Hindawi
Wireless Communications and Mobile Computing
Volume 2021, Article ID 6710074, 12 pages
https://doi.org/10.1155/2021/6710074

Research Article

Multi-Drone Edge Intelligence and SAR Smart Wearable Devices for Emergency Communication

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Received 3 September 2021; Revised 15 October 2021; Accepted 18 October 2021; Published 3 November 2021

Academic Editor: Stefan Panic

Disasters, either manmade or natural, call for rapid and timely actions. Due to disaster, all of the communication infrastructures are destroyed, and there is no way for connection between people in disaster and others outside the disaster range. Drone technology is the critical technology for delivering communication services and guiding people and monitoring the unwanted effects of a disaster. The collaboration of advanced technologies can reduce life losses, save people's lives, and manage the disaster crisis. The network performance of collaboration between the Internet of Things (IoT) and drone edge intelligence can help gather and process data, extend the wireless coverage area, deliver medical emergencies, provide real-time information about the emergency, and gather data from areas that are impossible for humans to reach. In this paper, we focus on the network performance for efficient collaboration of drone edge intelligence and smart wearable devices for disaster management. We focus mainly on network connectivity parameters for improving real-time data sharing between the drone edge intelligence and smart wearable devices. The relevant parameters that are considered in this study include delay, throughput, and the load from drone edge intelligence. It is further shown that network performance can have significant improvement when the abovementioned parameters are correctly optimised, and the improved performance can significantly improve the guiding/coordinating of search and rescue (SAR) teams effectively and efficiently.

1. Introduction

Disaster coordination and management become of vital importance [1, 2]. The management operations should be done early and quickly to save people's lives and reduce costs and the number of victims [3]. There are many roles for disaster management and recovery operations were discussed [4, 5]. Due to destroying all communication infrastructures, disaster mitigation, management, and recovery become very complicated, and the search and rescue (SAR) team can not perform tasks safely. Therefore, space technology is the alternative solution for disaster management, mitigation, and recovery, as well as help SAR to perform complex tasks efficiently and safely during a disaster.

Drone technology is a flying base station that flies in the sky for delivering communication services during a disaster.

Drone technology characteristics such as a line of sight, easy to deploy, and capture high-resolution images make drones the efficient solution for disaster mitigation, management, and recovery [6]. Furthermore, drone technology plays a vital role in identifying disabled people and the discovery of people and belongings of victims buried under ruined buildings. For example, drones were used during the Japan earthquake to assist in disaster operations efforts by capturing the images of affected areas and providing real-time data of the current event and reconstruction efforts. Therefore, drone technology is a promising and emerging technology for efficiently and effectively capturing a high-resolution image of the disaster-affected area as well as delivering supplies and extending the coverage area [7, 8]. Furthermore, managing the drone routing is very important to improve safety and enhance movement [9, 10].

Disaster management demands real-time information for providing and delivering emergency services to save people's lives. Recently, the advanced technology of the Internet of Things (IoT) enabled the collection of real-time data from different sources. Smart wearable devices (i.e., IoT devices) include sensors, actuators, and cameras, for smart environments [11, 12]. Thus, drones are equipped with onboard IoT devices connected to IoT devices to perform complex tasks effectively and efficiently [13]. In case of a disaster, drone technology is equipped with IoT devices to capture a map or high-resolution image and sense its surroundings. On the other hand, drones can be used to collect data from wearable SAR devices such as locations and environment status. Therefore, collaboration drones and smart wearable devices carried in the SAR body will bring a tactical solution for disaster management. Therefore, we propose the collaboration of drones and smart wearable devices based on the ad hoc network. The collaboration can significantly deliver immediate services, emergency services, guiding SAR operations, and activities during a disaster in real-time (i.e., flood, earthquakes, and terror attacks).

Inspired by the above observations, this paper focuses on the collaborative drone and IoT devices in the SAR body with the ad hoc network's help for disaster management and saving peoples' lives. This paper highlights drones' potential applications for energetically sustainable disaster management and the need for drone technology in emergency and management of sustainable disaster strategies. We focus on a collaborative drone for gathering data from the coordinator in the SAR body in which the coordinator is used to connecting with many IoT devices distributed in the SAR body. The main contributions of this work are as follows:

(i) We introduce the importance of collaborative drones and smart wearable devices (IoT devices) in the SAR body for disaster management and emergency relief coordinators

(ii) We focus on the network performance of the collaboration between drone edge intelligence and smart wearable devices. The network performance metrics such as delay and throughput, can help in guiding SAR to perform tasks effectively and efficiently during disaster management. The connectivity between the drone and smart wearable devices improves SAR service delivery effectively and efficiently to save people's lives during disaster via sharing data in real time

2. Related Work

Many researchers have carried out different experiments in the field of technology deployment for disaster management. However, the initial moments of disaster are critical and urgent attention is required to save people's lives and reduce costs. Drone technology represents a key technology for accessing disaster-affected areas, capturing required data efficiently, and monitoring SAR operations and disaster status. Collected data is sent by drone to the disaster area to make appropriate decisions and take necessary actions in real-time. Deruyck et al. [14] investigated the feasibility and performance of a drone-aided emergency network in case of a large-scale disaster. The authors of [15] introduced a quadcopter for emergency healthcare. Many wireless sensors have been deployed in drones for the collection of real-time data [16]. Drones have been designed with built-in wireless sensors, infrared cameras, and the global positioning system (GPS) for human detection during terror attacks or disaster [17]. Also, Plageras et al. [18] explained the wireless sensor network and how the data is collected from all sensors, stored, and retrieved from the cloud. Furthermore, Ray et al. [19] reviewed and summarized the issues related to IoT for disaster management early warning, data analytics, notification, knowledge aggregation, real-time analytics, remote monitoring, and victim localization. IoT is composed of the sensor (i.e., bridge, highway, and thermostat to collect weather data), connection (i.e., infrastructure that connects end to end sensors), and cloud, which is used for storage and analysis of the received data.

Sakhardande et al. [20] utilized the communication modes of IoT devices in smart cities to monitor and manage SAR activities during a disaster. Also, Boukerche et al. [21] proposed IoT-based disaster response and detection systems for improving SAR activities during a disaster. In this context, IoT devices were used for data gathering and the location of injured people after identity hazards after a disaster. The proposed system's architecture included smart sensors, smart processing, quick response, and an ad hoc network.

Deploying drone and IoT devices during the disaster were responsible for effective and efficient communication and data sensing [22] and the use of integrated technology to help SAR teams safely perform their tasks with greater efficiency. However, more IoT devices are employed for such progress to improve emergency response and preparedness. As drones fly over or closer to the disaster area, they can communicate to facilitate the coordination and surveillance of the event and SAR teams [2]. Real-time processing of the collected data by IoT devices is needed to identify the most affected areas and assist people where human intervention is risky, impossible, dirty, dangerous, and expensive. A drone equipped with IoT devices can be used to collect data from the disaster area and its surroundings. Aljehani and Inoue [23] proposed drone technology and IoT for enabling mobile tracking and image processing. The advanced technology was used to capture an image of a disaster event. Image data from a drone helped to evaluate the damaged area. Hence, collaborative drones and IoT devices make the performance of duties in disaster operations very easy, even in unreachable areas. Furthermore, drones and IoT collaboration is aimed at creating a safer, smarter, and healthier society. The authors of [6] introduced the collaboration between drones and the Internet of Public Safety Things (IoPST) to improve public safety in smart cities. Table 1 shows a summary of previous studies related to collaborative drone and IoT technologies for disaster management. Most of the above studies focus only on IoT technology and drones for disaster surveillance and emergency services. However, our proposed work focuses on evaluating performance metrics of the collaboration of smart drones, IoT, and ad hoc networks for efficient disaster management.

Each drone has a responsibility for the mission, planning the task, controlling the task, and ensuring the independent operation. The head drone has improved the management of information on its team. In this particular scenario, the authors improved the energy efficiency and drones trajectory by improving QoS (delay, throughput, BER, channel capacity, etc.) [24, 26]. Therefore, drone collaboration can interact with each other and coordinating their collaboration based on exchanging information, sharing the tasks, independent subtasks in monitoring any events. Briefly, the collaboration of multiple drones plays a critical role in reducing delay and energy consumption [25, 27–29]. Furthermore, it can improve QoS due to several reasons such as processing data closer to the event; deployment of edge computing is supported by improving QoS and reducing energy efficiency [30–35]. Efficient techniques may be used to create accurate models for controlling the movement, scheduling, and energy efficiency due to selecting the optimal trajectory to reach the event in real-time and save energy consumption.

3. Drone Edge Intelligence over Disaster Area

Drone edge intelligence has created a platform that may be used for various mobile applications, computing, networking, and storage. Drone edge intelligence collaborates with SAR for disaster management to complete routine tasks, link smart devices to the network, and collect, analyze, and transfer data to the cloud. This allows B5G networks to manage vast numbers of networking devices, SAR, and people while also allowing communication development with high bandwidth, intelligence, low latency, real-time processing, and low energy consumption. Drone edge intelligence has also lately acquired popularity because of its high mobility, adaptability, and inexpensive cost.

Drone edge gathers data from SAR, and disaster environment captures alive people affected by a disaster area [36]. Gathered data processes locally in drone edge and analyses. Based on data analyses, the SAR was guiding and coordinated accordingly safely and efficiently. The study focused on disaster prediction and recovery plans via drone edge computing. Furthermore, drone edge can be efficiently used for providing and collecting data at the same time. For example, in disaster situations, drone edge plays a vital role in gathering data in real time and reach fog over disaster areas plays a critical role in improving QoS [6], minimizing economic losses, reducing the energy consumption of drones, providing storage and processing, and network connectivity for the needs of the disaster event disaster in 0th response [37]. Furthermore, it represents the critical solution to managing the disaster due to its ability to fly closer to the event, environment, IoT devices, and SAR.

Indeed, collaborative drone edge can be flown to SARs during a disaster for providing them efficient connectivity with energy efficient or any objects in the disaster area for detecting, gathering accurate data about the objects, and then make computations over short ranges in order to save energy and send necessary data to SARs and cloud. The collaboration of several numbers of drone edge over disaster areas plays a critical role in improving QoS, minimizing economic losses, reducing the energy consumption of drones, providing storage, processing, and network connectivity for the disaster event's needs. The number of drone edge collaborations depends on the size of the disaster area, so if it is big, swarm drones are required for management and speed recovery. The advantages of collaboration drone edge intelligence are that they are potentially and adaptable scalable to deliver services over large disaster areas effectively and efficiently, and therefore, the cloud can be removed. Therefore, drone edge intelligence can collaborate autonomously and with SAR heterogeneously. Drone edge is widely used to serve wearable IoT devices in many applications [38, 39]. To perform tasks effectively and locally in the disaster, drone edge requires understanding the surrounding environment. However, drone edge collaborations are based on service delivery for supplying the SAR in large disaster areas to understand the tasks and environment. Understanding tasks and environments depend on the processing of drone edge collaboration. However, acting performing depends on efficient processing tools used in drone edge for processing in real time.

3.1. Large-Scale Emergency Response. In large-scale disasters such as volcanoes, earthquakes, floods, bushfires, and terrorist attacks, immediate action and fast response must be considered. The collaboration of drone fog, which carried computing and IoT devices, represents the tactical solution to provide fast observation about the situation and guiding SAR.

3.2. The Architecture of Drone Edge Intelligence Collaboration. Drone edge collaboration is aimed at offering a vital framework to deliver services to different IoT applications. These services depend on the operation of drone edge collaboration and environment services. The operation of drone edge collaboration includes security, location, trajectory, formation and scheduling, mobility, connectivity, and reliability. Environment services include swarm drone edge intelligence collaboration, IoT devices, smart wearable

Table 1: Summary on the collaborative of drones and IoT for disaster management in smart cities.

Ref.	Highlighted	Focus
[20] (2016)	Manage and monitor the disaster in smart cities	Use IoT devices for collaboratives to manage SAR activities in smart cities
[24] (2020)	Efficient channel modelling for UAV to ground communication	A low complexity UAV selection to reduce the complexity of signal processing without system performance degradation
[25] (2021)	Multi-UAV and SAR collaboration	Collaboration of multi-UAV and SAR in B5G for disaster management and recovery
[19] (2017)	IoT-enabled disaster management systems	Available techniques of IoT for disaster management
[23] (2019)	IoT and drone for disaster recovery	Drone and IoT for enabling mobile tracking and image processing
[21] (2018)	Architecture for smart disaster prediction and response system for smart cities	IoT-based disaster response and detection systems for improving SAR activities during a disaster
[6] (2019)	A collaboration of drones and IoPST	Drone technology and IoPST for enhancing public safety in smart cities
Work	Collaborative drones edge intelligence and wearable IoT devices for disaster management	Performance of communication networks between collaborative drones edge intelligence and wearable IoT device for enhancing the performance of SAR activities and operations in real-time

devices, and cloud. Drone edge intelligence collaboration services can be processing, communication, storage, control configuration, measurement, monitoring, and manage. Drone edge intelligence collaborations are considered to enable smooth operations among themselves (local service, remote services, security services, control services, management services, and monitoring services), cloud and IoT devices of different applications. Therefore, it can perform and utilize any application or services available in the cloud. Drone edge intelligence collaboration support flexible technique to keep connectivity of available services and accept the new services. Furthermore, drone edge intelligence collaboration can improve the implementation of collaborative services of multiple IoT applications. Each drone focuses on a particular monitoring area and shares information about its coverage area wireless with the closest drone to monitor disaster areas effectively and efficiently. Based on the charring information, trust, and sharing subtasks independently, collaborative drones adjusted their optimal trajectory to reach goals based on saving energy and keeping connectivity with other drones for updating the data of the disaster environment.

3.3. Drone Edge Intelligence and Disaster Management. In each stage, disaster management requires comprehensive data and accurate maps to plan and guide the recovery operations. SAR operations could be coordinated and guided to reach the affected disaster area based on real-time data collected from critical zones, surviving people, and refugee camps access. Therefore, drones represent a promising and emerging technology for gathering accurate information, extending the coverage area of a wireless network when it gets destroyed, and assisting SAR and relief teams in all disaster stages. During a disaster, a drone can be used to map the natural disaster area and predict the path of a disaster such as a flood and volcano. It can be deployed as soon as the disaster occurs, for example, to extinguish fires, because drone deployment is easy and rapid. Furthermore, drones can help make relief maps of an area, capture high-resolution maps, and conduct an autonomous search for victims in the affected area [9, 10]. Relief maps can be used to determine the impact of a disaster and are considered a source for decision making. For instance, a drone map can help avoid peril by identifying the best way or a smooth path to safely reach the most damaged areas, helping to deliver relief supplies. Therefore, drones naturally help disaster operations to ensure that they can act faster, safer, more effectively, and more efficiently. Furthermore, drone technology can provide surveillance and formative mapping assessment and allow responders to focus on the tasks that need attention immediately after a disaster. Figure 1 shows the disaster management cycle functions, including preparedness, mitigation, response, and recovery.

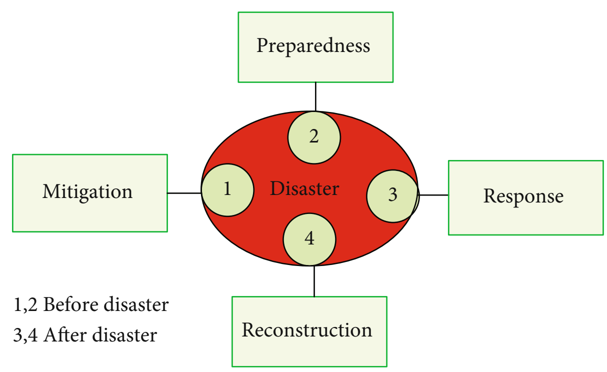

Figure 1: Disaster management strategies.

4. Drone Edge Intelligence and Smart Wearable Device Collaboration

Timing is everything in disaster management. By incorporating IoT devices into data gathering, emergency response

Before disaster After disaster

Figure 2: Integration of IoT and drone edge intelligence for disaster management.

Figure 3: Collaborative drones and IoT for disaster management.

plans, and public sector agencies, responders can use real-time information to make arrangements and reach citizens who need help. In the case of IoT wearable devices by SAR teams, the drone can follow the IoT services by embedding sensors, cameras, and communication devices. For example, response teams can also use wearable sensors for coordination, analytics, outreach strategies, and on-the-ground tactics. Furthermore, IoT sensors' value is to collect data about disaster surroundings and systematically broadcast signals from emergency areas. IoT devices can relay data to emergency teams and government agencies. For instance, sensors can measure the temperature, pressure, water quality, humidity, and smoke presence. Another example is using sensors in wildfires to detect how far and how fast the fire is spreading. In addition, sensors can monitor the water level at the first sign of flooding and send alerts regarding tsunamis or hurricanes. These sensors can be critical for necessary decisions like evacuating) an area at risk of flooding or guiding residents to the safest exit routes ahead of an emergency. IoT devices (e.g., detection devices, high-resolution cameras, infrared scans, and sensors) must make an accurate map. However, employing more IoT devices is required for such progress to improve emergency response and preparedness.

However, IoT devices with drones could be used for the SAR surveillance phase during a disaster, and then, data can be collected from wearable SAR IoT devices to support the recovery effort. Ad hoc technology can be used in cases with few or massive nodes; it can maintain the connection to all the nodes [40]. Furthermore, it provides the delivery of services [41, 42], such as audio and video, for heterogeneous teams [43] with a guaranteed QoS [44] to satisfy the needs of the rescue and relief teams' services. Today, drone technology is finding its way into IoT implementation because it is evolving very rapidly. Drones equipped with IoT can reach previously unreachable areas, as shown in Figure 2.

However, using a drone for effective disaster risk management should consider the storage, analysis, and processing of data. Furthermore, a drone equipped with smart devices, such as cameras, sensors, and actuators, may be guided to fly over a disaster area to capture high-resolution images, record video of the affected area, extend the coverage area, and sense things (e.g., wind speed, pollution, and temperature). A drone equipped with IoT could obtain accurate data quickly that can help make appropriate decisions and help SAR teams respond accordingly and perform their duty efficiently. While flying over or close to a disaster area, different types of drone technology may communicate to facilitate the event's coordination and surveillance, and SAR teams [2].

Real-time processing of the collected data by IoT devices is needed to identify the most affected areas and to assist people when human intervention is risky, impossible, dirty, dangerous, and expensive [45, 46]. Collected data will help rescue and relief teams to respond accordingly and perform their duties efficiently [45]. With IoT devices in the drone payload, it becomes very easy for disaster operations to perform their duties, even if in unreachable areas. With powerful IoT devices such as cameras, drones could collect information and pictures of the disaster area. Thus, the disaster center would get more explicit footage of the disaster without spending much money. Besides, owing to the small drone size, a drone can penetrate places that would otherwise be difficult for rescue teams or helicopters to enter and provide close-up views.

The collaboration of drones with IoT devices such as cameras (with high resolution) is suitable for creating 3D maps of a disaster area, determining mitigation options without risk, and providing clear images of potentially hazardous areas. The explicit photos and high-resolution images and videos allow the drone to create a measurable image of the disaster area with detail. Integrated technology (i.e., drones and IoT) helps the SAR team perform their tasks safely and with more efficiency. Furthermore, collaborative

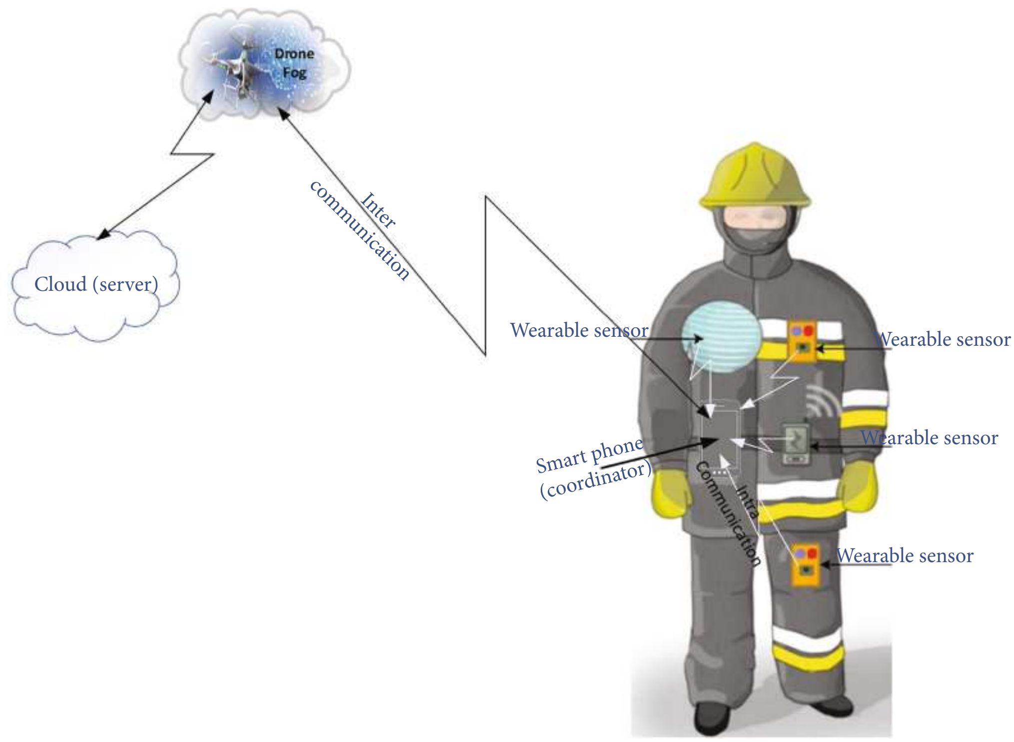

FIGURE 4: Connectivity framework of collaborative drone edge intelligence and SAR smart wearable devices during a disaster.

TABLE 2: Simulation environment.

Parameters	Value
Simulator	OPNET-14.5
Protocols	AODV
Simulation time	500 seconds
Speed	128
Update interval	500000 events
Value per statistic	100
No. of coordinators nodes	7

drones and IoT are aimed at creating a safer, smarter, and healthier society.

Traditionally, SAR is suffering from several impacts due to the need for natural support collaboration missions with people, guarantee efficient communication among the SAR team during a disaster event, and ensure the safety of SAR and people in missions. Therefore, edge intelligence drone technology will help people and first responders during the SAR mission. Smart wearable IoT devices are used to improve collaboration, communication, actuation, and monitoring of civilians and first responders in SAR missions. Therefore, the first responder should wear smart wearable IoT devices including a smartwatch, smart glasses, and smart devices that can detect the direction and motion, and biometric sensors (i.e., temperature, heart beating, pressure, and respiration) for tracking first responders, and smart devices that allow them to interact with disaster environments. The interaction between smart wearable IoT devices and the environment will improve the location, tracking, awareness, hazard alarm, and victims SAR. Smart wearable IoT devices will not only be used for gathering data from the surrounding environment but also they can also be used for monitoring the responders' activities in disaster areas. The collected data from smart wearable IoT devices are used for improving evacuation plans, SAR, and collaboration among the SAR team. Collaboration drone edge intelligence and SAR teams found simulated victims quicker due to the drone help. Drone edge intelligence offers enormous potential to assist SAR efforts. Drone edge intelligence and SAR collaboration enable affordable drone technology to expedite SAR missions as teams are faced with risk, resource constraints, and time. Collaborative drones fog, trajectory, tracking, and mission progress can play a vital role in relaying to SAR team centers for immediate operational and analysis of the observation.

5. Proposed Scenario

The proposed network architecture includes drones, IoT devices, the ad-hoc network, the SAR team, and the disaster center unit. Our proposed scenario is suitable for all disaster stages. Drones equipped with IoT play vital roles in disaster preparedness. For example, sensors in the drone board are used to collect physical information, such as the water level, vibration, displacement in a disaster area, and forwarding data to the disaster center unit. In addition, the camera is used to capture predictions of the affected area. Therefore, in this study, data collection by a drone equipped with IoT devices was analyzed for SAR operations' future help.

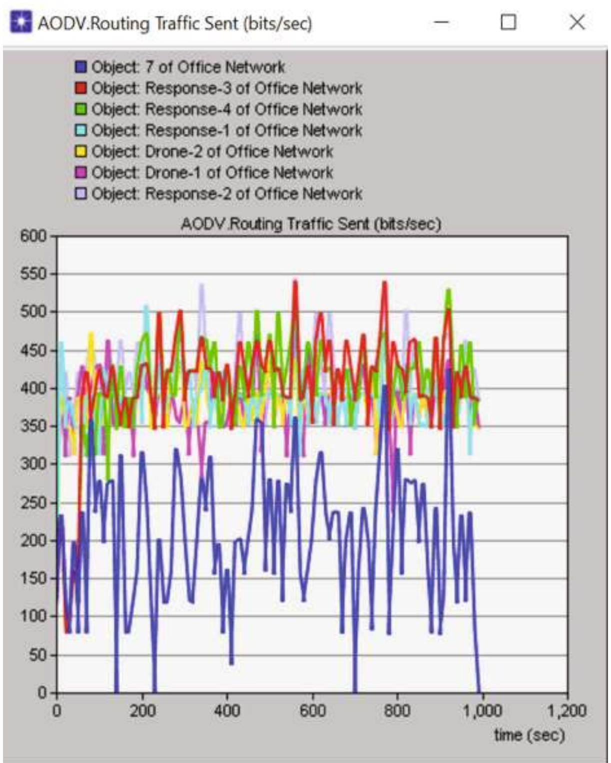

FIGURE 5: Routing traffic sent of different node in proposed scenario.

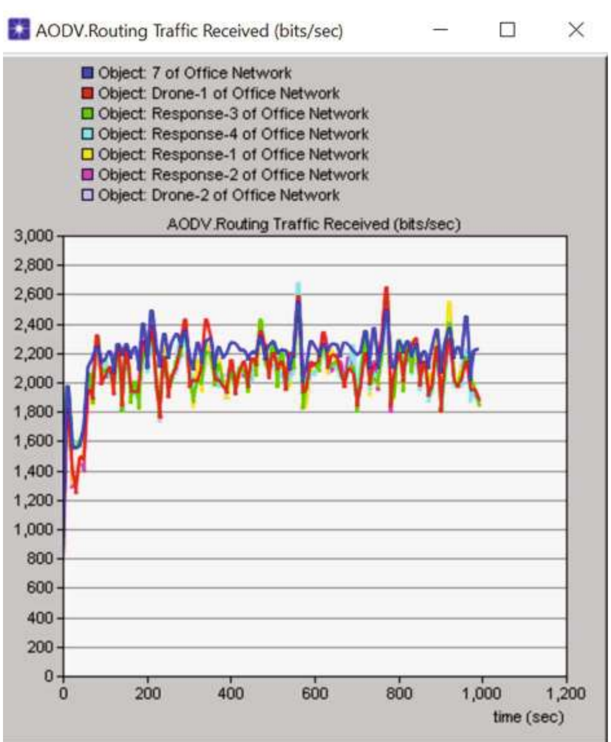

FIGURE 6: Routing traffic received of a different node in the proposed scenario.

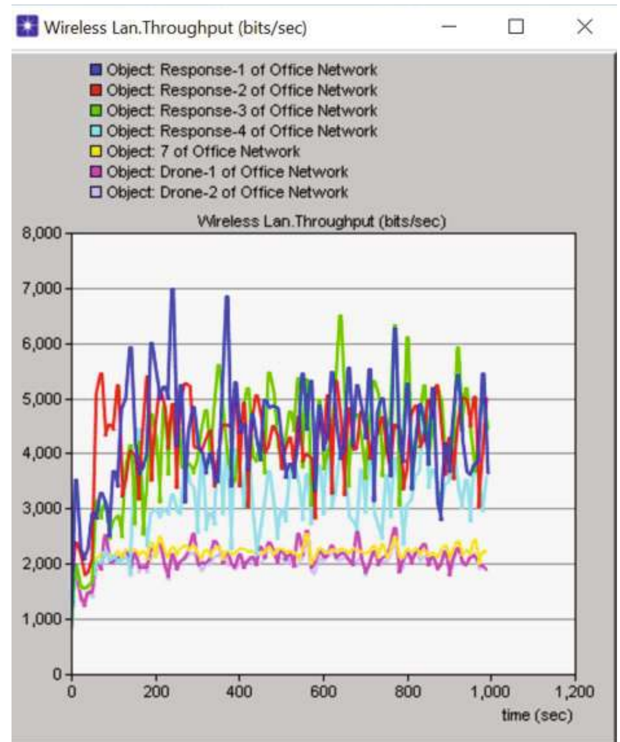

FIGURE 7: Throughput of a different node in the proposed scenario.

Our proposed collaboration network provides accurate and appropriate assistance for managing disasters and coordinating the SAR team according to updates on the disaster event during a disaster. Then, it can identify the SAR team's location (using IoT devices) and provide them with a safe and smooth path to reach the disaster area safely and perform their duties effectively and efficiently. In addition, the ad hoc network helps to reconnect and deliver disjointed communication services.

In the recovery stage, a drone equipped with IoT devices helps with relief missions and supply delivery. Data collected by a drone equipped with IoT devices improves the efficiency of the SAR mission executed by the drone. Furthermore, the data collected can be used to evaluate the damaged area and identify the requirements for reconstruction. In this stage, the ad hoc network gives the central disaster unit feedback about safe areas and evacuation routes based on the information gathered by a drone equipped with IoT devices.

Our contribution focuses mainly on maintaining the connection between the drones and the SAR team with IoT wearable devices during a disaster and its aftermath. The ad hoc network connects heterogonous groups or mobile nodes with drones and drones with the disaster unit center for data transformation in real time, as shown in Figure 3. Heterogeneous teams include drones, the SAR team, the relief team, people inside the affected area, and the disaster center. The proposed collaboration technologies are built for effective disaster preparedness and recovery. They satisfy several features such as real-time imaging, real-time deployment, the production of high-resolution images, energy

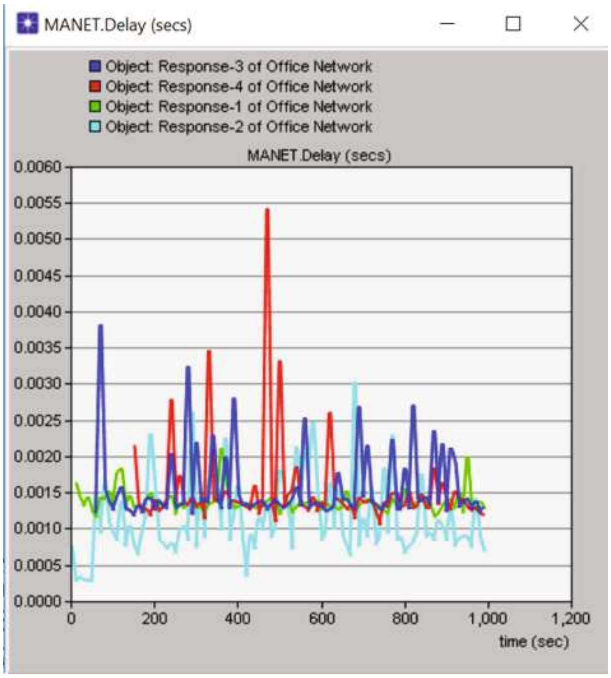

Figure 8: Delay of a different node in the proposed scenario.

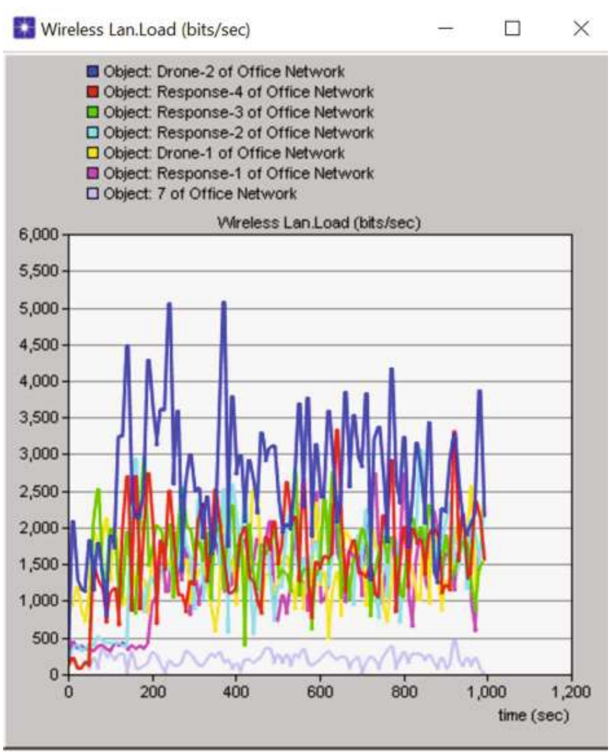

Figure 9: Load of a different node in the proposed scenario.

efficiency, connectivity, and reliability. Figure 4 shows smart wearable devices placed in the SAR body to identify the SAR status and location. Furthermore, it can sense the environment and send data to drone edge intelligence for analysis and forward action to SAR.

Table 3: Routing traffic sent for different nodes.

Object	Min	Avg	Max	Std Dev
Sever	0	195.46	425.6	92.316
Res-3	80	398.05	540.8	80.71
Res-4	80	393.6	531.2	82.38
Res-1	115.2	381.76	512	45.513
Drone-2	115.2	375.84	480	41.126
Drone-1	195.2	372.35	476.8	44.984
Res-2	230.4	412.67	544	49.609

5.1. Evaluation of the Performance Metrics of a Collaboration Network. The performance metrics of the proposed network, such as network load, throughput, delay, and traffic sent and received, are taken into consideration to evaluate the collaboration between drones and SAR to study the effects on the collaboration network.

5.1.1. Load. The load is referring to the amount of data traffic being carried by the collaboration network. Also, network load refers to a weight distribution system through network designing infrastructure [47], so it utilizes the most effective network protocol to overcome congestion. The network can face acute congestion as all the available resources are overutilized and overburdened. The authors of [48] calculated the network load based on computing the ratio of the volume of data received, and maximum data fluctuated within simulation time. However, the measured network load is given by [48], as shown in the following.

$$\text{Network load} = \frac{D_r}{bs - bu - (D_r - D_s)}, \tag{1}$$

where D_r and D_s represent data received and data sent, respectively. Although bs and bu represent buffer size and buffer unavailable, respectively.

$$\text{if } 0 \ll bu(t_0) \ll bs. \tag{2}$$

Then, equation (1) equals to

$$\frac{\int_{t_0}^{t} fD_r(t)dt}{bs - bu(t_0) - \int_{t_0}^{t} fD_r(t)dt - gD_s(t)dt}, \tag{3}$$

where $fD_r(t)$ and $gD_S(t)$ represent the receiving and sending time at rate t, respectively.

5.1.2. Throughput. Throughput refers to the ratio of total amounts of data reached to receiver from the source during the time taken by the receiver to receive the last packet [49]. Mobile ad hoc network requires for high throughput during a disaster event, which mathematically calculated by

$$\text{Throughput} = \frac{\text{delivered packets} \times \text{packet size} \times 8}{\text{Total simulation period}}. \tag{4}$$

Table 4: Routing traffic received for different nodes.

Object	Min	Avg	Max	Std Dev
Res-2	771.2	2,029.10	2,627.20	241.47
Drone-1	806.4	2,051.80	2,649.60	246.67
Sever	8 48	2,181.20	2,553.60	207.58
Res-3	848	2,046.30	2,620.80	218.41
Res-4	848	2,039.60	2,678.40	211.89
Res-1	848	2,036.50	2,595.20	242.81
Drone-2	848	2,011.40	2,476.80	220.66

Table 5: Throughput for different nodes.

Object	Min	Avg	Max	Std Dev
Drone-1	806.4	2,077.10	2,679.20	265.7
Res-1	848	4,253.90	7,004.80	997.9
Res-3	848	4,066.20	6,517.60	1,050.60
Res-4	848	3,046.10	4,840.80	718
Sever	848	2,181.80	2,553.60	208.2
Drone-2	848	2,011.40	2,476.80	220.7
Res-2	1,493.60	4,172.80	5,469.60	821.1

Table 6: Delay for different nodes.

Object	Min	Avg	Max	Std Dev
Res-2	0.000275	0.001127	0.003029	0.000525
Res-4	0.001078	0.001499	0.005436	0.000585
Res-1	0.001174	0.001367	0.002112	0.000147
Res-3	0.001183	0.001542	0.003814	0.000471

Table 7: Load for different nodes.

Object	Min	Avg	Max	Std Dev
Sever	0	196	483.2	93.92
Res-4	80	1,547.90	3,355.20	667.15
Res-3	80	1,537.20	2,964.00	585.02
Drone-2	115.2	2,591.00	5,092.80	899.08
Res-1	115.2	1,248.20	2,761.60	606.5
Res-2	230.4	1,414.80	3,074.40	649.48
Drone-1	499.2	1,408.10	2,565.60	457.66

5.1.3. Delay. The packets' average time to pass through the collaboration network from the source up to the destination is called end-to-end delay. On the other meaning, delay specifies how long it takes for a bit of data to travel across the network from sender to receiver. Hence, all the delays in the network are called the end-to-end packet delay. We have several kinds of delays D_{E-E} such as processing delay D_p, transmission delay D_t, and propagation delay D_d. If there are N number of nodes, then the total delay can be calculated by taking the average of all the packets, source-destination pairs, and network configuration.

$$D_{E-E} = N \times \left(D_p + D_t + D_d\right). \tag{5}$$

6. Result and Discussion

The OPNET 14.5 simulator was used in our simulation. The parameters used for simulation are shown in Table 2. The proposed scenario consists of two drones, four responders (SAR) and a server (data collection center). Due to mobile ad hoc network (MANET) technology's autonomous nature, we propose the connection of the SAR team and drones for performing the tasks effectively and efficiently. Furthermore, the ad hoc on-demand distance vector (AODV) routing protocol is considered for unicast and multicast routing services. The simulation time is 1000 seconds. One drone is moving around and closer to the events as shown in Figure 3. This drone will capture the event's images and share them with the SAR team inside the flooded area to allow them to perform the appropriate actions according to the available data. Drone-2 is used to deliver the supplies required by responders or people in a particular disaster area. (Note that Res stands for responder) Res-1, Res-2, and Res-3 guide drone-1 and their wearable IoT devices help drone-1 and drone-2 to identify their locations.

The evaluation of the network's performance considers many metrics such as the delay, routing traffic sent and received, load, and throughput, as shown in Figures 5–9. All figures show the performance metrics for drones and responders during the disaster event. The sent and received routing traffic is measured for each device and drone, as shown in Figures 5 and 6, respectively. Both figures show the efficient performance of sending and receiving traffic between collaborative drones and responders. Furthermore, Tables 3 and 4 show the minimum, maximum, average, and standard deviation (Std Dev) traffic sending and receiving. The maximum traffic sent is changed from 540.8 bits/-sec at Res-3 to 425.6 bits/sec at the server as shown in Table 3. The maximum traffic received changes from 2678.40 bits/sec at Res-4 to 2476.80 bits/sec at drone-2 as shown in Table 4.

The throughput represents the total data traffic successfully received in bits per second, which is forwarded to the drones. Increasing the size of the packet through all nodes leads to increased throughput. Therefore, increasing the packet size leads to different throughputs, as shown in Figure 7. However, the throughput decreases when the number of nodes increases. Each node has a different throughput, and Table 5 shows the minimum, maximum, average, and standard deviation (Std Dev). The maximum throughput changes from 7004.80 bits/sec at Res-1 to 2553.60 bits/sec at the server. Also, the average throughput changes from a maximum of 4253.90 at Res-1 to 2011.40 at drone-2.

The time delay is affected by the increasing number of wireless nodes and will decrease with the increase in packet size through all the different numbers of nodes, as shown in Figure 8. Each node has a different path and different delay according to the distance between the drone and that particular node. In the case of minimum delay, Res-2 has the lowest delay, but Res-3 has the highest minimum delay. However, drone-1 and drone-2 have no delay due to the line of sight. Table 6 illustrates the average and maximum delays for each node. It is shown that the delay is very low and is significantly enhanced. Also, Table 7 is shown the traffic load between different nodes according to drones.

7. Conclusion

Drones have become one of the most promising and powerful new technologies to enhance disaster operations (i.e., response, rescue, search, and relief). Therefore, during a disaster, the combination of drone and IoT devices will be used to provide relief team with better situational awareness, Therefore, we examine the network performance of drone edge intelligence and SAR (smart wearable devices) for disaster management. The evaluation of the performance is based on the network connectivity i.e., delay, load, and throughput. The network performance metrics such as delay and throughput, can help in guiding SAR to perform tasks efficiently during disaster management. The results show that the collaboration of drone edge intelligence and SAR with ad hoc network allow 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. Furthermore, the connectivity between drone edge intelligence and SAR significantly improved based on network performance metrics. In the future, machine learning techniques could be used in drones 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. Furthermore, transmission and processing of the image to drone edge intelligence may be considered in future studies.

Data Availability

No available data.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 847577 and a research grant from Science Foundation Ireland (SFI) under Grant Number 16/RC/3918 (Ireland's European Structural and Investment Funds Programmes and the European Regional Development Fund 2014-2020). The authors are grateful to the Deanship of Scientific Research at Taif University, Kingdom of Saudi Arabia, for funding this project through Taif University Researchers Supporting Project (no. TURSP-2020/265).

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