and UAV and Received Signal Strength is also collected by the UAV. A comprehensive simulation has been performed to determine the usefulness of the proposed algorithm in real-time DM applications. Mozaffari et al. (2016) have explored the use of a UAV as a flying BS. The concept was used to provide a particular geographic area with wireless on-the-fly communication services for a given communication network between devices. The authors outlined their concerns in two different scenarios involving static and a mobile UAV. The authors continue to say that if the UAV travels precisely across the specified area, the overall coverage and rate of communication can be significantly improved. Moreover, Kwon and Hailes (2014) proposed the dynamic positioning algorithm to establish communication between participating nodes via a UAV relay. The proposed method can be used in real-life situations like an earthquake and data collection from distributed sensor nodes. A direct link between nodes within the UAV range was created. It also suggested a programmatic structure in which various nodes depending on the number of visits and communication range, are prioritized to cover the whole set of distributed nodes.

Luo et al. (2014) discussed a communication system with some ground-based terminals together with a network BS to establish communications with a UAV as relief between them. They developed an algorithm to optimize the relation between the ground bases and relay terminals. They also discussed the use of new UAV-relay systems in the existing network if the current UAV relay does not comply with the minimum connection criteria. In a remote and hostile environment, normally fixed gateway approaches can operate but may cause decoding errors since mobile nodes are far away from the gateway. Saraereh et al. (2020) propose that intermediate UAVs be employed to transfer messages from ground-based Long Range (LoRa) nodes to a distant BS to prevent decoding errors and increase the reliability of communication. The LoRa based UAV architecture is focused primarily on an ad hoc Wi-Fi network, in which UAVs are a relay of communication between LoRa and BS nodes. A distributed topology control algorithm for UAVs is also suggested to boost architecture performance. The algorithm uses the technique of motion prediction and virtual spring forces to update the UAV topology periodically to suit the movement of surface-moving LoRa ground nodes.

6.3 | Communication between UAV and ground users

On the basis of the user's real-time needs, UAVs are easily deployable. They can be flexibly configured in a 3D environment, enabling UAV networks to provide ground users on-demand infrastructure and scalable services at a lower cost than terrestrial BS. The fundamental communication requirement of UAS can be divided into two types: Payload Communication (PC) and Control and Non-Payload Communication (CNPC; Zeng et al., 2018).

- *PC*: PC refers to the exchange of information between UAV and ground users that are mission-related such as video in the real-time, image, data transmission relaying. For example, the UAV must transmit the captured video to end-users on time through PCs for the aerial video graphic application. UAV PC typically has considerably higher data rate requirements compared with CNPC. For example, to allow full high-definition transmission of UAV videos to the ground users, the transmission rate is approximately multiple Mb/s and higher than 30 Mb/s for 4K video. For UAV-based airborne communication, the data rate need is very higher for wireless backhauling, which is up to tens of Gb/s.
- *CNPC*: CNPC denotes the two-way communications between UAV and ground BSs to make flight operations secure, effective, and reliable. CNPC messages comprise flight altitude, velocity, navigation aids, sense-and-avoid information, remote command and control for nonautonomous UAV in real-time, flight command (such as waypoint) update for semiautonomous UAV, and Air Traffic Control relaying information. CNPC generally requires a low data rate (e.g., 100 Kb/s), but its high reliability, low latency, and high-security requirements are relatively high.

Liu et al. (2019b) offer a new architecture for UAV networks with NOMA-supported extensive access capabilities. It evaluates the performance of the NOMA-enabled UAV networks through the adoption of stochastic geometry to design UAV and ground user positions. It illustrates the issue of UAV positioning using machine learning methods, as ground users wander and when UAVs can change their locations accordingly in three dimensions. Similar work is also done by Sharma and Kim (2017) for downlink communication where UAVs act as a flying BS, which is used to communicate using NOMA with two ground users. For LoS, UAV-to-ground communication, the Rician fading model is used, and Outage Probability (OP) is also investigated for both the ground users. The OP equation of users U_1 and U_2 with NOMA at the location (r, θ) of UAV $\mathcal{S}$ is defined in Equations (1) and (2), respectively, as

$$\mathcal{P}^{\mathcal{N}}_{\text{out},1} = 1 - \left[Q\left(\sqrt{2\mathcal{K}_1,} \sqrt{\frac{2(1+\mathcal{K}_1)\varnothing_1 d_1^{\alpha}}{\mathcal{P}_{\mathcal{S}}(a_1 - \varnothing_1 a_{2)}}} \right) \right]^2, \tag{1}$$

$$\mathcal{P}^{\mathcal{N}}_{\text{out},2} = \left[1 - Q\left(\sqrt{2\mathcal{K}_2,} \sqrt{\frac{2(1+\mathcal{K}_2)\varnothing_2 d_2^{\alpha}}{\mathcal{P}_{\mathcal{S}} a_2}} \right) \right]^2, \tag{2}$$

where $\mathcal{P}^{\mathcal{N}}_{\text{out}}$ denotes the outage probability, Q denotes the Marcum Q-function of the first order, $\mathcal{K}$ is the Rician function, d_1, d_2 are the Euclidian distance from the ground user U_1 and U_2 to UAV $\mathcal{S}$, a_1, a_2 are the power allocation coefficients, $\varnothing_i = 2^{\mathcal{R}_i} - 1$, where $\mathcal{R}_i$ is the target rate.

Zeng et al. (2018) describe the cellular-connected UAV technology and its special connectivity criteria, and also its possible advantages, the bandwidth requirement, and new design concepts. It then put in place promising technologies for the next generation of heterogeneous 3D wireless networks for ground users and an aerial system. Khan et al. (2021) present a layered architecture for DM taking LAP as well as HAP UAVs. It describes UAV and ground user communication both for the uplink and downlink. Moreover, it takes into consideration various factors like obstacles inside and outside buildings that affect the PL model. Furthermore, it considers different user altitudes in a multistory building to carry out the performance metrics. Kim et al. (2018) provide a movement control algorithm in real-time to monitor the large UAVs that offer urban disaster-site urgency cellular connections. This algorithm reduces the consumption of energy per downlink rate, thus preventing a collision of inter-UAV with temporal wind turbulence. The real-time UAV downlink rate $R_i(t)$ is defined in Equation (3) as

$$R_i(t) = B \log_2\left(1 + \frac{g_i(t) P_u \cdot 10^{-L_i(t)/10}}{N_o B}\right), \tag{3}$$

where B is the bandwidth, $g_i(t)$ is the fading coefficient, P_u is the power spectral density, $L_i(t)$ is the PL, and N_o is the noise spectral density. Here, $\|\cdot\|$ it is used to specify the Euclidean norm. Also, the total consumption of energy and mechanical motions per unit downlink rate for the downlink transmission is given in Equation (4) as

$$E_i(\mathcal{V}_i(t), \mathcal{Z}_i(t)) = \frac{e_{m,i}(t) + e_{w,i}(t)}{R_i(t)}, \tag{4}$$

where $\mathcal{V}_i(t)$ is the set of UAV velocities, $\mathcal{Z}_i(t)$ is the set of their locations, $e_{m,i}(t)$ is the energy consumption for movement control, and $e_{w,i}(t)$ is the energy consumption for transmission.

6.4 | Communication between multi-UAVs

Complicated situations arise when a single UAV in a particular mission cannot cover a disaster region. In such instances, several UAVs are used to cover a collection of nodes within a restricted zone. Ponda et al. (2012) introduced a cooperative distributed planning algorithm known as the Consensus-Based Bundle Algorithm (CBBA) for a group of heterogeneous agents working in a dynamic environment to guarantee network connectivity with partial communication services. The UAV-relayed algorithm allows the team to execute and hit the task without constraining the participating agents. To carry out the mission, CBBA used agents that are free as relays to bind to the BS for network connectivity. The authors have also tested the algorithm based on simulation findings, and practical fields test both for indoor and outdoor, which have confirmed that CBBA is ideal for implementations in real-time. In the same way, UAV swarms as communication relays have been studied for the reliability and range of ground-based ad hoc networks (Palat et al., 2005). The authors visualized the application of multi-UAV using a distributed MultiInput MultiOutput scheme on a cluster and also noted the efficiency of distributed Orthogonal Space–Time Block Codes and distributed beam-forming transmit in ideal and nonideal situations for various UAV flights. The efficiency of both approaches was verified by various simulation parameters. For both schemes, the efficiency of the BER was analyzed together with the different Rice K-factors results. They concluded that better performance could be accomplished with hierarchical beam-forming in the case of lower carrier frequencies.

When a swarm of UAVs is distributed to monitor several nodes traveling in a restricted area, the difficulty increases. Charlesworth (2014) suggested a noncooperative game strategy in which each UAV chooses its future position independently without the assistance of any central planning agent. The solution suggested using the UAV as a play–actor and the handheld nodes as payoffs. The UAVs have sufficient data to determine and separately conduct their actions at the positions of the UAVs and other mobile nodes. The monitoring of large areas can be done by deploying multi-UAV flight formations. During formation flying, individual UAVs communicate and exchange information. However, the risk of security arises from such communication. In the insecurity area, which falls between the group communication range and UAV group range, multi-UAV communication can root for severe information leakage. To resolve this problem, Wu et al. (2019) discuss two aspects: cooperative control and secure communication. A clustering algorithm to speed up the multi-UAV formation converge is proposed to enforce cooperative control. The UAV group forms a flock by increasing the flight control factor to accelerate multi-UAV convergence. The Hierarchical Virtual Communication Ring technique is applied to decrease the insecure range and to diminish the boundary of group communication to promote secure communication.

In different catastrophe surveillance systems, several mini-UAVs may be used. These UAVs may be operated from a ground-based controlling station or a completely distributed FANET. A collection of network protocols must be built as part of the protocol stack to accomplish distributed operations. Joshi et al. (2020) developed many FANET networking protocols, namely, routing protocol, time division-based MAC protocol, and clustering protocols for a specific networking topology. The proposed FANET network can be used with multiple cluster creation to traverse vast and disjoint terrain. UAVs use adaptive power communication strategies to maintain separation between clusters and to maximize network capacity. Lin et al. (2019a) looked at the problem of trajectory planning for UAV-aided multi-UAV networks in a postdisaster situation, for which two heuristic algorithms, that is, the Nearest Assignment (NA) and the Trajectory Balancing (TB) algorithms, are suggested to boost coverage performance. With the application of Linear Programming techniques, the trajectories are balanced; thus, the TB algorithm proposed can achieve greater coverage performance, while the NA algorithm proposed has benefits of computational complexity. Depending on the practical parameters of various postdisaster situations, the network should choose the most appropriate algorithm.

7 | OPEN RESEARCH CHALLENGES AND FUTURE DIRECTIONS FOR DM

Although UAV systems face critical challenges but are still one of the best technological options to deal with natural and man-made disasters. This section will summarize some of these challenges and issues so that practitioners and system designers can have a roadmap to perform research work in this area. In general, the UAV network is still unable to deal with problems, such as processing power restrictions, power supply limitations, maneuverability under challenging circumstances, and maximum physical load size. While there are techniques of power generation, they are not adequately implemented and used enough in practice. Although powerful onboard computers in UAV motherboards are now installed, their processing efficiency remains lower than that of a computer server system. Some of the major challenges are highlighted as follows:

- *Coverage, connectivity, and mobility*: Communication turns out to be a major issue during a disaster. In most cases, infrastructure has been destroyed, making it difficult to maintain 2G, 3G, 4G, and 5G connectivity. During the disaster, a significant number of the BS could also be impaired or completely shattered. Furthermore, many victims in the impacted region could not call for help in the affected area. Connectivity can be provided by using a UAV-mounted BS or UAVs as a relay node. The number of UAVs in most cases is not enough to guarantee stable connectivity. In this situation, Delay-Tolerant mode can be required use. However, it added a whole new set of problems. UAVs are very closely connected to headquarter (managing actions) but need reliable and secure communication and wide bandwidth to transmit images and videos timely and get control information. It is a lot more challenging to develop more autonomous UAV software. Collision avoidance and mobility support around UAV's Internet are some of the key issues that need to be addressed in the future.
- *Reliability and robustness*: Flying UAVs must eliminate collisions and barriers with other UAVs. This can be accomplished by image processing, but it can be improved by the exchange of data about their speed, flight trajectory, and position. Inter-UAV communication is essential to accomplish collaborative work. The biggest problem here is scalability, as there is a vast number of drones in dense regions. The quality of communication is heavily dependent on the level of drone autonomy. Further, user control drones would need less communication with other UAVs, which will allow high traffic to their ground stations. Independent drones may add more UAV communication to make decisions jointly.
- *Interoperability*: In an emergency disaster relief situation, heterogeneity is, in fact, one of the main problems. Ideally, we want every user to collaborate, but it is a virtually impossible task in reality. Various user power, operating systems, communication technologies, and protocols make it complicated but necessary for collaboration to take place. To create direct communication between network devices, it is important to connect heterogeneous devices with different communication technologies (ZigBee, Bluetooth, Wi-Fi, LTE, etc.). Devices in a different environment (smartphones on the ground, UAV in the air) are also designed to operate optimally in given conditions. Communicating with each other can decrease radio performance significantly. Interoperability problems emerged in the layered architecture by integrating different communication technologies as every technology operates on specific communication protocols. The data exchange between these nodes must, therefore, be carried out in a multiprotocol situation. The challenge is highly significant to research protocols that can work efficiently in this situation.
- *QoS*: UAVs have limited flight time, and their numbers are restricted due to their potentially high costs. Every UAV message in the network cannot be transmitted, even when storage and protocols are unlimited and enable you to move around a device. In this case, prioritizing traffic could be a big challenge. On the most critical note, the consolidation of data and the fusion of redundant information will significantly increase the device's performance. There could be a large number of errors in data gathered from various sources (sensors, crowdsensing, UAVs) that must be controlled. Many current solutions will reduce errors in a homogeneous situation. However, it is always a big challenge to build the framework for treating errors generated from various data sources.
- *Security and privacy*: One of the challenges in UAV communication is privacy and security issues, including spoofing, jamming, and eavesdropping within aerial networks for DM. Artificial intelligence solutions and lightweight techniques should be used to

cope with these challenges. Nowadays, blockchain can also be used as an application during emergencies for DM.

- *Latency*: In UAV tasks such as fire monitoring, SAR, and so forth, reliability and latency have to be maintained to assist rescue teams and protect the survivors. In hazardous conditions, continuous video streaming requires a secure connection between ground stations and UAVs. Ultrahigh reliability and ultralow latency would be required to tackle cellular communication in the next generation to ensure a stable connection.
- *Energy constraint*: Concerning drones, energy constraint is the biggest issue with drone/UAV communication. In the circumstances such as mission-critical infrastructure and DM, it is more critical. There has been a lot of work done in battery science, but problems must be resolved with beam-forming techniques in the future.
- *Channel and PL model*: The Channel and PL model of higher carrier frequencies is challenging in areas bounded by high-rise buildings, especially in areas with a denser deployment of the BS. The communication between UAVs and ground users for edge computing requires a lot of complexities. The primary reason is that wireless communication channels are extremely fluctuating between UAV–UAV and GUs–UAV. The stochastic channel model can be seen as a possible solution for overcoming these challenges by precisely tuning different 3D-channel parameters for the changing environment.
- *Asymmetric uplink and downlink*: In general, cell-based UAV communications are much more likely to support the uplink transmission from UAV to BSs, particularly for high data rate applications such as aerial imaging and video streaming. It differs from the existing cellular network, which is primarily configured to accommodate the more prevalent downlink traffic. So, more work is required for determining the feasibility of using LTE networks for asymmetric traffic with large UAV installation. Moreover, new technology should be built for future 5G and beyond cellular networks to fulfill the particular demand for better UAV traffic. Another choice is to use radically different frequency bands for downlink and uplink communications, for example, the regular sub-6 GHz for UAV downlink and millimeter-Wave (mmWave) for UAV uplink.
- *Resource constraint and UAV placement*: UAV plays an important role in DM since it executes different computing functions at the edge. Therefore, optimizing the assignment of resources, task planning, management of key control functions, and interfacing with other systems have to be streamlined to achieve optimal performance. The placement of the UAV cloud at the edge is a big challenge and requires adequate research. Thus, the placement of UAVs in 3D with low energy consumption and minimal processing time constraints demands focus on achieving high performance in computation at the edge. Moreover, to produce effective performance, user mobility and UAV trajectory need to be focused on. As UAVs are prone to the energy limit, this constraint must be included to ensure network performance in the design of scheduling algorithms.
- *Reliable communication*: Another open challenge that needs to be tackled for public safety in the future is ultrareliable communication. Most research is already going on in this area, but it will be a challenge again with the emergence of IoT and a growing number of connected devices.
- *Simulation tools*: Network simulator version 2 (NS2) and optimized network engineering tools (OPNET) have been used for performance evaluation for most of the current routing schemes. However, NS2 and OPNET do not possess a channel model for UAV communication. Moreover, it does not support 3D communication, which is an important feature for UAV design. Therefore, significant changes are also required to allow these tools to fulfill multi-UAV system specifications. Besides, simulation software should have mobility models that emulate exact UAV movement patterns to construct a practical simulation environment, as the mobility models would have a significant impact on the performance results.
- *Rule and regulations*: UAV's latest technological advancement has revolutionized data collection methods and has thus allowed new areas of scientific study and environmental surveillance. Nevertheless, the regulation has had difficulties in preserving drone technology as it is advanced rapidly. Different countries are implementing their drone's rules and their use at different levels. There are several aspects to the laws of different countries that are common, but there are other variations. The regulatory situation is continuously changing, and it was difficult to enforce it in effect up to now. However, drone pilots have a crucial duty to ensure that they fly safely and legally. Moreover, pilots who use drones for commercial purposes should be conscious that different regulations are generally in place for the enthusiast (including scientific investigations). Authorized training, appropriate registration, and flight permission for drones should always be requested at the location of the flight where applicable.

8 | CONCLUSION

The paper identified the major applications of the UAV network for DM and highlighted the open research issues related to UAVs in DMS. Together with the WSN and IoT, UAV networks are a successful future technology for DM applications based on the surveyed research. In this article, we concentrated on the combined role of the WSN, IoT, and UAV systems that can play in natural and man-made DM. The first major contribution of this paper is the classification of current research work that uses different technologies integrated with UAVs for DM in the following application areas: monitoring, forecasting, and early warning system, disaster information fusion and sharing, situational awareness, logistics, and evacuation support, damage assessment, standalone communication system, SAR mission, media coverage, medical health and emergency, and infrastructure reconstruction. It also focuses on different network technologies and architecture that are used in the DMS. After that, it discusses other important aspects of UAVs for providing emergency communication during natural and man-made disasters. We hope that the critical research challenges and opportunities described in this survey will help pave the way for researchers to improve UAV collaboration applications in the future. It also tries to propose and implement a model integrating with different technologies and analyze the various performance metrics for DM in the future.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no data sets were generated or analyzed during the current study.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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