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Survey on Collaborative Smart Drones and Internet of Things for Improving Smartness of Smart Cities

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ABSTRACT Smart cities contain intelligent things which can intelligently automatically and collaboratively enhance life quality, save people's lives, and act a sustainable resource ecosystem. To achieve these advanced collaborative technologies such as drones, robotics, artificial intelligence, and Internet of Things (IoT) are required to increase the smartness of smart cities by improving the connectivity, energy efficiency, and quality of services (QoS). Therefore, collaborative drones and IoT play a vital role in supporting a lot of smart-city applications such as those involved in communication, transportation, agriculture,safety and security, disaster mitigation, environmental protection, service delivery, energy saving, e-waste reduction, weather monitoring, healthcare, etc. This paper presents a survey of the potential techniques and applications of collaborative drones and IoT which have recently been proposed in order to increase the smartness of smart cities. It provides a comprehensive overview highlighting the recent and ongoing research on collaborative drone and IoT in improving the real-time application of smart cities. This survey is different from previous ones in term of breadth, scope, and focus. In particular, we focus on the new concept of collaborative drones and IoT for improving smart-city applications. This survey attempts to show how collaborative drones and IoT improve the smartness of smart cities based on data collection, privacy and security, public safety, disaster management, energy consumption and quality of life in smart cities. It mainly focuses on the measurement of the smartness of smart cities, i.e., environmental aspects, life quality, public safety, and disaster management.

INDEX TERMS ICT, smart city, energy consumption, smart drone, IoT, pollutions, gathering data, IoD, disaster, public safety, security and privacy, collaborative drone, IoT.

I. INTRODUCTION

In the context of smart cities, the smartness measurement is related to quality of life, healthcare, public safety, disaster management, environmental aspects (such as energy efficiency, air quality, traffic monitoring, etc.), and services. Consequently, advanced and modern Information and Communication Technologies (ICT), Artificial Intelligence (AI), and robotics play vital roles in making cities smarter. These technologies help improve the infrastructure of smart cities and make smart services possible in order to improve the overall quality of life of the residents. An important aspect of smart cities is the provision of efficient infrastructure and the reduction of the cost of services while making such services and facilities ubiquitous. Recently, several studies have been conducted to enhance the characteristics of smart cities [1], [2] in different domains [3] and different aspects [4], [5], and with a focus on sustainability [6], [7]. A common undercurrent that runs in all of these studies is the fact that efficient integration of smart services and ICT solutions is required. More recently, drone technology has significantly contributed to making a city smarter. Presently, it is difficult to envisage a smart city without drone services [8].

Drones are autonomous robots that fly in the sky and are associated with different applications in civilian society

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such as communication, transportation, agriculture, safety and security, disaster mitigation, environmental protection, intelligence gathering, surveillance, and reconnaissance operations. Drones are poised to become an integral part of smart cities and improve overall life experience in the sense of monitoring pollution, accident investigation, fire-fighting, package delivery, supporting first responder activities, delivering medicine, monitoring traffic, and supervising construction sites. Drone technology can further lead to enormous secondary benefits such as reducing power consumption, conserving resources, reducing pollution, accessing hazardous and disaster areas, and increasing preparedness for emergencies. Advances in technologies in the area of sensors, data processing, and rechargeable batteries have made drones more affordable. Drones can also act as aerial base station (BS) to deliver communication services (both uplink and downlink) for the subscribers on the ground. Agility and line-of-sight (LoS) are the features that have made drones play an essential role in the Internet of Things (IoT) framework.

The advent of IoT has enabled significant advances in smart cities applications such as smart homes, smart streets, smart parking, smart power grids, etc. The main idea of IoT is that everything can connect and communicate over the Internet, for example,smartphones, buildings, home appliances, vehicles, and even natural objects, creating a smart world and vast global infrastructure for an information-driven society. The development of such applications has become critical to our lifestyles, the economy, and the environment. Apart from economic growth, the overall development of a geographical entity is also driven by green technologies which protect the environment from harmful emissions and hazardous wastes, conserve natural resources, mitigate the consequences of climate change, and reduce pollution and power consumption. A massive number of IoT devices which can cooperate, communicate and share information, is the needed for modern smart city infrastructure. Considering that a large number of interconnected devices is required, the minimization of operating costs and power conservation strategies is becoming more and more critical [9]–[11]. Load balancing also plays a vital role in enhancing the lifetime of the network by reducing the over-consumption of energy by smart devices.

Drones can move dynamically towards the IoT devices and collect data, establish a real-time connection, process the data and transmit information over to the collection nodes or other devices [12]. The efficient deployment and mobility of drones to collect data from IoT devices on the ground with minimum transmit power and enhanced communication reliability and connectivity were investigated in [13], [14]. It was reported that IoT transmitted power can be reduced by 45% while increasing the yield to a maximum of 28% [13]. Also, in another related work, a drone was considered the middleware for energy efficient discovery in the IoT and sensor networks [15]. The proposed technique provided an efficient energy model to offer IoT and sensor network solutions. Furthermore, Motlagh et al. [16] proposed a steering technique among multiple 4G networks to ensure reliable connectivity of smart devices with drones, which supports a high quality of service (QoS) and consumes an acceptable amount of energy. Mozaffari et al. [17] proposed a multi-clustering technique of IoT devices wherein each cluster was served by one or more drone. Due to the use of drones, the transmitted power of the IoT devices reduced by 56% compared to the fixed Voronoi deployment method. In this particular case, drones were used to enhance the energy efficiency because the transmission range of IoT devices was limited [18]. Furthermore, the collaborative wireless network between drones and IoT devices plays a vital role in providing an efficient solution to the routing loop problem in traditional sensor networks, and enhancing the lifetime of the sensors through optimal division of the load. However, these solutions rely on the formation of an optimal topology and routing scheme for utilization of the coordination between the drones and the Wireless Sensor Network (WSN).

Briefly, as shown in Fig. 1, a collaboration between drones and IoT can provide broad applications in smart cities such as the monitoring of large areas, border surveillance, data gathering, public safety, disaster management, and obstacle avoidance [19]. Figure. 1 shows the collaboration of drones and IoT for several applications of smart cities such as gathering data from IoT devices for energy efficiency, collecting pollution data and predicting the air quality, monitoring sport events, generating high resolution 3D maps, providing security, disaster management for saving people's lives, delivering services such as food and blood in real time, and monitoring accidents and victims.

A. RELATED WORK

Many studies have surveyed technologies and strategies related to enhancing the smartness level of smart cities by using drones in different applications [17], [20]–[29]. The smartness of smart cities has been evaluated on several factors such as smart living, smart environment, smart people, smart economy, smart mobility, smart tourism, smart governance and so on. Mohamed *et al.* [24] reviewed the potential applications of, and technical issues arising from, integrated drones in smart cities. Furthermore, they discussed the enabling technologies which have been developed to support the integration of drone in smart cities. The authors of [21] summarized the enabling technologies that could be used for green IoT for making smart cities smarter and greener.

The authors of [23] described drone-enabled intelligent transportation for a smart city. They also highlighted the potential applications and challenges for drone-enabled intelligent transportation for next generation smart cities. Alam *et al.* [20] presented an architecture of an intelligent transportation system with distributed and decentralized decision making to make streets smarter by smart parking. Under this system, traffic management would be managed efficiently in smart cities by locating the vacant parking slots and communicating this information to drivers in a given area.

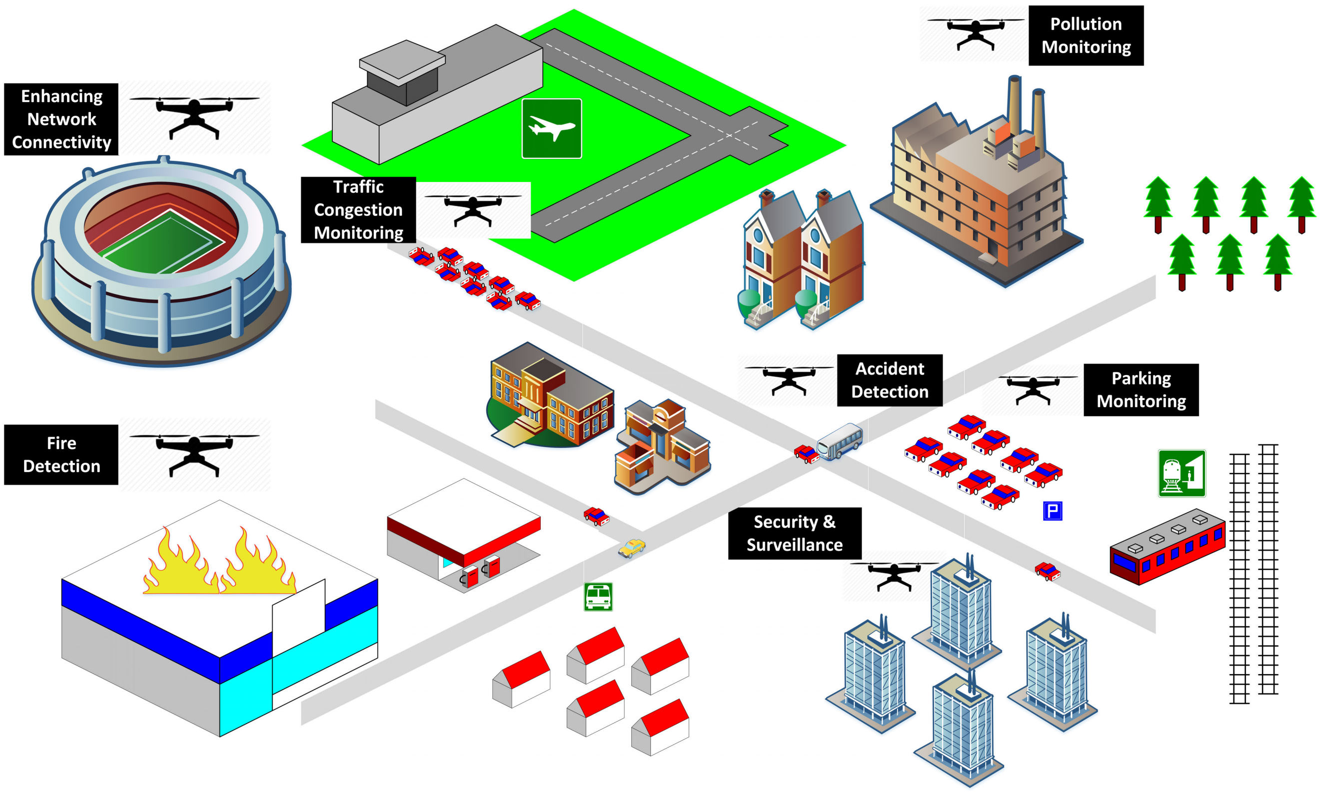

FIGURE 1. Collaborative drone and IoT for improving the smartness of smart cities.

Furthermore, the authors of [29] discussed various frameworks for smart cities monitoring based on smart drones. Authors of [22] surveyed the potential physical– and cyber–threats which might arise from the use of drones in different ways to track, detect, and interdict malicious drones. The authors of [28] reviewed various aspects of drone usage such as privacy, cyber-security, and public safety in future smart cities.

Motlagh *et al.* [26] highlighted and reviewed drone architecture for delivering IoT services from a drone. Furthermore, they discussed the use of drones equipped with IoT devices such as Radio Frequency IDentification (RFID), sensors, and cameras that are used for data collection. The authors of [25] introduced the concept of drones-equipped with IoT devices for delivering services to a large coverage area from a drone in the sky. They mainly discussed how a drone could be used for crowd surveillance based on face recognition. Furthermore, they compared video data processing on the drone payload and mobile edge computing node. The findings demonstrated the efficiency of the mobile edge computing based offloading technique in the context of processing time, and energy consumption. The authors of [17] described how swarm drones could be used for collecting data from IoT devices on the ground to minimize the transmission power from IoT devices. Each drone was shown to deliver services to a cluster of IoT devices on the ground by taking the mobility of IoT devices in smart cities into consideration. The authors of [18] extended the collaboration between drone-enabled connectivity and IoT. A drone was considered to serve the ground users such as download users and device-to-device users. The findings showed that the usage of device-to-device users fell with an increase in the drone height because of the fact that a greater distance from the drone increased the path loss.

Processing the collected data onboard a drone is required for several operations such as image processing, path monitoring and control, and dynamic sense. The authors of [30] designed powerful and useful devices for processing data with low power consumption. The authors of [31] applied machine learning schemes to images captured by drone-based IoT devices such as cameras. The Convolutional Neural Network (CNN) with the Support Vector Machine (SVM) was used to identify the exact videos and images taken by IoT devices on the drone.

Briefly, the surveys conducted in [26] and [25] were primarily limited to architectures for delivering IoT services from drones. Similarly, the surveys conducted in [20], [23] were restricted to intelligent transportation in smart cities by using a drone. The studies in [27] and [22] focused on the applications and benefits of drones for wireless telecommunication. Furthermore, the studies detailed in [24] and [21] looked at the enabling technologies that integrate drones and smart cities to make them smarter and greener. Besides, the authors of [28] only discussed the drone applications for

TABLE 1. Comparison of surveys highlighted and current work.

Ref.	IoT	Drone	Drone & IoT	Smart cities	Security & privacy	Energy consumption	Gather data	Public safety	Life quality	Disaster management	Highlighted
[17] (2016)	⋆	⋆	⋆			⋆	⋆				Swarm drones for data collection from IoT devices
[18] (2016)	⋆	⋆	⋆			⋆	⋆				Connectivity of drones and IoT devices
[24] (2018)		⋆		⋆							Integrated drones in smart cities
[23] (2017)		⋆		⋆					⋆		Drones enabled intelligent transportation for a smart city
[26] (2016)	⋆	⋆	⋆								Drone architecture for delivering IoT services
[21] (2018)	⋆			⋆		⋆			⋆		Enabling technologies to reduce pollution, energy consumption, and resource usage of IoT.
[20] (2018)	⋆			⋆			⋆		⋆		Traffic management in smart cities
[25] (2017)	⋆	⋆	⋆	⋆			⋆		⋆		Drone-based IoT platform for crowd surveillance in smart cities
[29] (2018)		⋆					⋆				Smart cities monitoring based on smart drones
[32] (2019)	⋆	⋆	⋆	⋆			⋆	⋆		⋆	Collaboration between drones and IoT for public safety in smart cities
[33] (2016)	⋆			⋆			⋆				Collaboration between the fog cloud of IoT devices
[34] (2016)	⋆	⋆	⋆	⋆				⋆	⋆	⋆	Drone connected IoT devices in smart cities applications
[8] (2014)											Applications and opportunities for drones in smart cities.
[28] (2016)		⋆		⋆	⋆			⋆			Drone usage for privacy, cybersecurity, and public safety in the future of smart cities
[35] (2013)				⋆	⋆						Enhancing citizen privacy in smart cities
[36] (2014)		⋆		⋆	⋆						Drone controls, co-regulation, self-regulation and formal laws for various applications
[37] (2017)	⋆			⋆	⋆		⋆				Integration of various technologies for enabling smart cities such as IoT, cloud computing and communication network technologies
[38] (2016)				⋆	⋆						Privacy and security challenges in smart cities
[39] (2018)	⋆	⋆	⋆	⋆	⋆		⋆		⋆		Securing and decentralizing swarm behavior of drones for smart cities
[21] (2018)	⋆	⋆		⋆		⋆	⋆		⋆		Enabling technology to green IoT for making smart cities smarter and greener
This work	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	Collaborative drones and IoT for improving the smartness of smart cities

privacy and public safety, while the monitoring issues in a smart city were discussed in [29]. In short, the existing literature on collaborative drones and IoT for smart cities applications is fragmented and calls for a comprehensive overview of how the collaboration between drones and IoT can indeed be used. Surprisingly, no review has been thoroughly carried out considering the importance of drone collaboration and IoT, to improve the smartness of smart cities, and its applications. In light of the above discussion, a comparison of related work is shown in Table 1.

B. CONTRIBUTION

The main contribution of this paper is the provision of a comprehensive overview of collaborative drones and IoT applications for smart cities. Toward this aim, the approach is to gather the available research contributions from the sparse literature on drone-based IoT, that addresses the applications, challenges, and opportunities of drone collaborations with IoT frameworks for improving life quality in smart cities. To the best of our knowledge, this survey constitutes one of the first comprehensive surveys on

FIGURE 2. Survey contributions.

how to fully exploit the potential of collaborative drones and IoT applications for improving the smartness of smart cities. Also, we highlight the drone's potential for delivering IoT services from the sky. In order to achieve the aim of this paper, we address the following key topics, as shown in Fig. 2:

- In section II, we present a comprehensive overview of the collaboration of drones and IoT.
- In section III, we provide a discussion on security and privacy issues, as well as promising solutions associated with the collaboration of drones and IoT for enhancing the smartness of smart cities.
- In section IV, we discuss how collaborations between drones and IoT devices could be used to reduce energy consumption and increase the smartness and greening of smart cities.
- In section V, we outline the crucial role of collaboration between drones and IoT in gathering data. The collection of smart data and on-board processing in real-time plays a vital role in enhancing smart city applications.
- In section VI, we highlight how IoT and drone collaborations could be leveraged for improving life quality by controlling the pollution hazards of smart cities.
- In section VII, we discuss issues related to public safety in smart cities, and determine how a collaborative arrangement between drones and IoT may help.
- In Section VIII, we introduce the collaboration of drones and IoT for disaster management in smart cities.
- In section IX, we provide a summary of the applications of drone and IoT collaboration for smart cities.
- Lastly, discussion and future directions are highlighted in Section X.

II. OVERVIEW OF THE COLLABORATION BETWEEN DRONES AND THE IOT

Collaboration between advanced technologies is about sharing information for performing common tasks effectively and efficiently according to needs. The benefits and applications of drones in wireless telecommunication were presented in [27]. Therefore, the collaboration of IoT devices for sensing data leads to an increase in the accuracy of data collection by exploiting the similarity of capturing data from multiple IoT devices [40]. Collaboration within the fog cloud of IoT devices was discussed in [33]. The authors of [8] presented the applications, challenges, and opportunities for drones in smart cities. Several challenges were discussed, such as privacy, safety, and ethical use. Furthermore, the issues of cybersecurity, public safety, and privacy of drones for smart cities were discussed in [28].

A. SMART DRONES

A drone has unique characteristics. It is dynamic, easy to repair, easy to deploy, and able to measure a multitude of quantities from anywhere at any time. It is a low-cost solution for collecting and delivering information to intelligent mechanisms/software capable of performing the required data analysis (such as analyzing the image or video in real time). The usage of the drone will dramatically facilitate the development of farming, defense, insurance inspection, law enforcement, emergency aid, pollution monitoring, disaster recovery, parcel delivery, and many other industries. Therefore, drones play a significant role in our connection with society as well as improving the quality of life in smart cities. The number of drones in the air is expected to grow rapidly in the coming years. Drones have enormous potential to enable many applications related to military, civilian, governmental sector and commercial aspects, due to their capability to perform complex tasks effectively and efficiently in real time. Jensen [41] introduced the drone phenomenon and its potential application for smart cities. He explored the connectivity issues related to drones for smart cities and discussed how drones would enhance smart cities applications, such as tracking, surveillance, and object detection; general purpose distributed processing application; data collection; path planning; navigation; and collision prevention, as shown in Fig. 3. Furthermore, the authors [42] discussed the convergence of several machine learning techniques for path planning effectively and efficiently to enhance the connectivity, mobility, and QoS.

A group of drones represents a cluster which uses the Flying Ad-hoc NETwork (FANET) technology for communication among its members, and also for sharing data gathered (by the onboard IoT devices) with other IoT devices on the ground. Using their inherent properties of ability, mobility, and agility, drones can efficiently enhance the QoS of 5G cellular networks. Also, they have been deployed to improve wireless capacity and coverage at temporary events such as sports, disaster recovery, crime monitoring, etc. [43]. Drones have also been used to enable the communication when

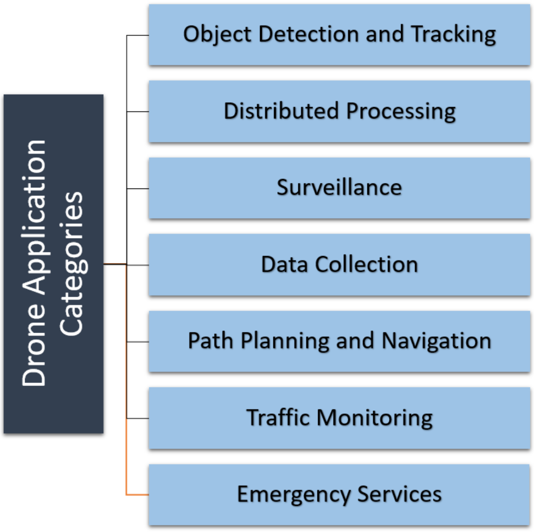

FIGURE 3. Drone applications categories.

traditional wireless networks are destroyed to support disaster relief activities [44]. Similarly, Merwaday and Guvenc [45] explored the use of a drone BS as a temporary station during a disaster relief operation. In addition to the work of [44], [45], Bor-Yaliniz and Yanikomeroglu [46] envisioned a drone cellular network which is capable of bringing the delivery of wireless networks to anywhere based on demand and at any time. Authors of [47] considered drone as a sink node in a wireless communication network for collecting data from sensors. The optimization of the drone network service area was also investigated.

A drone payload may contain an on-board computer, and sensors connected to other devices, which allow humans to control it. Furthermore, it can be programmed to carry out tasks, and fly itself according to the guidance of its internal systems. Also, it can be controlled by using remote computers to carry out the tasks of physical security and agriculture. Drones can also provide effective help to track deforestation and monitor environmental parameters such as air and water quality. Furthermore, small tracking devices, which can be monitored through drones, are used to observe and quantify endangered species.

Smart drones must be designed to achieve the convergence of four aspects which are data, connectivity, services, and type of devices used. Smart drones are being used to support first responders' tasks, document accident scenes, and monitor construction sites, and therefore, drones are poised to become an integral network part of smart cities. By promising a connected society and cheap storage, processing, and robotics, drones are leading the way toward a revolution in smart cities.

B. DRONE, ICT, AND IOT FOR SMART CITIES

Information and Communication Technologies (ICT) have evolved into a diverse ecosystem, which combines robots, sensors, communication technologies, software, humans and real-time processing. For instance, Amsterdam is using ICT for maintaining a sustainable lifestyle, while London is using ICT to process waste and ensure proper utilization of resources. Furthermore, ICT plays a vital role in improving smart cities, but the security challenges need to be managed because of their inherent part of ICT [59]–[61]. Drone technology is the future of IoT and is slated to provide a revolution in IoT developments and applications especially in smart cities. Some researchers even consider the drone to be an essential IoT device [62], [63]. Furthermore, IoT devices have also been used to enhance the potential tasks of swarm drones for providing autonomous cooperation [64]. With the advances in ICT, IoT presents a high potential to bolster economic and environmental sustainability [9]. These hot and green technologies, such as machine to machine (M2M) communications, sensors, RFID, 5G cellular networks, etc., make the cities greener and smarter [14]. An evaluation of the impact of ICT on important issues with environmental concerns (e.g. power consumption and CO_2 emissions) was presented in [21], [65].

1) DRONES AND RFID

RFID is considered one of the most promising wireless communication systems used to enable IoT. Furthermore, it does not need LoS and can map the real world into a visual map very easily [66]. RFID devices can be classified as passive and active [66]. RFID plays a vital role that helps the world to be greener by reducing the emissions of the vehicle, saving energy and improving waste disposal, etc. Reducing the size of RFID tags and producing energy efficient algorithms for optimizing tag estimation are required for green RFID [66]–[70].

Hubbard *et al.* [48] discussed the combination of drone and RFID technologies, and focused on enhancing the lifetime of drone battery and RFID reader detection range. The advantage of combining drones and RFID is the provision of additional information that can be implemented in supply chain management systems. Similarly, the authors of [49] proposed a feasibility analysis of how it is possible to recharge a multipurpose RFID tag using a drone in an environmental monitoring operations. Furthermore, the study in [50] presented a solution for monitoring operation in harsh environments using RFID with a drone. It proposed a set of RFID tags that can be equipped with various sets of sensors and distributed over the monitored area with a reader installed on the drone. The main idea of using a drone is to collect data from the RFID sensors scattered throughout the area by directly approaching them, flying above them, and downloading measured data [50]. Previous findings show that the system works coherently and tags can be powerful monitoring instruments, especially where the monitoring is needed for a large area or a harsh environment. Choi *et al.* [51] studied the drone indoor localization technique using passive Ultra-High Frequency (UHF) far-field RFID systems. The study aimed to achieve simple and cost efficient for drone tracking and localization.

2) DRONES AND SENSORS

A sensor node is a combination of an enormous number of small sensing devices, power sources, processing equipment and communication unit(s), which has been discussed in detail in [71]. Sensor nodes are being deployed around the world to measure local and global environmental conditions. They have limited power and low processing as well as small storage capacity, while Base Station (BS) node is powerful. Each sensor node reads parameters such as temperature, sound, pressure, humidity, acceleration, etc from its surroundings. Sensors also communicate with each other and deliver the needed sensory data to the BS using ad-hoc technology. Mehmood and Song [72] discussed smart energy, efficient routing communication protocols for WSN concerning the design trade-offs. WSNs have been used in various applications in smart cities such as fire detection [73]–[75], object tracking [76]–[78], environmental monitoring [52], [71], [79], [80], routing and load-balancing [81], [82], evolving constraints in the military [83], control and monitoring of machine health, and industrial process monitoring [71].

The idea of green IoT has arisen for keeping sensor nodes in sleep mode for most of their life to save energy [84], [85]. WSNs can be realized very simply when data communication occurs at ultra-low power. Sensors can utilize energy harvested directly from the environment such as the sun, vibrations, kinetic energy, temperature differentials, etc. [86]–[88]. Therefore, green WSN is an emerging concept in which the lifespan and throughput performance are maximized while the CO_2 emissions are reduced. The goal of WSN is to supply sufficient energy to enhance the system lifetime and contribute to reliable/robust transmission without compromising the overall QoS. Zhao *et al.* [89] proposed a QoS routing path selection scheme for wireless community mesh networks in which the quality of the channel is monitored and can be used to enhance the communication efficiency in smart cities. The study detailed in [11] proposed an optimization method for the implementation for an energy efficient and scalable IoT. The technique introduces a hierarchical network design, a model for the energy efficient IoT and a minimum energy consumption transmission algorithm to implement the optimal model. The results show that the technique is more energy efficient and flexible than the traditional WSN technique and consequently it can be implemented for efficient communication in the green IoT.

Similarly, to improve energy efficiency of WSNs, the authors of [90] investigated a technique that showed a significant improvement in energy savings and reduced the delays. In addition to the work of [11], [90], the study in [91] focused on increasing the energy efficiency, extending the network's lifetime, reducing of some relay nodes, and reducing the system budget for green IoT. The work was implemented in four steps. First, a hierarchical system framework was created and sensor/actuator nodes, relay nodes, and BS were placed. The second step was node clustering. The third step was the creation of an optimization model to realize IoT, and finally, the fourth step was the calculation of minimal energy among the nodes. The findings show that the proposed approach is pliable, energy-saving and cost-effective when compared with the existing WSNs deployment scheme. Furthermore, the study in [92] investigated wireless energy harvesting, the wake-up radio scheme, and error control coding to enable solutions for enhancing the performance of green WSNs while reducing their carbon footprint.

IoT sensor networks are required for a large number of sensors deployed over large areas. The collection of data from each sensor in an IoT based sensor network is difficult as it generates a tremendous volume of sensing data and requires drones to follow along long routes resulting in high energy consumption, higher delays, and exposure to hazardous environments. Therefore, the use of drones has been proposed for IoT sensor networks. To enhance the functionality of the drones, Malaver *et al.* [93] presented the development of integration of a WSN and a drone-powered by solar energy to improve their versatility for different applications. The CO_2 concentration was also monitored in real-time during data collection by using the integrated system. This system was applicable and recommended for different applications such as agriculture, mining studies, bush-fires, and zoological and botanical studies [94]. Furthermore, the particle swarm optimization technique (PSO) was used to analyze data gathered by the integrated system [95]. Also, the collection data with low power and a large coverage area using a particular integrated system was discussed in [52].

During a data gathering process, data may take two paths. First, data can be transmitted from the sensors at the ground to the airborne drone. Then, this data is sent from the drone to the central analysis station. The bandwidth allocation and energy allocation for sensing and transmitting data in the two steps have been considered and discussed [53]. Therefore, the combination of drones and WSNs can provide a solution for the utilization of energy resources. Drones have the capability to control the mode of the sensor network node (sleep or active) for energy efficiency. Furthermore, it has been shown that the cooperation of WSNs and smart drones was energy efficient, providing a better battery lifetime [54].

3) DRONES AND 5G

Green wireless communication plays a crucial role in green IoT. Green communications and networking refer to sustainable, energy-aware, energy-efficient, and environmentally-a ware technologies. The idea of a green communication network refers to low CO_2 emissions, low exposure to radiation and energy efficiency. Koutitas *et al.* [96] proposed a genetic algorithm optimized for developing network planning, where the findings showed significant reduction in carbon emissions, and cost savings and low exposure to radiation. In the same direction, Naeem *et al.* [97] discussed how to maximize the data rate, and minimize CO_2 emissions in cognitive WSNs. The desig of vehicular ad-hoc networks (VANETs) has also been proposed to decrease energy consumption [98].

The investigated details of the energy efficiency of 5G mobile communication networks were discussed from three aspects theoretical models, technological developments, and applications in [99]. Regarding the next-generation network (NGN), Abrol *et al.* [100] presented the influences, and the growing technologies along with the need for energy efficiency. The need for adopting energy efficiency and reducing carbon footprint is to fulfill the demands for increasing the capacity, enhancing the data rate and providing a high QoS for the NGN. Many types of research have been done to save energy by using solar power, and these have also led to an enhanced QoS [101]–[106]. Furthermore, the utility-based adaptive duty cycle (UADC) algorithm has been proposed to reduce delay, increase energy efficiency, and elongate the battery lifetime [107]. The hypertext transfer protocol was used to enhance the lifetime and shorten the delay to provide reliable service [108]. The application of network coding based communication techniques and reliable storage was shown to be useful for saving energy for green IoT [109]. The energy consumed was minimized by using networked fog centers, the TCP/IP protocol, and intra-fog communication [110].

Nowadays, 5G is expected to impact our environment and life considerably, in a manner similar to what the IoT promised, to make it efficient and comfortable. The 5G applications and its services for our society include e-health, robotic communication, interaction of humans and robotics, media, transport and logistics, e-learning, e-governance, public safety, automotive and industrial systems, etc. The authors of [110], [111] discussed the intelligent techniques that are in use for robotic communication to perform tasks effectively and efficiently. Chan *et al.* [112] developed a set of models for evaluating the use-phase of power consumption and CO_2 emissions of wireless telecommunication network services.

Furthermore, Motlagh *et al.* [16] proposed a steering technique among multiple 4G networks to ensure reliable and efficient connectivity via drones, which supports high QoS and consumes an acceptable amount of energy. Xu *et al.* [55] proposed a single drone as a mobile sink, along with a cluster of sensor nodes, and focused on reducing message delays. On the other hand, as energy supply on drones is limited, protocols in various layers should contribute towards the greening of the network [113]. Therefore, the drone is an emerging and useful technique for delivering wireless services to users on the ground, and it is lucrative for applications demanding a large coverage area and reduced power consumption. The most prominent issues in the next generation heterogeneous network are the capacity and coverage. To increase the capacity and coverage of wireless networks, Sharma *et al.* [114] presented an intelligent solution using a drone for accurate and efficient placement.

The authors of [58] summarized many aspects of communication using drones. They investigated the self-adaptive power allocation technique for drones based on the minimum data rate and maximum allowable interference. Furthermore, technology enabling a drone to be used in a 5G communication network was also introduced. The findings showed that drone technology helped to maintain the QoS for all users in the drone coverage area. Statistical propagation for predicting the path loss between the drone and the terrestrial terminal was given [115]. The authors of [116] also discussed the prediction of path loss based on the urban environment. Mozaffari *et al.* [18] proposed the coexistence of a drone with another IoT device on the ground based on the machine-to-machine (M2M) communication network.

The integration of a drone and WSN is a useful technology for the utilization of energy resources [54], [117]. In addition to cooperation and integration of drones and WSN, authors in [56] considered the communication links between drones and WSN to optimize scheduling and drone trajectory for minimizing the energy consumption in the WSN during data collection. The idea was supported by a study in [57], which reveals that transmission energy reduced because the drone is capable of moving sequentially close to each node of the WSNs and collecting data from them. Rashed *et al.* [118], [119] highlighted a trade-off between minimizing the operation time and maximizing the covered nodes to choose the specific mobility pattern. Several studies of the combination of advanced technologies such as drones, ICT, and IoT are summarized in Table 2.

III. PRIVACY AND SECURITY ISSUES IN DRONES AND IOT COLLABORATION

Smart cities can not be considered truly smart unless the security and privacy concerns of the users have reached an acceptable level. There are several challenges in the privacy and security to be addressed for improving the smartness of smart cities. Several privacy and security issues solutions and challenges have been discussed for different smart city applications in [120], [121]. Furthermore, the authors of [121] identified two types of security mechanisms in smart cities, operation security and data security, in which the security of the data itself depends on the security of the operations. Furthermore in [120], smart city applications were introduced, and several security challenges were discussed such as secure information processing, privacy leakage, and dependability in control. The authors of [122] introduced the security and privacy issues in the integration of IoT devices for smart cities. It was deemed essential to guarantee the security of end users and information of private and public systems such as smart grids and smart mobility. Gong et al. [123] proposed a homomorphic encryption technique to guarantee transmission security and evaluate next-generation mobile edge computing. Also, Eckhoff and Wagner [59] discussed the applications areas, attackers and their data sources, privacy, enabling technologies of a smart city.

Parvez *et al.* [60] introduced machine learning (ML) techniques to secure the smart grid. For privacy in smart cities, Eckhoff and Wagner [59] introduced the taxonomies of privacy for different applications, potential attackers, enabling technologies and data sources for attacks. Furthermore, they

TABLE 2. Summary on combination of drone, ICT, and IoT for smart cities.

Ref.	Highlighted	Technologies	Ideology
[48] (2016)	Enhance the lifetime of drone battery	RFID and drone	Provide additional information
[49] (2015)	Recharge a multipurpose RFID tag using a drone in environmental monitoring	RFID and drone	Continuing data collection and monitoring
[50] (2015)	Monitoring operation in harsh environments using RFID with a drone	RFID and drone	Powerful monitoring instruments, particularly when the monitoring is needed for a large area or a harsh environment
[51] (2012)	Drone localization and tracking	RFID and drone	Cost effectiveness and efficiency
[52] (2017)	Collecting data with low power and large coverage area	Sensors and drone	Low power and large coverage area
[53] (2014)	Gathering data from sensors	Sensors and drone	Enhancing the bandwidth and energy consumption. Manage the node network mode
[54] (2016)	Cooperation of WSN and smart drone	Sensors and drone	provided energy efficient relaying for a better lifetime
[16] (2017)	Steering technique among multiple 4G networks via drones,	4G and drone	Reliable and efficient connectivity. High QoS Energy efficiency
[55] (2016)	Drone as mobile sink and cluster of sensors nodes	Communication	Reducing message delays
[56] (2017)	Optimize schedule and drones trajectory during communication with WSN	Communication	Minimizing the energy consumption of WSN during data collecting
[57] (2016)	Moving sequentially close to each of the WSNs and collecting data from	Communication	Reduce transmission energy
[58] (2018)	Aspects of communication using drones	Drone enabler for 5G technology	Minimum data rate and maximum allowable interference. Maintaining the QoS for all user in the drone coverage area.

TABLE 3. Privacy dimensions.

Privacy dimensions	Focus
Transactions	Protect queries and responses
Mobility	Secure location coordinates
Communications	Protect communication channels
Bodily	Protect physical aspects
Territorial	Protect personal property and space
Identity	Protect personal data related to an individual

described the existing privacy enhancement technologies in real smart cities and discussed the solutions of various challenges. The authors of [35] presented the citizen's privacy concept based on five privacies dimension, *viz.* identity, location, query, footprint, and owner. Several technologies were proposed and combined for enhancing citizen privacy in smart cities. The privacy dimensions of smart cities are shown in Table 3.

Smart cities include a large number of IoT devices such as sensors, cameras, actuators RFID, etc., which are used for data collection and transferring the collected data via advanced wireless communication technologies into the data center (server) allowing data to be processed and intelligent actions to be taken accordingly. Millions of smart IoT devices are distributed in smart cities to collect data from different applications, but these devices usually have limited computational power which leads to weak cryptography and issues in data security. The collected data includes the history of the environment surrounding IoT devices. Based on collected data, smart cities can be monitored in real time, and intelligent services can be delivered as needed. However, such collected data from different applications of smart cities dictates the need for privacy and security in order to control smart cities facilities and people's lives. Otherwise, any compromised device may make the entire data collection vulnerable.

To keep IoT devices in smart cities secure, they should be located in places where unauthenticated persons can not reach and access. Furthermore, the IoT network infrastructure should be authenticated to collect or send data in a particular network. Gharaibeh *et al.* [37] discussed the integration of various technologies for enabling smart cities such as IoT, cloud computing and communication network technologies. Furthermore, they identified the techniques applicable for data privacy and security that are protected by underlying IoT devices in smart cities. Furthermore, the authors of [38] reviewed the security aspects of smart cities and introduced privacy and security challenges. They focused on the unique challenges to smart cities applications such as smart grids, smart mobility, and IoT. In order to maintain privacy and security in smart cities, the authors of [124] proposed an architecture based on IoT and mobile ad hoc

TABLE 4. Attack categories in smart cities.

Attack Categories	Function
Confidentiality	Attacks that related information access and unauthorized monitoring
Integrity	Attacks that • Seeks to break into the system • Maks the system inefficient
Availability	Attacks that brings the system down

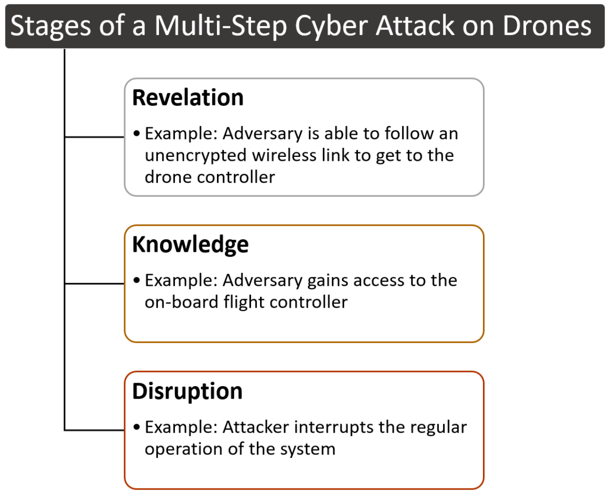

FIGURE 4. Steps of a typical multi-step cyber-attack on drones.

networks (MANETs). The three general data properties that need to be secured for information collected in smart cities, are the confidentiality, integrity and availability (CIA) of the data [125]. Further detail is provided in Table 4.

A smart city is not only about connected IoT devices and vehicle mobility and their networks, but also contains dynamic aspects such as autonomous drones. The security of autonomous swarm drones when performing tasks over smart cities was discussed [39]. The authors of [39] proposed the SHARK protocol for secured autonomous and heterogeneous swarm drones for ensuring the security of swarm drone applications over smart cities. Also, the authors of [126] explored a novel solution for securing information sharing (and provided a 3D visualization) between swarm drones in a smart city. The findings of the proposed technique showed the security prowess of drone context exchange validation and provided a secured path for drone to drone collaboration. The authors of [127] focused on the examination of cyber security aspects of drone-assisted public safety networks in light of the fact that sensitive data could be sent over the drone network. The findings showed that security risks and attacks still existed. Many studies have discussed drone path attacks such as [128], [129]. The authors of [130] discussed the dependency of drones on GPS which may get attacked and lead to the loss of drone control. For smart cities, drones cyber-attacks can be divided into the categories of revelation, knowledge, and disruption as shown in Fig. 4. There are several security issues related to drones applications in smart cities such as drone-hijacking, waypoint alterations, and signal jamming.

With limitless civilian applications, drones need various levels of security features according to the type of application. One study [131] provided details of the security faults in civilian drones applications such as unsecured WiFi, openly accessible Telnet, etc. Furthermore, Pleban *et al.* [132] highlighted the importance of securing communication links with encryption. They classified threats in two groups device threats and communication threats. Both of the above studies found that civilian drones do not apply cryptographic techniques to secure the connecting link between the ground controller and drones. Therefore, civilian drones are susceptible to connection denial, remote hijacking, video interception and total control (takeover) by adversaries [131]. The authors of [133] proposed the verifierBee path planning technique for securing the drones positions and finding the shortest path. Furthermore, the authors of [134] introduced future directions and challenges for drone safety, security, and privacy in smart cities.

It needs to be pointed out that securing drones does not only involve securing the communication channel, drone environment, and path. Efforts must also be made to secure the controller because it is also prone to attacks. Clarke [36] reviewed the drone controls, co-regulation, self-regulation and formal laws for various form of surveillance. He also identified the shortfall of the regulation framework.Namely, if the controller fails to handle the attack, the total drone communication system will be uncontrollable. Thus, the authors of [135] proposed an efficient linearly homomorphic authenticated encryption technique for controlling multiple drones in real-time operation to ensure that they fly autonomously and safely. The proposed technique ensures security against forgery and eavesdropping attacks, and therefore, it guarantees the successful operation of a multi-rotor flying robot successfully. Also, the authors of [134] introduced the issues of privacy, security, and safety in civilian drones. Furthermore, they identified the salient drone properties required for secured operation.

Interestingly, the Internet of Drones (IoD) environment represents a major and emerging technology that has enormous civilian applications in smart cities due to real-time data access and data accuracy. Several issues regarding security and privacy of the IoD environment were discussed in [136]–[138]. It is typically not prudent to allow a user direct access to the IoD, as this would give users with malicious intentions several chances to attack the IoD environment, for example, through jamming, clogging, and hacking [136]. Therefore, the authors discussed how the user should access the data collected from the IoD environment in the server securely. The server could be placed between the drones and the users, so that users cannot access the data from a drone directly, but it can be done via the server to protect the IoD environment from attacks. However, some times, the data collected on the server is not real-time data. Therefore, the user needs to access the real data in the drone environment, so that the user can make intelligent decisions in real-time to save people's life during emergencies. Thus, designing an efficient, secure technique for user authentication in IoD is required. An authentication key agreement technique was proposed to allow users to directly access the IoD environments [138]. Furthermore, Lin *et al.* [137] provided potential solutions for privacy leakage, flexible accessibility and data confidentiality protection, and also discussed the architecture needed to gather data with privacy and security in the IoD environment. Also, Choudhary *et al.* [139] proposed a deep neural network (DNN) based security framework which provides highly secure and reliable mechanisms for IoD.

The collaboration of drones and IoT technologies such as RFID, M2M, WSN, cloud computing and advanced communication technologies expands the role of collaborative drones for many applications in smart cities. Baig *et al.* [140] surveyed the vulnerabilities and associated threats of smart cities and identified components such as building automation systems, smart grids, smart vehicles and drones with IoT and cloud enabling technologies. Also, the authors of [63] discussed a solution for the privacy and security of drone applications in smart cities enabled by 5G and IoT. Furthermore, they introduced the security and privacy challenges of collaborative drones and IoT, end-to-end (E2E) privacy, prevention and security in real time, and the dynamic IoT environment.

Ensuring the security off collaborative drones and IoT devices in smart cities is complex tasks due to the requirement for an efficient combination of various techniques that are associated with drone operations and IoT networking aspects. The complexity of collaborative drones and IoT set-ups can be enormous, with people and machines interacting with each other in smart cities through the complex processes of the ecosystem [134]. In light of this, security aspects of IoT along with dronesrequire different techniques for different layers such as the perception, link, network and application layers.

In the perception layer, security threats are mostly related to the possibility of physical damage, so the authors of [134], [141] suggested hardware techniques that should be employed, such as tamper protection and break-in detection systems. Table 5 illustrates the various security threats and the data resources that need protection for drone and IoT collaborations. Here, the security involves authorizing the users to access data generated by physical objects. Furthermore, E2E communication needs to be present to ensure security using advanced techniques such as digital signature and lightweight cryptography. In the case of detection systems, co-location proofs were proposed to act against routing attacks by [142], [143]. The authors of [143] discussed the security services applied in the link layer including E2E security, while the authors of [144] proposed secure channel protocols to ensure robust communication.

TABLE 5. Security threats and data sources in a drone and IoT collaborative environment.

Security Threats	Data Sources
• Communication • Maintaining data confidential • Accessible data in real time – IoT devises failure in drone payload – Cloud storage data – Secure Communication link – Communication jamming and injection – Fog cloud	• Cloud management • Drone environment • Smart IoT devices • Fog cloud • Structural health measurement • Smart parking • Smartphone detection • Smart lighting • Traffic congestion monitors • Smart Roads • Waste management monitors

For securing the network layers of drone and IoT collaborative set-ups, the authors of [134] discussed secure routing, IP security, and secure transportation. Furthermore, the authors of [145] discussed how IPv6 routing could apply for secure drones and IoT collaboration for low power protocols [146]. Moreover, routing of the data network infrastructure for drone security can provide robust identification and ensure objects integrity, as reported in [147]. Such routing can enhance a drone's autonomy, lower its energy consumption, and improve its flying time. On the other hand, securing the application layer calls for several techniques such as a simple object access protocol, a constrained application protocol [142] and intrusion detection systems [148]. Lastly, for drone destination identification, path planning, and self-organization, machine learning based computer vision and video processing techniques are required [149].

IV. DRONE AND IOT COLLABORATION FOR ENERGY EFFICIENCY

The drone is a critical technology for enabling green IoT which will provide energy efficient solutions by minimizing power consumption in IoT devices. Standalone IoT devices need high transmission power for sending information over long distances. Once the IoT devices are made to collaborate with a drone, the agile and flying drone can physically go to the vicinity of these IoT devices to collect, process, and transmit data to other nodes/stations which are outside the coverage area of the IoT devices. Drones will also use efficient communication technologies to transfer/exchange data with each other and with IoT devices in the ground through M2M communication. The authors of [150] proposed a Genetic Algorithm (GA) for drone-assisted IoT sensor networks based on the sensor density, energy consumption and flight time and fly risk level. Furthermore, Mozaffari et al. [151] evaluated and argued the optimal altitude values for small drone cell clouds which lead to the minimum transmit power and maximum coverage area.

Incorporating the processing and controlling features in each machine is the primary objective of IoT equipment. IoT devices in drones are used to manage, process, and deliver data. The co-operative framework for the drone-WSN was introduced [117]. It is composed of fixed-group leaders,

TABLE 6. Summary on improving energy efficiency in smart cities.

Reference	Highlight	Ideology
[150] (2016)	Drone-assisted IoT sensor networks	• Energy consumption • Flight time and fly risk level
[151] (2015)	Optimal values for altitude for small drone cell	• Minimum transmit power • Maximum coverage area
[152] (2017)	Drone-based WSN for gathering data	• Reducing energy consumption • Reducing flying time and latency of data collection
[153] (2014)	Data gathering in WSNs by employing mobile agents and drone	• Saving time and energy of sensor nodes
[54] (2016)	Cooperation of drone with WSN	• Providing energy efficient relaying for a better life
[154] (2016)	Drone docking system collaboration with IoT devices environment	• Reducing wasted resources, energy and also ensure the security
[155] (2013)	Automatic battery replacement mechanism	• Allowing longer operation time

sensor nodes, and drones-sink. The finding of this study was that the energy consumption and complexity of the process of group leader election were reduced. The strategies of drone-based WSN for gathering data were discussed in [152]. The employed strategies were able to reduce energy consumption, flying time and latency of data collection. The authors in [153] proposed an algorithm for data gathering in WSNs by employing two technologies: mobile agents and drones. Both technologies were used for saving time and energy of sensor nodes. A case study was done based on searching for people in a disaster (e.g. an earthquake). Also, the proposed work appears to be suitable for gathering data in many applications in real smart cities also. Zorbas *et al.* [156] discussed the mathematical formulation of efficient energy management for IoT devices. The model was able to detect the events that happened on the ground and minimize energy consumption in a particular coverage area. Furthermore, Sharma *et al.* [54] proved the importance of drone and WSN cooperation for providing energy efficient relaying. The findings showed that the proposed technique was able to enhance drone routing with less delay and a large coverage area with better battery lifetime. The required power for the drone system was modeled and it was found that the energy efficiency can be improved only by adding more energy efficient components in the emerging technologies [157]. Choi *et al.* [158] determined the energy efficiency of the drone-based relay by taking into account the speed and load factors. A wired drone docking system has also been proposed to perform many functions through collaboration with IoT devices to reduce resources, energy wastage and to also ensure security [154]. Seo *et al.* [159] proposed the use of drone technology over the IoT security platform, for monitoring and providing an emergency response in buildings by utilizing beacons. For addressing issues related to drone battery life, the authors of [155] developed an automatic battery replacement mechanism. Automatic battery replacement allowed drones to keep working without manual intervention. The proposed practical work successfully assessed the use of drones for continuous surveillance in outdoor and indoor environments. A summary of previous studies and techniques used for improving the energy efficiency in smart cities by using a collaboration between drones and the IoT is shown in Table 6.

V. DATA COLLECTION IN SMART CITIES USING COLLABORATION OF DRONES AND IOT

The most critical asset in a smart city scenario is data. To achieve smart city characteristics and cater to the application domains, data must be collected, stored, and processed in real-time in order to ensure that the required tasks can be performed collaboratively. In many applications of smart cities, smart IoT devices (such as cameras, sensors, etc.) are distributed for collecting data from the surrounding environment. Smart IoT devices in smart cities are small and have limited battery [160]. Therefore, these smart IoT devices are not able to transmit the signal over long distances, because of energy constraints [12], [13], [17]. To fulfill the promises of eco-friendliness and sustainability in smart cities, the reduction of the energy consumption is an absolute necessity, and the minimization of pollution and hazardous waste is also required to enhance the overall quality of experience [70], [161].

Recently, drones have started to represent a microcosm of the entire IoT domain in the sense that these drones can interact and respond to their environment much like the other entities in the IoT framework. Therefore, they can be deployed to different locations, carry flexible loads, measure and provide analytics about anything anywhere and at any time. The exciting aspects of drones and IoT collaboration are the lower prices and better connectivity and delivery of high QoS. Drone height plays a vital role in delivering services to IoT devices and collecting data from IoT devices. Due to the advent of drone-based IoT, the IoT equipment on-board a drone may include devices such as sensors, digital cameras, actuators, and communication technologies, such as

FIGURE 5. A drone equipped IoT devices for data gathering.

Wi-Fi, 5G, LTE, or Ad-hoc networks, as shown in Fig. 5. This equipment is used to remotely control the devices, collect data, and deliver services effectively and efficiently. Hence, drones can collect data from IoT devices via the equipment that has already been added to the drone's payload. Delivering services from drones is performed via wireless communication technologies such as WiFi, LTE, and 5G.

Wireless communication technologies such as 4G/5G networks offer significant potential for enhancing the effectiveness of drones equipped with sensors, cameras, and GPS receivers, in delivering IoT services from great heights. Using drones to fly as relays for IoT has numerous benefits such as reliability and energy conservation. Drones are required to gather data from IoT on the ground to minimize transmission power while retaining reliability [17]. Furthermore in such scenarios, the energy consumption in IoT devices is significantly reduced, and the drones can serve the ground devices for a longer duration. Drones have also been employed to guide search and rescue (SAR)teams, where wearable smart devices are connected to drones for guidance regarding suitable and safe routes [32].

Furthermore, drones can act as the crucial technology component in IoT device communication to collect data from small devices such as health-care monitoring equipment, environmental sensors, etc. [160], [162], [163]. The authors of [164] considered the use of drones and IoT devices together in a disaster response setting and provided the facilities for event detection, and automatic network repaired. Smart drones equipped with IoT devices are able to collect, store, and process data to enable drones to perform complex tasks effectively and efficiently. Because of the energy required for processing IoT data and performing IoT tasks urgently, Koulali *et al.* [165] suggested that the processing of data should be done locally, and then the processed data should be delivered to the cloud so that the necessary actions can be taken. However, the processing and storage of data on IoT devices requires high energy expenditure. It is expected that the use of drones will contribute to reducing the energy used, and will control the active and sleep modes of IoT devices to produce green IoT technology. The various scenarios in which a drone can be effectively used to gather data, such as disaster management, public safety, agriculture, etc. are summarized in Table 7. Furthermore, drones can be used to gather data in the smart cities for many applications such as dynamic coordination and data routing, accident monitoring, intelligent transport systems, disaster recovery, public safety, and relaying data from isolated ground sensors to a BS, etc.

The collaboration of drones and IoT for gathering data can be leveraged in different ways: (i) drones gathering data from ground IoT devices and delivering collected data to the nearest BS [169], (ii) drones equipped with IoT devices for gathering data [170] (iii) drone equipped with IoT devices and also collecting data from IoT devices in smart cities. For instance, drones used for public safety tasks can collect data from wearable devices carried by the members of SAR teams. In another case, data gathered by a drone can be put to use in the agriculture industry, serving many applications such as crop monitoring, drought monitoring, yield estimates, water quality monitoring, disease detection, identification of tree species, etc.

VI. COLLABORATION OF DRONES AND IOT FOR IMPROVING LIFE QUALITY

Recently, the monitoring and control of air pollution have become important issues in the modern industrialized world. Typically sensors are used for gathering pollution data which is consumed for monitoring purposes. However, the power transmission capabilities of these miniature sensors is limited, and often, such sensors are not suitable for sending data in real time. To circumvent this issue, the sensors can be carried by drones, and then data process and onward transmission can be divided into two parts: the onboard sensor can sense/collect pollution data, and the drone's communication equipment with its larger power sources, can easily send the data across over much larger distances than those possible using a standalone sensor [171], [172]. In that regard, Villa *et al.* [173] established the best installation points for four gas sensors and a Particle Number Concentration (PNC) monitor, onboard a hexacopter. They developed a drone system which is capable of measuring point source emissions. Their study focused on the air flow behavior, and evaluation of the performance of CO_2, CO, NO_2 and NO sensors for measuring the harmful gaseous emissions in a particular geographical area. Several other potential applications of drone technology have also been explored for interacting with sensors to perform tasks such as soil moisture sensing, remote crop monitoring, infrastructure monitoring, water quality monitoring, and remote sensor deployment [174]. For controlling the gas emissions from a greenhouse, Hamilton *et al.* [94] highlighted the importance of a solar-powered drone equipped with a CO_2 sensing system integrated with a WSN.

TABLE 7. Summary on improving data gathering from smart cities.

Data collection	Scenarios	Ref.	Summary of Work
General	Dynamic coordination and data routing	[23] (2017)	• Building a backbone of the drone network and keeping it connected at all times. • In the scenario, the real-time communication is important; drone will move inside the transmission range and tried to maintain its connectivity with other devices. • In the scenario, real-time communication is not important; drone may leave the communication range, gather data, store data and come back to communication range and data to the required dominator.
	Monitoring accident	[166] (2018)	• The drone can rapidly fly over the traffic until reaching the accident location. • Drone reaches the accident location; it can send a detailed report about the situation. • The drone can establish a real-time communication channel between the accident site and the rescue team still on their way.
	Intelligent Transportation Systems	[23] (2017)	• Helping to improve traffic • Enhancing better safety and security on the road • Enhancing driver comfort.
Drone collect data from IoT device in the ground	Relay data from isolated ground sensors to a BS	[167] (2017)	• Maintaining the connectivity
	Disaster management	[168] (2018)	• Usage of the drone as 0th responders to deliver communication service to victims • Collecting data and the use of local search the optimal position.
A drone equipped IoT devices	A drone equipped with an IoT device to perform specific tasks	[63] (2018)	• Drones may be equipped with high-end electro-optical sensors, and radars for providing resolutions from submillimeter to a few centimeters • Drones may be equipped with sensors at the lower end of the spectrum for simultaneous localization and mapping, and ultrasonic sensors for sense and obstacle-avoidance methods • Drones may be equipped with thermal sensors to monitor environmental and weather conditions.
A drone equipped IoT and gathered data from IoT	Public safety	[32] (2019)	• Gathering data in real-time • Guiding SAR for saving people lives.
	Signal strength during data collection	[14] (2018)	• Maintaining connectivity • Provisioning optimal QoS • Identifying drone coverage area

The authors of [175] reviewed the existing drone techniques for monitoring the environment. Furthermore, the authors [176] proposed drones equipped with off-the-shelf sensors for monitoring tasks, but they did not consider the guidance system. To solve this issue, the same authors proposed the adoption of drone-mounted pollution control system based on a meta-heuristic and PSO techniques, which allowed the user to monitor a specific area and focused on the most polluted zones [177]. In another pertinent work, [178], the authors proposed using equipment in drones such as Pixhawk Autopilot for drone control along with onboard processing and storage devices, to sense and store environmental pollution data. Furthermore, the authors of [179] developed a modular drone platform that is capable of real-time monitoring of multiple air pollutants.

Šmídl and Hofman [180] extended the idea of mobile stations to autonomously navigated drones for pollution monitoring. The work demonstrated the applications of the drone platform in air pollution research, focused on roadside air pollution profiling and emergency monitoring for air pollution episodes. On the other hand, Zang *et al.* [181] demonstrated the application of drones for the investigation of water pollution in south-west China. Drones were shown to be effective in such a climatic scenario because of their

TABLE 8. Summary on improving life quality in smart cities.

Ref.	Highlighted	Work Summary
[173] (2016)	Sensors on board a hexacopter	Air flow behavior and evaluation of the performance of CO2, CO, NO2 and NO sensors for measuring the pollution emissions in a particular area.
[94] (2017)	Integrated of drone and WSN	Drones for detecting greenhouse Gases with help of WSN technology.
[182] (2018)	Real-time monitoring of air pollution	Developed and designed a modular drone-based platform which was capable of real-time monitoring of air pollution in smart cities. The proposed model included drone, sensors, ground station, data acquisition, and data fusion. The proposed system was high precision and stable for air pollution control.
[183] (2018)	Air quality in smart cities	Collaboration between drone for sensing the tasks and sending data in real-time to the server.

ability to work in environmental conditions with low air pressure, high altitude, severe weather, strong air turbulence, and persistent cloud cover. Gu et al. [182] developed and designed a modular drone-based platform which was capable of real-time monitoring of air pollution in smart cities. The proposed model included drone, sensors, ground station, data acquisition equipment, and a data processing module. The proposed system exhibited high precision and was shown to be suitable for air pollution monitoring. Furthermore, the authors of [183] designed a long-range air quality monitor aboard a drone. The proposed prototype could be used to monitor air pollution easily. In this setup, the collaboration between drones was shown to be effective in the sense that one drone was sensing the data, and another drone was used to send data in real-time to the server. Table 8 depicts a summary of the outcomes of the collaboration of drones and IoT for improving life quality in smart city.

FIGURE 6. Collaborative drone and IoT for public safety [32].

VII. COLLABORATIVE DRONE AND IOT FOR PUBLIC SAFETY IN SMART CITIES

As has been discussed earlier, the limited transmission power of miniaturized sensors and handheld devices makes them unable to send their captured data over long distances. Drone technology, however, can deliver services over a large geographical area in real time. The use of drone technology represents the cheapest and most efficient way to accomplish tasks such as monitoring a criminal on the run, finding a missing person, surveying a disaster scene, etc., especially in time-critical situations. Therefore, the best features of collaboration between drone and IoT devices are those that are supposed to achieve and provide maximum benefits, such as reprogrammability, good sensing capability, ability to interconnect and identify things, ubiquity, communication capability, etc. Wearable internet of public safety things (IoPST) devices connect in smart cities for public safety and allow first responders to share information with command posts and relevant parties. These connected devices can help relief and monitoring teams to identify when or where disasters or crimes have happened, as shown in Fig. 6. Using this information, the interested parties (law enforcement agencies in the case of crimes, rescue teams in the case of disasters) can quickly make appreciated decisions in order to track down perpetrators or provide aid, whatever the case may be. Figure. 6 shows the capability of a drone equipped with IoT technology to capture data in real-time for disaster events and send the captured data to the disaster control center to make an appreciate decision in real time. Drone 1 is used to capture real information from the disastrous fire. Drone 1 is used to communicate with SAR teams, send real-time data about the disaster, and guide SAR to reach the disaster area using an accessible and safe path. The SAR team members are wearing IoT devices that help the drones to identify their location, and suitably guide them according to the disaster situaion. Furthermore, drone 1, which happens to be above the disaster area when the tragedy occurred can communicate with other drones and forward real-time data. Therefore, effective collaboration between drones and IoT devices plays a critical role in enhancing the public safety and reducing the impact of disaster in smart city.

The authors of [18] analyzed how the deployment of a drone as a BS could deliver communication services to a particular area. Furthermore, the coexistence between heterogeneous devices and drones was discussed. Fundamental operation and techniques were introduced for enhancing

TABLE 9. Summary of improving public safety in smart cities.

Ref.	Highlighted	Collaborative drones and IoT	SAR and Public Safety	Focus
[168] (2018)	Importance of using IoT and big data for disaster management and public safety	✓	✓	Using drone as 0^{th} responder to deliver communication service to victims. Collection of data and the use of local searching to find the optimal position.
[24] (2018)	Integrating drones in smart cities	✓	✓	cost-effective services. reduce resource consumption.
[185] (2018)	Drone as 0^{th} responder and its best position	✓	✓	0^{th} responder is to arrive at the disaster scenario before the 1^{st} responder. Finding the best position of 0^{th} responders.
[14] (2018)	Signal strength between drone and IoT device in smart cities	✓		Predicting the accurate signal strength.
[32] (2019)	The collaboration of drone and IoPST	✓	✓	The collaboration of advanced technologies for public safety. Efficient connectivity services. Enhancing QoS.

the efficiency and accuracy of public safety network using IoT technologies. The authors of [184] reviewed the techniques and the availability of IoT for disaster management. Reina *et al.* [168] outlined the disaster management and the importance of using IoT and big data. The study focused on the use of drones as 0^{th} responders to deliver communication service to victims in a disaster. The main idea of an 0^{th} responder is to arrive at the disaster area before the first responders. The work was divided into two parts: the collection of data and the use of local search to find the optimal position in which the drone could deliver communication services to the victims.

Furthermore, the work in [168] was supported by [185], in which the position of the 0^{th} responder was considered for delivering communication services to victims in disaster areas. However, maintaining the connectivity link between the 0^{th} responder and other responders was not discussed. Therefore, Alsamhi *et al.* [14] developed an artificial neural network (ANN) to predict the signal strength between the drone and wearable IoT devices or other responders on the ground to maintain connectivity for delivering services.

A concise summary of the effects of effective collaboration between drones and IoT devices for public safety in smart cities is shown in Table 9.

VIII. COLLABORATION OF DRONE AND IOT FOR DISASTER MANAGEMENT

Apart from the promise of intelligent services, the concept of a smart city also encapsulates effective and efficient planning towards responses to emergency and critical situations. This is generally achieved by assigning SAR activities to disaster areas in real time. In this context, using AI techniques for image analytics plays a vital role in identifying things and events in real time. Visual records of disaster areas can have significant effects on the selection of an effective disaster response. In that light, Chaudhuri and Bose [186] examined the effectiveness of the machine learning technique to manage disasters in smart cities. The proposed technique was used to classify images, containing photographs of disaster areas, with high accuracy.

Sakhardande *et al.* [187] utilized the various communication modes of IoT devices to monitor and manage the SAR activities during a disaster. Furthermore, the idea of intelligent transportation with the help of cloud computing and VANETs technologies has also been proposed for disaster management systems in smart cities [188]. Also, Boukerche *et al.* [189] proposed an IoT based disaster response and detection system for improving SAR activities during a disaster. In this context, IoT devices were used for data gathering, localing injured people, and identifying hazards. The architecture of the proposed system included smart sensors, smart processing, smart responses, and an ad hoc communication network.

Collaboration among drones and IoT devices such as cameras, sensors, and actuators can be used for disaster management and SAR guiding by providing high-resolution imagery, and videos of the affected area and extended coverage area as well as providing real-time weather records (e.g. wind speed, pollution levels, temperature, etc.). Drones flying over or closer to a disaster area can communicate amongst themselves, as well as with a central station, to facilitate the coordination and surveillance of the event and operations team [26]. Real-time processing of the collected data by IoT devices is needed to identify the most affected areas and to assist people where human intervention is risky, impossible, dangerous, and expensive. A drone equipped with IoT devices can be used to collect data from disaster area and its surroundings. Collected data will help rescue and relief teams to respond accordingly to ensure tasks are performed efficiently. Aljehani et al. proposed drone technology together with IoT devices for enabling mobile tracking and image processing [190]. The advanced technology was used to capture an image of the disaster event. Image data from a drone helped to evaluate damaged areas.

TABLE 10. Summary on improving disaster management in smart cities.

Ref.	Highlighted	Focus
[186] (2019)	The effectiveness of machine learning for disaster management	Image classification help to improve the effectiveness of the search operation in real-time
[187] (2016)	Manage and monitor the disaster in smart cities	Using IoT devices for collaboratives to manage SAR activities in smart cities
[188] (2014)	The disaster management system in smart cities	Integration of advanced technologies such as intelligent transportation, cloud computing and VANET for disaster management
[184] (2017)	Challenges and research trends in IoT-enabled disaster management systems	Techniques and the availability of IoT for disaster management
[190] (2019)	IoT and drone for disaster recovery	Drone technology and IoT for enabling mobile tracking and image processing
[189] (2018)	Architecture for smart disaster prediction, discovery, and response system for smart cities	IoT based disaster response and detection systems for improving SAR activities during disaster
This Work	Collaborative drone and IoT for disaster management	Techniques and the logical strategies of the collaborative drone and IoT for disaster management in smart cities

A drone equipped with IoT devices such as 3D cameras can be used to capture high-resolution images to make relief maps of the region under consideration. In this way, a disaster center receives explicit footage of the actual scene without having to deploy human/robot ground teams. Also, a drone can penetrate places that would otherwise be difficult for rescue teams or helicopters to enter and provide close-up views. The most important advantage of the map is to understand the impact of the disaster on the region. Afterwards, AI techniques can be used for decision making and taking desired actions based on the captured map. The desired signal strength from the drone is optimized using an ANN [14]. The prediction and estimation of the signal strength is important for enhancing the QoS. Furthermore, appropriate communication protocols are required for disaster management, because disaster types have different notions of occurrence, damage ability, and time mishap. The energy efficiency of IoT protocols plays a vital role in discovering local sensor devices and gateways for delivering communication services in such a power constrained scenario.

Timing is everything in a disaster situation. By incorporating IoT data into emergency response plans, public sector agencies and responders can use real-time information to make arrangements and reach the people who need help. In the case of IoT wearable devices worn by SAR teams, the drone can assist the IoT services by carrying sensors, cameras, and communication devices, etc. For example, response teams can also use wearable sensors for coordination, analytics, outreach strategies, and on-the-ground tactics. Also, the drone may also be used as a gateway which can connect to the monitoring server as well as, controlling different IoT devices on the drone itself. Furthermore, it can carry IoT devices such as thermal imaging devices, multispectral cameras, microphones, and sniffers. Motlagh *et al.* [16] established a steering mechanism on the drone payload to decrease the energy consumption and guarantee a higher data transmission rate through proper selection of the received signal strength indicator (RSSI). The performance of the steering mechanism led to an increase in the probability of having a high transmission data rate, high QoS, and acceptable energy consumption.Regarding flexible deployment of drone technology, 4G communication will help to control multiple drones from anywhere, enabling real-time data transmission, processing, and sharing.

The work in [191] considered the deployment of drone and IoT devices during a disaster for effective and efficient communication and data sensing, and the use of integrated technology to help SAR to perform their tasks safely. Application areas of such systems include transportation, public safety, energy, healthcare, and telecommunication. Table 10 shows a summary of previous studies related to collaborative drone and IoT technologies for disaster management in smart cities.

Figure. 6 shows the importance of using drones in collaboration with IoT devices for disaster management in smart cites. Drone 1 is equipped with IoT sensors to capture data in real-time and forward it to a central unit for further decision making and the performance of intelligent actions. Furthermore, drone 1 is also used to connect directly with the wearable IoT devices worn by the SAR team to guide them along a safe path and protect their lives.

IX. MISCELLANEOUS APPLICATIONS OF COLLABORATION OF DRONES AND IOT

Smart cities demand smart data. IoT devices are capable of collecting this data. However, distributing a massive number of IoT devices will consume energy and incur high costs. Therefore, smart drones can be equipped with IoT devices, which can be used to collect data from a large coverage area with energy savings and reduced carbon emissions. In the near future, a massive number of drones will be used to improve city life, document accident scenes, support first responder activities, and monitor construction sites. The requirements of drones to make a city smarter were discussed in [34], [192], [193]. The authors of [34] associated a critical role to the drone in smart cities, wherein the drone was used as a relay station and kept connectivity in particular applications such as emergency services and disaster recovery. Furthermore, the future directions of research and challenges were discussed in that work.

Won *et al.* [194] discussed the need for secure communication protocols for collaboration between drones and IoT devices. The protocols involve different types of fixed IoT devices or mobile devices with different capacities. The various aspects of drones in future smart cities, relating to cyber-security, privacy, and public safety were discussed in [28]. Furthermore, the applications of drones for smart cities and the opportunities to solve todays problems were also discussed in [41], [194]. Recently, the rate of crime in urban areas, such as street crime, vandalism, and terrorism has increased. Therefore, anticipating crimes through detection and recognition of criminals among crowds of people is vital. In this vein, drones with the help of IoT devices can be used to track, detect, and recognize criminals, follow criminal movement to discover exact hiding places, and provide immunity from any potential hazards that the criminals may pose. To improve the performance of disaster sensing while saving energy, the drone-cloud framework was proposed for disaster sensing applications under the condition of irregular, intermittent, and limited environment networks [195]. In another related work, it was argued that providing excellent accuracy is sufficient for real-time disaster relief [196]. The use of drones to provide various services was also discussed in [197].

To secure a smart home, a drone can provide adaptive security by working as a home surveillance system. It would use solar-powered sensors to detect physical movement, any acoustic signal, and even vibrations on the ground, and would be capable of approaching and monitoring the areas of interest once a further investigation command is given. Also, apart from the possibility of using solar-powered equipment, wireless power transmission techniques can be used to charge the batteries of drones and IoT devices in the drone payload.

Collaborative drones and IoT devices also promise a revolution in agriculture through the combination of big data, aerial imagery, and other means to optimize productivity. Wang *et al.* [174] explored several potential applications where drones interact with sensor tags to perform tasks such as soil moisture sensing, remote crop monitoring, infrastructure monitoring, water quality monitoring, and remote sensor deployment. In their work, a drone was equipped with IoT devices and included the capability for seamless connection and data collection in the cloud.

Collaborative drones and IoT devices can also help to monitor power distribution lines, tend to crops, or deliver packages. Nowadays, another significant field and application of collaborative drones and IoT is doing the often dangerous

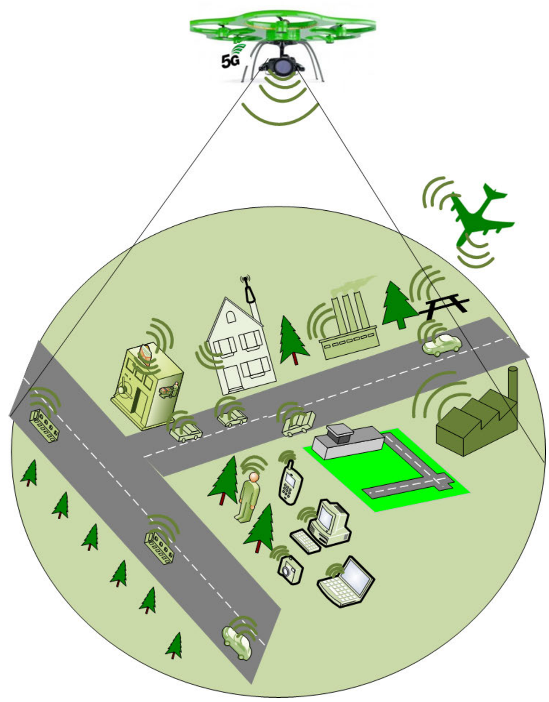

FIGURE 7. **Collaborative smart drone and IoT for smart cities.**

work of power crews in surveying storm damage or maintaining power lines. Therefore, collaboration between drones and IoT devices can be used to find and inspect downed power lines faster than manned crew members after a storm or hurricane. Furthermore, drones can cover a larger area much faster, while keeping crews out of danger. In this particular case, drones can send real-time data and live video streams back to smart grid systems, allowing power companies to manage potential electrical problems like never before. Therefore, drones reduce both inspection time and cost.

Collaboration between drones and IoT devices can also provide a viable solution for tasks such as the delivery of food aid and medical supplies to areas hit by a disaster. Nowadays, humans are probably most interested in collaborations between drones and IoT to save people's lives during public safety and emergencies. Therefore, future collaborations of drones and wearable/implantable medical devices will revolutionize healthcare, moving closer to a model in which IoT sensors monitor health continuously. If patients are not able to travel tens or hundreds of miles to receive a diagnosis, collaborative drone and IoT devices can be used to treat them. Table.11 illustrates the applications of collaborative drones and IoT and its advantages for smart cities. Some of the more pertinent applications are further explained below.

A. EMERGENCY SERVICES AND DISASTER MANAGEMENT

Emergency applications in smart cities are a very important factor in saving people lives. Some emergency cases occur in difficult to access areas, and delays in physically reaching them may impact the response performance. Therefore,

TABLE 11. A summary on collaborative drones and IoT applications with the associated advantages.

Smart cities application	Collaborative drone and IoT function	Advantage of collaboration
Monitoring traffic	• Real-time data about traffic • Smart car parking • Controlling the traffic	• Fast processing and accurate decision making
Wireless communication	• Scalable communication network • Enable the connectivity over a large area • Maintaining QoS	• Enhancing the performance of delivering communication services
Public safety and health care	• Deliver medical in case of emergency • Help rescue and relief team for performing the tasks	• Saving human lives • Reducing the cost and economic losses • Offering health emergency in real-time
Disaster management	• Monitoring the status of disaster • Enabling communication • Search and monitoring the survivors	• Saving people lives • Reducing economic losses • Effective and efficient control of disaster management • Faster response
Data collection	• Collected data • Send data • Preprocessing data • Act based on collected data	• Enhance energy efficiency of IoT device on the ground of smart cities • Delivering collected data in real-time in smart cities
Fog computing	• Low latency services • Distributed services to the large coverage area • Enhance the QoS provisioning. âĂŸ • Efficient communication with different communication technologies	• Enhancing the smartness of smart cities service • Enhancing the quality of life in smart cities
Delivering	• Fast delivering goods	• Better services for customer • Faster delivery of food in smart cities

collaborative drones and IoT can play vital roles in improving the emergency response in smart cities. Drones equipped with sensors can perform as zero responders for victims in a very crowded area in smart cities. In this case, the drone can send the victim's location, find a smooth path for SAR, and update the situation to an emergency response team, while at the same time also monitoring the victim's status. Also, response teams wear IoT devices that keep them in contact with drones. Moreover, collaborative drone and IoT can deliver on-demand broadband communication services and collect data about the emergency environment [198], [199].

Terrorist attacks and natural and man-made disasters are examples of disasters that affect smart cities and represent very challenging situations. The Control, management and preparation of such disasters is extremely important. The sooner the response reaches the affected area, the higher the reduction in the overall cost to the economy will be, and the higher the chance that more lives are saved will be. The aerial platform has been proposed as one technology that can deliver broadband communication services such as the high altitude platform [200], [201],and tethered balloon [200], [202]–[204], while drones have more recently been put forward as an even more effective and efficient technology for delivering broadband communication in disaster monitoring and mitigation [14], [32], [205], [206]. Furthermore, due to their agility, drones can also be used to transport equipment, and medical supplies to the needy.

B. DATA COLLECTION

Effective collaborations between drones and IoT devices can also be leveraged to gather and transfer data in real-time. In conventional techniques, the transfer of collected data usually occurs via multi-hops and relays, leading to delays and errors [14], [32]. For such cases, collaborative drones play a vital role in collecting data from IoT devices and transfering data to the main station [207]. Thus, collaborative drones can reduce the energy required by the IoT devices, by reducing the distance over which data needs to be transmitted (IoT device to nearby drone, instead of IoT device to a far-away base station), and thus extending their battery life [14], [21], [208]. Several techniques have been developed for efficient data collection and communication between drones and IoT devices [32], [63], [95], [209].

C. MONITORING TRAFFIC

Traffic congestion is considered one of the major issues facing smart cities. It occurs due to sudden increases in the number of vehicles for many reasons such as rush hour, construction work, large events, or accidents. It may occur at any time in any place in a smart city. Therefore, effective and efficient techniques and technologies are required to mitigate such situations. Static cameras installed on the streets can provide some information, but not a detailed report about the congestion [210]. Drone is a crucial technology for collecting congestion data and sending it in real time. Several techniques

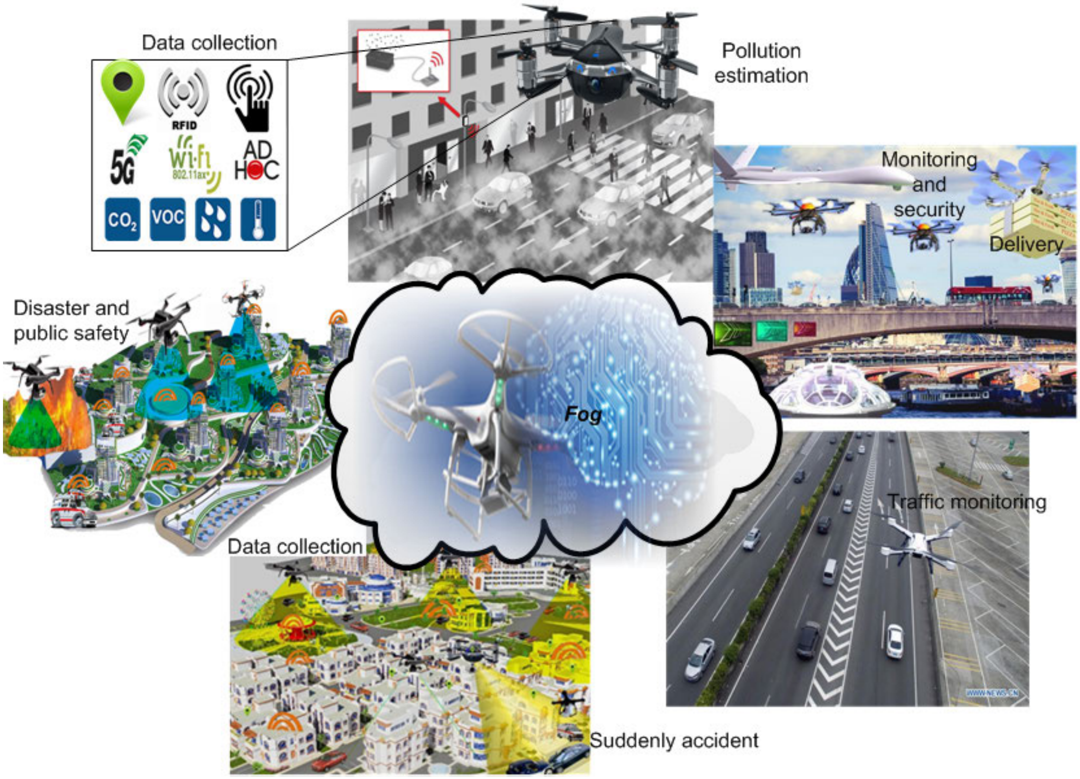

FIGURE 8. Application examples of collaborative drones and IoT in smart cities.

TABLE 12. Summary of open issues of collaborative drones and IoT applications in smart cities.

Collaborative drones and IoT applications	Challenges	Open issues
Monitoring traffic	• Sending the video streams to the traffic center requires low latency and high bandwidth	• Security leads to major hacking
Wireless communication	• Optimizing drone position over smart cities • The flying path for better coverage in smart cities	• Security and safe operations
Public safety and health care	• Reliability and safety requirements • Maintenance and development costs	• Inaccurately delivered medical elements
Disaster management	• Coordination of smart drones • Fast decision making • Accurate analysis • Different disaster situation	• Different disasters need different designated tools of drones and IoT devices
Data collection	• Energy efficiency • Coexistence with other existing systems • Path planning	• High delay in data gathering leads to a high delay in decision making
Fog computing	• Energy efficiency • Security • Load balancing and selection location • Coexistence with other existing systems	• Security and operation parameters definition
Delivering	• Coexistence with other existing systems • Efficient operation	• Possibility of accident occurring
Security and Privcay	• Authenticate the collected data • Enhancing the authenticated data for improving the policing tasks	• Securing fog cloud and cloud

have been used for efficient and effective communication and exploration of the data collected by drones, such as those presented in [14], [32], [211], [212]. Traffic congestion can also occur due to trying to find park spots when there are limited parking spaces. This causes drivers to navigate the area several times at low speed. To help in such scenarios,

TABLE 13. Research directions, challenges, and insights.

Study	Directions	Challenges	Future insights
[26] (2016)	Drone-based IoT services	Manage and Control a massive number of drones for such reasons: • Drone equips many different IoT devices • Different videos are taken from a different angle from same drone position	• It is very important to find an efficient scheme that can manage and control the power conserve of IoT devices in the drone payload. • Security is a critical issue on the drone-based IoT services, and therefore, finding accurate and efficient techniques to avoid the hacking drone communication is required.
[224] (2014)	Flight time enhancement	• Battery lifetime	• Drone battery lifetime is needed to improve for allowing the drone to fly for long distance and increase the time of drone flight.
[30] (2017)	–Real-time application –Real-time processing –Accurate decision making	• Collecting a large amount of unlabeled data becomes less expensive • Unsolved real-world issues	• DL technique is required to be implemented in the drones payload to demonstrate data analysis by low power and efficient DL in support real-time applications
[225] (2016)	Energy consumption	• Energy Limitations	• Finding suitable techniques for efficient batteries, new lighter materials, and energy harvesting may lead to potential applications use of drones technology.
[31] (2017)	Intelligent techniques	• Drones battery • Real-time and reliable communications with the ground center given QoS and energy constraints	• Implementation and design of an efficient power distributed algorithms are required for real-time processing of swarm drones images, captured videos, and gathering data.
[186] (2019)	Identify solution for SAR operations	• SAR safety in disastar area • Requiring minimal changes to the existing smart city infrastructure by utilizing huge amounts of data already captured	• Drones equipped with camera would be applicable to every disaster situation. • DL on the unstructured visual data of a smart city holds promise for large-scale implementation to : 1) Enhance disaster response activities during disaster 2) Provide richer information through analysis image and vedio streams captured by drones
[133]	Security and Privacy	• Extraction of live drone state without power down	• Securing the optimal and short path of drone • Securing the drone position
[139]	Intelligent techniques for secure IoD	• Data security on the transmission line • Authorized access to sensor data	• Applying ML techniques between fog cloud (drone) and IoT cloud • Applying ML techniques for securing transmission data between IoT device and fog cloud (drone).

D'Aloia *et al.* [213] proposed drones technology to map the parking area and finding empty parking spots. Therefore, collaborative drones and IoT devices in vehicles help the driver to find empty parking spots quickly.

D. CROWD MONITORING AND SECURITY

In smart cities, drones can assist policemen in security measures and safety enforcement. Due to the easy deployment of drones, they can be deployed rapidly to gather real-time data and support police operations in various cases such as robbery or traffic hit-and-runs [214]. Collaborative drones and IoT technologies such as human behavior recognition [215], motion detection [216] etc. can also help make cities smarter. Such collaborations between drones and IoT devices could make the surveillance process more effective and less expensive, as compared with a human workforce.

E. FOG COMPUTING

The integration of IoT devices and cloud computing will improve many smart cities applications due to the cost reduction and elastic resource provision. Clouds can be utilized for the data storage of IoT applications in smart cities. However, there are some restrictions on the feasible integration of IoT applications and cloud servers, such as the latency/response time, mobility, difficulty of adding heterogeneous devices, and issues related to context and location awareness. Bonomi *et al.* [217] proposed a fog computing architecture to overcome the above restrictions.

The concept of a 'Fog cloud' deals with improving the basic cloud computing service by offering small platforms placed at the network edges i.e. closer to IoT devices. Thus, fog computing provides an easy way to access the storage services very close to the actual applications. The response time is thereby reduced. Fog computing has been proposed to improve the efficiency and effectiveness of operation in many applications such as energy management, smart grid, smart building, smart transportation, and city monitoring [218]–[220].

Interestingly, drone-based fog computing is a new concept that was recently introduced in [221], while the collaboration between drones and clouds was discussed in [222], [223]. The authors of [221] introduced the advantages of collaborative drones to support IoT based fog computing based on drone mobility, flexibility and ease of deployment in smart cities. Thus, the collaborative drones can be used to load a fixed fog unit, or replace a faulty or lost unit in case of a disaster situation to support SAR.

X. DISCUSSION AND FUTURE DIRECTIONS

Recently, there have been various fruitful efforts towards enhancing the smartness of cities using advanced techniques and collaboration between different technologies. Drone technology, ML and IoT are key to making smart cities smarter, greener, and more sustainable.

As has been elaborated throughout this paper, a combination of drones and IoT devices could be used to perform the following tasks in a more efficient manner: data collection and dissemination, pollution monitoring, security and surveillance, traffic de-congestion, the provision of on-demand communication links, emergency rescue and response team support, agricultural monitoring, and many others.

However, before the promised collaboration between drones and IoT devices can be made fully functional, there are several open issues that need to be addressed. Table 12 illustrates the open issues and challenges of collaboration between drones and IoT for application in smart cities. Table 13 presents a compilation of the directions that future research in this field is expected to take, along with a listing of future insights.

The most pressing issues in this field include prolonging the battery lifetime of drones, constructing better and reliable communication protocols between the drones and the base stations, improving data security, route planning for the drones, and incorporating the capability to deal with a wide variety of heterogenous devices and sensors, while improving their present ability to make informed and intelligent decisions.

Related to toward the development of more intelligent and privacy-oriented drones, the use of ML for security with attention to privacy is mentioned in [226]. To keep the network secure from cyber-attacks, ML may be applied between the IoT framework and drones. ML can also be applied to detect attacks during training, and to identify security vulnerability using adversarial set-ups [227]–[230]., However, the current techniques do not eliminate all types of vulnerabilities. Therefore, advanced research is required to find better solutions for securing the collaborative networks of drones and IoT devices. Further to that, designing secure authentication techniques for heterogenous collaborative environment is another challenge. This issue was first identified by the authors of [231], who pointed out several shortfalls in the authentication techniques of smart cities.

XI. CONCLUSION

Smart cities are made up of intelligent things which can intelligently and automatically collaborate to enhance life quality, save peoples lives, and sustain resources. Recently, the advent of drone technology has played a vital role in enhancing many real-time applications of smart cities. Drones can be equipped with IoT devices, and can also be made to collaborate with IoT devices to make civilian life better in numerous ways and to protect our environment. The collaboration between drones and IoT has the potential to change our lives drastically via data gathering and real-time analysis to enhance life quality, lower energy consumption, and provide a high QoS, as well as many other advantages. This survey differs from the previous efforts in terms of its breadth, scope, and focus. In particular, we have focused on the new concept of the collaboration of drones and IoT for improving smart city applications. In doing so, we have presented a thorough study on the most recent works on drones and IoT collaboration, its importance, and its application domains in smart cities. We have also provided concise work challenges and research insights, which should be addressed to further enhance the effectiveness of such collaboration.

APPENDIX: LIST OF ABBREVIATIONS

- 4G: Fourth Generation (Mobile Network)
- AI: Artificial Intelligence
- 5G: Fifth Generation (Mobile Network)
- ANN: Artificial Neural Network
- BS: Base Station
- CCN: Convolutional Neural Network
- DL: Deep Learning
- DNN: Deep Neural Network
- E2E: End to End
- FANET: Fly Ad hock Network
- GA: Genetic Algorithm
- GPS: Global Positioning System
- ICT: Information and Communication Technologies
- IoD: Internet of Drone
- IoPST: Internet of Public Safety Things
- IoT: Internet of Things
- LoS: Line of Sight
- LTE: Long TermÂ Evolution
- M2M: Machine to Machine
- MANET: Mobile Ad hoc Network
- ML: Machine Learning
- NGN: Next-Generation Network
- NN: Neural Network
- PNC: Particle Number Concentration
- PSO: Particle Swarm Optimization Technique
- QoS: Quality of Services
- RFID: Radio Frequency IDentification
- RSSI: Received Signal Strength Indicator
- SAR: Search and Rescue
- UADC: Utility-based Adaptive Duty Cycle
- VANET: Vehicular Ad hoc Network
- WSN: Wireless Sensor Network

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