# *UAV and fog computing for IoE-based systems: a case study on environment disasters prediction and recovery plans*

# UAV and Fog Computing for IoE-based Systems: A Case Study on Environment Disasters Prediction and Recovery Plans

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***Abstract*:** In the past few years, an exponential upsurge in the development and use of the Internet of Everything (IoE)-based systems has evolved. IoE-based systems bring together the power of embedded smart things (e.g., sensors and actuators), flying-things (e.g., drones), and machine learning and data processing mediums (e.g., fog and edge computing) to create intelligent and powerful networked systems. These systems benefit various aspects of our modern smart cities – ranging from healthcare and smart homes to smart motorways, for example, via making informed decisions. In IoE-based systems, sensors sense the surrounding environment and return data for processing: Unmanned Aerial Vehicles (UAVs) survey and scan areas that are difficult to reach by human beings (e.g., oceans and mountains), and machine learning algorithms are used to classify data, interpret and learn from collected data over fog and edge computing nodes. In fact, the integration of UAVs, fog computing and machine learning provide fast, cost-effective, and safe deployments for many civil and military applications. While fog computing is a new network paradigm of distributed computing nodes at the edge of the network, fog extends the cloud's capability to the edge to provide better Quality of Service (QoS), and it is particularly suitable for applications that have strict requirements on latency and reliability. Also, fog computing has the advantage of providing the support of mobility, location awareness, scalability and efficient integration with other systems such as Cloud computing. Fog computing and UAV are an integral part of the future Information and Communication Technologies (ICT) that are able to achieve higher functionality, optimized resources utilization and better management to improve both Quality of Service (QoS) and Quality of Experiences (QoE). Such systems that can combine both these technologies are natural disaster prediction systems, which could use fog-based algorithms to predict and warn for upcoming disaster threats, such as floods. The fog computing algorithms use data to make decisions and predictions from both the embedded-sensors, such as environmental sensors and data from flying-things, such as data from UAV that include live images and videos.

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# 1 Introduction

With the rapid increase of population in cities and the continuous movement of people from rural areas to the cities, the challenges for city's administrators who are striving to maintain or enhance the city's services and the citizens Quality of Life (QoL) [1] increases. This push for the community to adopt and invest in new technologies to help city's administrators to not only control the city, but also to provide reliable, sustainable and high quality of services to the citizens. This results in adopting various types of embedded systems that rely on sensors, actuators, drones, machine learning technologies and different type of data processing mediums (e.g., fog and edge computing) to create intelligent and powerful internet systems, introducing the so called Internet of Everything (IoE) [2, 3], hence bringing the concept the Smart City (SC) as every thing becomes connected and able exchange data [1, 4]. IoE and SC technologies are rapidly becoming interested in utilising the advanced Information and Communication Technologies (ICT), such as robotics and Unmanned Aerial Vehicles (UAVs) [2] in order to provide convenient services. The goal of SC is to provide efficient infrastructures and services that satisfy citizens needs, whilst reducing costs. The European Network of Living Labs and EPIC (i.e., European Platform for Intelligent Cities) defined the SC as *"The use of discrete new technology applications such as RFID and Internet of Things through more holistic conception of intelligent, integrated working that is closely linked to the concept of living and user generated services"* [1, 5].

ICT aims at developing efficient infrastructures that involve dynamic monitoring and adjustments to the infrastructures to handle sudden occasion, such as environmental disasters and hazard. Environmental disasters are events that cannot be prevented [6]. The physical extent of the disaster makes it very hard and in some cases completely impossible for humans to react to it and face the problem [7]. In addition, after a disaster occurrence, it usual that most of communication infrastructures collapse due to the damage created by the disaster to the infrastructure [6], such as communication antennas, control stations, power resources etc. Nevertheless, some systems such as natural disaster management systems can be used to forecast that neutral disaster is approaching. Hence, their effects can be mitigated by adopting a proper early warnings systems and post-disasters recovery plans, thus aiding the communication systems that are essential to support disasters management systems. Therefore, the ICT recent trend is about adopting the use of UAV and fog computing as a data processing medium for disasters management.

UAVs can be adopted for both pre and post disasters systems processes. The UAVs are able to aid the pre disaster processes by providing a real-time data from the sky about any environmental changes that could lead to, or forecasting that, a disaster is approaching [1, 8]. UAVs can fly over certain areas in a given time-period and with a given update-frequency to monitor and assist in disasters prediction and taking actions when it occurs [5, 9]. Also, in post disaster situations, UAVs can assist rescue teams to find vulnerable people or maintain connectivity with vulnerable people and direct them to a safe areas and evacuation routes based on the information gathered when disaster is progressing.

Fog computing also can be adopted for both pre and post disasters system processes. Fog computing is use to gather and process data gathered from Wireless Sensors Network (WSN) in the pre disasters period. Fog nodes can be disrupted over the city and form a mesh network to process WSN data in real-time and report back to control stations [10, 11]. Fog node can be deployed with some machine learning algorithms to act-upon, and learn from, the data collected from WSN. Hence, fog nodes will be able to make intelligent and powerful networked systems for natural disaster forecasting [1, 12]. Although fog nodes can be very useful for pre disasters system processes, they are least effective/important in post-disasters processes as they might be collapsed/damaged by the disaster. However, they might able to indicate that a particular area might be affected.

This chapter highlights the importance of UAVs and fog in serving natural disaster management systems. UAVs can work independently or in collaboration with fog nodes in the monitoring processing by involving the cameras and WSN to collect and analyze huge amounts of data in real-time. Fog nodes assists the UAVs in processing data due to UAVs on-board micro-processors limited capacities. The remainder of this chapter is organised as follows: Section 2, provides an overview of the disasters management related technologies of IoE, UAVs and fog computing. Section 3, addresses the general technical connectivity of deploying both UAVs and fog nodes for disasters management. Section 4, presents the stages of a natural disaster along with the use of UAVs and fog nodes in disaster monitoring, early warning and planning search and rescue missions. Finally, Section 5 concludes this chapter.

# 2 Background

Smart Cities (SC) are cities that adopt and invest in smart solutions and recent technologies to improve the Quality of Life (QoL) for the citizens. SC vision is not only to enhance the QoL by creating efficiency, improve sustainability, servicing needs and better utilising resources, but also to reduce the negative impact on the environment [1] by early warning for natural disasters. The SC concept integrates Information and Communication Technology (ICT), and various physical devices connected to the network to optimize the efficiency of SC operations/services and make the the citizens connected [13, 4]. SC technologies allow infinite control for administrators and serveries to interact directly with both community and infrastructure to monitor what is happening in the surrounding community/environment as well as managing urban flows and allow real-time responses [4]. Therefore, SC could be more prepared to respond to challenges (i.e., disasters) than normal cites with a simple traditional relationship with its citizens, community and environment [14]. Important properties of SC systems and applications are the robustness, resource efficiency, adaptable and cooperativeness. Thus, SC systems bring together the power of Internet of Everything (IoE), Unmanned Aerial Vehicles (UAVs) and Fog Computing to serve public needs and improve the QoL.

## 2.1 Internet of Everything

Internet of Everything (IoE) is the network of physical devices which is able to establish connections among each other and exchange data. In IoE area, the concept of *Everything* refers to anything able to connect to the Internet and exchange data over this IoE network, thus, this could point to a diversity of devices (e.g., wearable), vehicles (e.g. smart cars), smart home appliances (e.g., smart appliances), and so forth.

Cisco IBSG estimated that approximately 50-billion sensors will be connected to the IoE as soon as 2020 [10, 15]. According to IBM, currently we are creating $2\dot{5}$ Quintillion bytes of data every day through different sensing devices [16] world wide. International Data Corporation predicts that from 2005 to 2020, the digital universe will grow from 130 exabytes to 40,000 exabytes, or 40 trillion gigabytes (i.e., more than 5200 gigabytes for every human on earth in 2020) [16]. It is clear that we are entering the era of "Big Data" which is accelerated by Unmanned Aerial Vehicle (UAV) which feed the network with heavy-weighted data packets from its on-board camera [10, 17, 11]. UAVs emerging technology becomes widely accepted for video surveillance applications/systems due to its abilities in monitoring a target from the sky using the on-board cameras and sensors to collect huge amounts of data in real-time and transmit them to a ground stations.

Information and Communication Technology (ICT) is continuously enhancing its infrastructure to provide appropriate data processing mediums to serve the massive data generated by the IoE. Thus, providing secure transformation channels, rapid processing, and proper use of data. ICT based operation models that organisations adopt, have been swinging from centralization (e.g., mainframe) to decentralisation (e.g., client-server) and vice-versa. The latest swing towards centralisation embraces *Cloud* computing by making software, platform, and infrastructure available to organizations as services (i.e., anything-as-a-services) or utility in return for a fee. However, research has proven that cloud may not be a feasible solution for IoE data due to several factors such as high latency [18], network bandwidth, reliability, and security [18, 19]. A new swing rises toward $fog$ computing is developing ICT and become future trends, thus, attracting the Research and Development (R&D) community.

IoE-based systems bring together the power of embedded smart things (e.g., sensors and actuators) and flying-things (e.g., UAVs) along with the data processing mediums (e.g., fog and edge computing) to create intelligent and powerful networked systems.

## 2.2 Unmanned Aerial Vehicle (UAV)

The continuous development of robotics resulted in serious enhancements to the design and capabilities of UAVs. In varying sized inexpensive UAVs equipped with microprocessors, local data storage as well as on-board sensors, actuators and cameras. In addition, most UAVs are supported with a wireless communication device that enable UAVs to establish various type of connections with either other UAVs or ground controllers. UAVs are reliable and operate with high level of flight stability, unlike a few years ago when UAVs could lose communication or lose sustainability which leads to UAVs overturning. UAVs were mainly developed for military applications, but also numerous civil applications have recently emerged and contributed in improving UAV capabilities in a more cost-effective manner [1]. The on-board UAVs system is usually able to offer various type of services ranging from sensing and navigation, to data gathering and processing besides the transformation of these data to ground stations. UAVs also called drones, have received increasing interest for environmental and natural disaster monitoring [20], border surveillance, emergency assistance, search and rescue missions, and relay communications [1, 20]. UAVs are useful, especially small multicopters, in monitoring practices due to their ease of deployment and low acquisition and maintenance costs [20].

The incredible advancement in developing small and cheap UAVs has resulted in having the UAVs deployed and adopted in different industries, also their reliability and efficiency makes it more acceptable for the public. The typical architecture of a UAV consists of number of inter-connected components and sub-systems that allows UAVs to operate to such high performance. The main systems and components are flying control systems including landing processes, communication control system, monitoring system, sensors, actuator and data processing system.

Two main types of UAVs are there, the types are identified from the actual architecture of the UAV, it can be either fixed-wing UAvs architecture or rotary-wing UAVs architecture [21]. Fixed-wing UAVs are airplane-like vehicles. These UAVs perform horizontal Takeoff-and-Landing operations, such as passenger airplanes. While, the rotary-wing UAVs perform Vertical Takeoff-and-Landing. Hence, they can hover on a specific locations during the flight, this feature especially important for surveillance UAVs. Some UAVs that are generally formes as wireless ad-hoc network called Aerial Ad-Hoc Networks (AANETs) [22, 23]. AANET vehicles have the abilities to move at high speeds or, on the contrary, to maintain specific positions when it is needed [9], this type found in helicopter-like architecture. Moreover, UAVs make advantage of the fact that air-to-air communications usually are less affected by disruptions than ground-to-ground communication links [9].

Different technologies has been used for the communications within the UAV networks to establish sustainable communication among UAvs or between a UAv and base stations. Table 1 presents some of the most common technologies used in UAVs. It worth noting that several UAVs development do not rely on only one technology but multiple ones are adopted. This is extremely important for UAVs to have backup plan for when one UAV system is not available due to failures. Thus, there is still the possibility to use an alternative one for the connection with the other UAVs or ground station. The IEEE 802.11 is always the main choice for designing UAVs networks due to its massive use in commercial wireless devices as it can offers high bandwidth [9]. However, IEEE 802.1 technology would only support star or multi-star topologies. Other technologies would be required to implement the ideal case of hierarchical or flat mesh networks [9, 24]

Table 1: Most common technologies used in UAVs networking [9]

| Technology | Type | Available at |
|---|---|---|
| VHF, UHF | 915 MHz (UHF) | [25] |
| IEEE 802.11 (Wi-Fi) | IEEE 802.11a | [26] |
| | IEEE 802.11b | [27, 28] |
| GPRS, 3 G, LTE | | [29, 30, 31] |
| Satellite | | [31, 32] |
| Airmax | | [33] |

### 2.3 Fog Computing

Smart cities systems applications rely mostly on data provided from sensors, actuators, and other wireless devices. These applications and systems are normally integrated with a cloud-based data centre to perform the the required processing and analysis of the data for various purposes. Cloud-based approach is adopted for long term now and it was good enough for data storage, powerful processing, and advanced services. However with the emerge of IoE and UAVs the generated data every second becomes much bigger than it used to be, hence a greater demand on developing and new data processing mediums becomes essential. Nevertheless, integrating IoE applications with the cloud has many restrictions as the cloud cannot deal with the essential characteristics and requirements of IoE applications such as highly heterogeneous devices, mobility, low-latency responses, location and context awareness [1, 10]. Fog computing was proposed by CISCO [10, 17] to overcome these restrictions.

Fog computing can improve the cloud computing paradigm by offering smaller platforms located at the network edges closer to the IoE devices and networks. Fog computing offers the ability to extend the storage, networking and computing capabilities of the cloud but with better positioning within the network in relation to the end-devices, such as IoE smart Objects, that require this data with low latency [10, 17]. Fog computing is not a replacement to cloud, but only extends the services to the edge of the network with the ability to reduc latency and improve availability to the end-users. Using fog computing, an application in a certain area can utilize an architecture that uses a dedicated computer available locally. This provides access to computing and storage services at a smaller scale, but very close to the application, thus reducing response times and providing localized services. As a result, access to cloud services can be minimized, yet efficiently accessible when needed. [1, 10].

A new paradigm of UAV based fog computing was introduced recently [12]. This paradigm brings togather the power and advantages of fog computing and UAVs to better support IoE systems and applications by utilizing UAVs services along with the support of fog nodes services to achieve certain tasks forming UAV-Fog networks. UAV-Fog computing can provide flexibility, mobility, and fast deployment features to support IoE systems in a smart city. UAV-Fog can be used for different purposes, such as disaster management systems. For example, in disaster situations, UAV-Fog can be deployed to support search and rescue operations.

# 3 UAV-Fog Collaboration and Coordination

This section of the chapter discusses the network between UAVs and fog nodes, including both collaboration and coordination modes for the networked UAVs and fog nodes, see Figure 1. Simply put, the horizontal networking among UAVs (e.g., UAV-2-UAV) or fog nodes (e.g., $\mathcal{F}$og-2-$\mathcal{F}$og) is a collaborations mode. This collaboration mode triggers when two or more networked objects (i.e., UAV or fog) are networked to serve one user or works toward achieving one task. For example, two UAVs monitor the two sides of a long-bridge and report to each other upon hazard detection to take action like informing the rescue team or closing down a bridge, while the vertical networking among UAVs and fog nodes (e.g., UAV-2-fog or fog-2-UAV) is a coordination mode. This coordination mode triggers when a UAV networks with a fog node or vice versa. Such mode occurs when a process needs to be carried out over several steps. For example, due to the limited processing capabilities of the UAVs, they will not be able to process live images taken by its on-board camera, therefore, fog will help in performing image processing for these images and report back to the UAV.

## 3.1 Collaborative UAVs

The minimal design requirement of any UAV must includes a micro-controller and wireless transceivers [34]. UAVs are equipped with a micro-controller to process received commands and allow to be externally controlled via remote controller where desired. While the wireless transceivers are embedded in UAVs to allow UAVs communication among themselves and with other objects on the ground, such as fog nodes. When two or more UAVs are communicating among each other to achieve one task, they are forming a so called UAV *ad-hoc* network. The advances in ad-hoc communication paradigm among UAVs suits the main requirements of UAVs systems, which are: 1) node mobility and 2) adaptive network topology. The ad-hoc network allows data packets to be shared among networked UAVs with no delay (i.e., in real-time) [34, 35, 36]. Thus, the shared data packets are routed through the networked UAVs with a path taken depending on the used routing protocol. According to [34, 37], there are two main routing protocols, proactive routing protocol and reactive routing protocol. In proactive routing, the networked UAVs knows the shortest network path to each other. Thus, the shortest data is logged locally and updated frequently upon UAVs location updates. Hence, due to the big amount of packets transmitted over the network regularly to maintain connectivity, the overall available network bandwidth will be reduced. In reactive routing, the shortest paths needs to be known only when data packets needs to be sent among UAVs. Thus, reactive routing requires more time compared to proactive routing that knows paths ahead of time which allows a low end-to-end time delay for

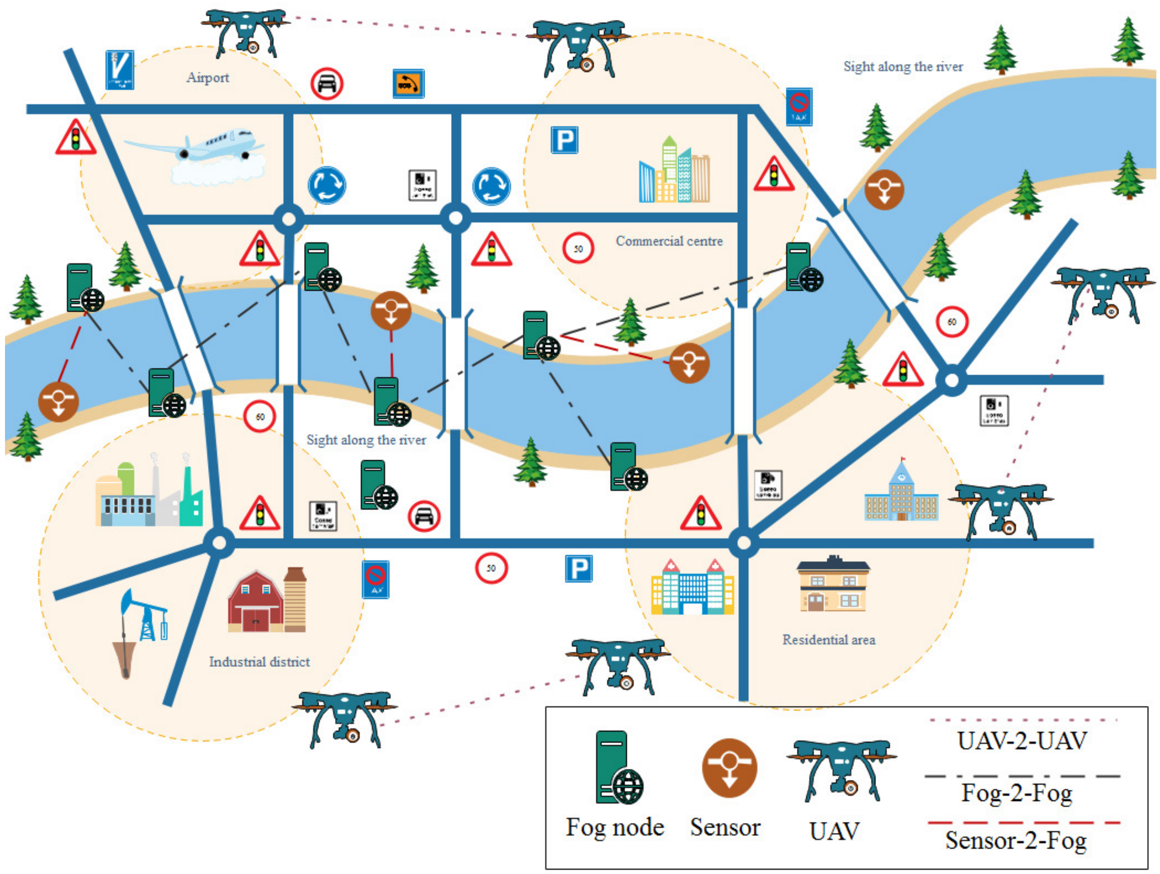


Figure 1: Smart City with UAvs and Fog computing

sending data packets. Therefore, when choosing a routing protocol, a trade-off must be made between time-delay and available bandwidth.

Most systems that adopt UAVs technologies are notable with their rapid changes in either the network topology and/or the networking connectives, hence, UAVs are adopted based on their abilities to operate in a highly dynamic environment [8]. For example, as most UAVs are self-programmed during the time of operation, some mission conditions may change for various reasons, such as weather conditions changes that may effect UAV connectivity, and thus it requires the UAV to act accordingly. In such a scenario, if a UAV has no opportunity to establish an ad-hoc network with other UAVs to regain signal to complete the initial mission or return to ground, the UAV will be highly unreliable [38]. Therefore, the adoption of the ad-hoc network in UAVs systems will feature the connectivity among UAVs, and hence enhances the reliability of the UAVs [38]. In addition, UAVs battery life is another important reason where the collaboration among UAVs is important. Networked UAVs could help in reducing the drawback of UAV limited time of operation by triggering the UAV to outsource the processes to another UAV before it go offline. The majority of UAVs have about 20-30 minutes of flight time [39], and the way to extend network lifetime is by alternate network responsibilities among UAVs through the ad-hoc network.

Due to the ad-hoc nature of UAVs, the topology of the network may change over time. Also, UAVs can consist on different types of UAVs organized in different hierarchies [9, 8]. Such that, a sub-group of UAVs may only be equipped for long-range communications services in order to communicate with external networks. While, another sub-group of UAVs maybe designed for sensing and monitoring tasks only [40], hence carrying some specific sensors and cameras. Each group would share the data packets with their equals UAVs within the group, but they also can send the information to other sup-group when required [9]. This flexibility, in terms of topology and hierarchy, allows UAVs to adapt to variety of systems needs. The most common wireless technologies used for UAV–2-UAV communication is the IEEE 802.11 standards, While IEEE 802.115.4 is used for other UAV communications with other connected objects [9].

## 3.2 Collaborative Fogs Computing

This section discusses the network model that supports $\mathcal{F}$og-2-$\mathcal{F}$og Collaboration. The Collaboration between fog nodes is about gathering multiple fog nodes to perform/achieve a specific task in a certain situation or scenario. Fog computing become members of a federation because of their capabilities that satisfy the needs and requirements of a situation assigned to this federation for handling. Hence, fogs are described and discovered for federation and then selected for a particular federation according to *planned* and *ad-hoc* federations [41].

- Planned federation, formed at design-time, all its fog nodes participants are already identified and ready to act according to a task's needs and requirements.
- Ad-hoc federation, formed at run-time, fogs are joint together according to certain occasions where each fog can empower the federation with various types of processing and controls that enhance.

Consider a scenario where a fog node accepts a data-processing request from a UAV. Fog will process the request and respond back to the UAV in real-time. However, when the fog node is busy processing other UAV's requests, it may only be able to process part of the payload and offload the remaining parts or offload the whole request to other fog nodes. Therefore, either *planned* or *ad-hoc* should be supported by the fog so it can collaborate with the other fog nodes in the network to serve the request sent from the UAV. Hence, there are two approaches to model interactions among fog nodes. 1) the centralised model, which relies on a central node that controls the interactions among the fog nodes in one domain. 2) the decentralised model, which relies on a universal protocol that allows direct interactions among fog nodes so that each fog identifies the best fog node to collaborate with. In the decentralised fog model, the fogs are distributed as a mesh network, hence there is no need for a centralised fog node to share the state of fog nodes and its location. Instead, each fog node runs a protocol to distribute their updated state (e.g., load and location) information with the neighbouring nodes. Thereafter, each fog node will hold a list of best fog nodes which can be updated periodically. The decentralised model is more suitable for scenarios where a UAVs system is in operation as fog node can cope with the mobility of UAVs, hence more flexibility in data acquisition. The process of selecting and sorting the best neighbouring fog nodes is based on the possibilities of collaboration between the fog nodes and able to provide data processing with low latency and high reliability. More details on such $\mathcal{F}$og-2-$\mathcal{F}$og collaboration can be found in [10].

## 3.3 Coordination of UAV and fog

Integrating UAVs with the fog computing paradigm can boost the reliability of service times and availability, thus enabling many applications to have advanced services utilization in smart cities. Fog computing can provide powerful services for the operations of the UAVs. For example, using a fog based system to process and analyse the image taken by the UAV camera in real-time [42, 43].

Having the coordination between UAVs and fog nodes is extremely important when it comes to the systems where large amount of data is collected every millisecond. The coordination of UAV and fog nodes is useful for rapid data processing, thus fog nodes will act as external processing unit for the data captured by UAV, such as sensed data or regular stream of live images. This huge amount of data will require immediate processing before its importance vanishes. Moreover, sensed data is generally where different types can be collected in different time-interval, such as images or sensors data streams at defined time intervals, critical location data, and mission's commands. Hence, UAVs on-board processors are not powerful enough to cope with all these data types especially when it come to systems where real-time data processing is essential for decision making [1]. Therefore, the coordination of UAV and fog is especially important in the dissemination of critical data. Important events should be transmitted reliably at all costs. Therefore, the aim is to achieve low latency, high reliability, and a high success ratio of data delivery in UAVs and fog nodes data routing in mission-critical applications, such as disaster prediction systems.

Effective coordination among UAVs and fog nodes relies on timely information sharing. However, the time varying flight environment and the intermittent link connectivity pose great challenges to message delivery. The main objective of UAVs and fog coordination are threefold:

- System latency: The objective of the coordination networking among UAVs and fog nodes is to minimise latency from timely sensitive application, such as disasters hazard monitoring systems where the time between the hazard detection and the delivery of message to rescue team is very critical.
- System reliability: this is about the success ratio of data packets delivery. In UAV-Fog packets delivery, the minimal packets losses and faster sharing-time, the higher is the reliability. Therefore, in the scenario of disaster systems, provide

reliable communication for critical data is essential to ensure that the sensed data is being transmitted to the desired destination successfully.

- System self-adaption: the networking protocols should be able to deal with the mobility of UAVs. Hence, UAVs must always maintain a good connectivity with the nearest fog nodes to transmit its data. It is worth noting that this process could be an energy intensive process.

During UAVs time of operation, the weather condition may change and some of the UAVs may be disconnected. If the ad-hoc UAV system cannot support this scenario, it can maintain the connectivity through fog computing. This connectivity feature enhances the reliability of the UAVs system. Therefore, in a UAV-Fog network all UAVs will be connected to a ground fog node via wireless communication.

To provide robust UAV network control and information acquisition, emphasis must be placed on communication security. Malicious attacks are closely related to UAV network operation, so robust communication protocols play a critical role.

The coordination between UAVs and fog nodes also helps in ensuring privacy and trust within the UAVs systems by monitoring all the privacy policy for the shared data. For example, video footage that is recorded by a UAV during the disaster response may contain a sensitive frames (e.g., dead or wounded people) that should be censored [44]. Indeed, this will raise a number of important questions about the information privacy and trust when using a UAVs to gather multimedia information (e.g., live images) about the people who affected by a natural disaster [44]. Thus, fog nodes could have the abilities to run extensive image processing to determine whether the shared images may breach any privacy policies.

# 4 UAV-Fog for Environment Disasters Management

Natural disasters occur frequently worldwide and they are considered as a factor that affects human life and development [7]. Natural disaster are significant adverse incidents result from some natural processes of the earth (e.g., earthquakes and floods) or geological processes (e.g., volcano) [45]. A natural disaster can severely impact the environment and people's lives and infrastructures [46], such as telecommunication systems. This raises big challenges to traditional disaster monitoring systems and makes the rescue actions harder to achieve and sometime ineffective. However, natural disaster severity highly depends on the affected population's resilience (i.e., the ability to recover) as well as the infrastructure available to handle such events.

In natural disasters, such as flood, the rescue and emergency response management is very challenging. Hence, early efforts in event/circumstances monitoring, analysis, rescue operations and emergency arrangements are extremely important [1]. In most of these state of affairs, rescue teams cannot easily and quickly enough reaches vulnerable people and also most of the infrastructures, such as communication systems may be damaged because of the impact of the disasters [47]. Thus proper management and early actions are significantly required for such circumstances.

Utilizing UAVs and fog computing can effectively improve the disaster monitoring/prediction in such circumstances of a natural disasters [48, 1, 49]. Fog computing and UAVs can be used as flexible and reliable networking infrastructure for data sharing and monitoring the situation in real-time. In addition, they are very safe tools for monitoring the current situation without risking human lives dealing with the disaster.

## 4.1 Disaster Management Stages

It is important to understand the nature of a disaster and its stages to effectively respond to them and developing a feasible disaster management and prediction method. The disaster stages concept has been used in past decades to describe and examine disasters and to organise emergency management processes [7]. The continuous processes of disaster management known as disaster management cycle [50, 7], is the most common stages of a disaster management cycle shown in Figure 2, thus they cover the following processes [51]:

- Predicting and planning before a disaster can happens. The goal is to minimize the effects of a disaster by give early warning and identifying risk zones. Also, planing and preparedness to how to respond to a disaster.
- Rescue operations and response to emergencies when a disaster happen. The goal is to minimise the hazards formed by a disaster.
- Recovering after the disaster. The goal is to assess the damages created by a disaster. Also, acquire some knowledge that can be used to prepare and evaluate a prediction model for such disasters.

Response time to disaster hazard during a natural disaster is key in saving human lives, especially those who live/work in the affected areas. UAV-Fog can assist disaster management processes, thus they can improve the processes of acquiring real-time data from the environment, through the the embedded environmental sensors connected to the fog nodes, or data from the sky, through the sensors and camera connected to the UAVs. UAV-Fog can assist with the following processes of a disaster management:

1. Disasters Monitoring, Preparedness and Early Warning.
2. Situational Awareness, Logistics, and Evacuation.
3. Search and Rescue Missions

Each disaster management process imposes a set of UAVs and fog nodes tasks. Each task may require different lengths of time and with varying priority levels [44]. Therefore, a static network of fog nodes and UAVs is no longer sustainable for disaster

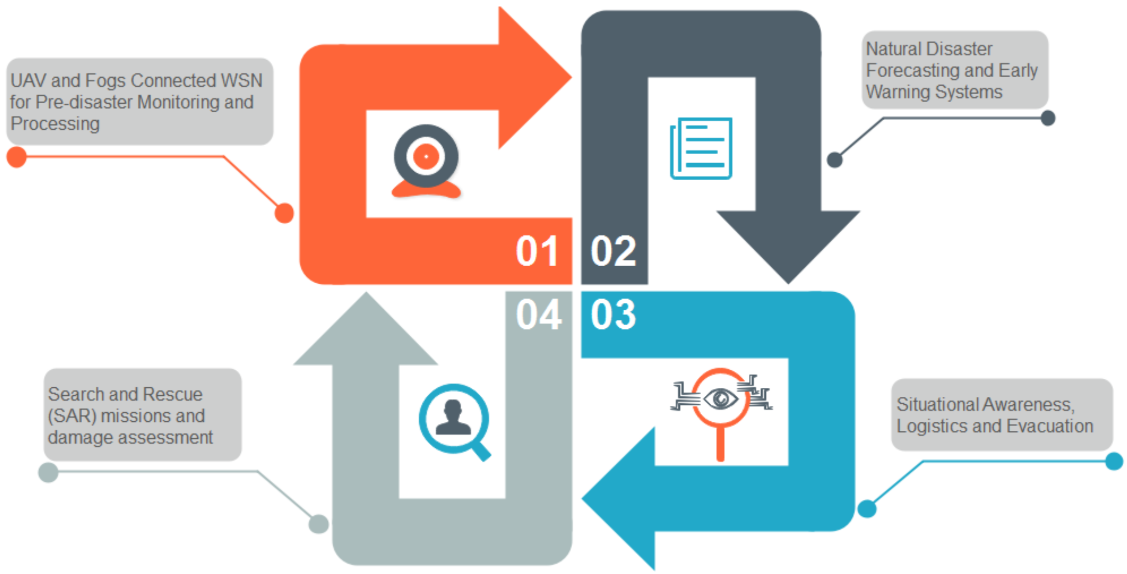


Figure 2: Natural Disaster stages

managements processes. Instead, the network must continuously evolve in topology and capability, having reasonable capabilities of networking coordination between UAVs and Fog nodes as well as collaboration features among them (i.e., UAV-2-UAV and $\mathcal{F}$og-2-$\mathcal{F}$og) so they can be self adapted with situations, when a disaster is progressing.

## 4.2 Disasters Monitoring, Preparedness and Early Warning

At this stage of disasters management processes, the UAVs and fogs systems are classified into three main groups: monitoring, preparedness, and early warning systems. This classification follows the disaster management phases, where the forecast group of systems refers to the prevention, preparedness and rescue operations for a natural disaster. The prevention covers the monitoring of a disaster through all stages as UAV-Fog system will provide disaster information during all the phases. While the preparedness, includes all procedures required for how to deal with a disaster hazards, and the rescue operations refers to a disaster response and recovery.

### 4.2.1 Disasters Monitoring

The UAVs technologies and advanced Wireless Sensor Network (WSN) technology that often used with fog computing has recently gain more attention and improvement, thus it is being used for many disasters management systems, especially in disasters monitoring systems.

Some disaster monitoring systems require the WSN sensed data to be transmitted in real-time to a control station through a multi-fog communication. For example, when a hazard detected by a sensor, such as a flood sensor, the fog nodes should be able to acquire this data from sensors in real-time and transmitted straight to the disasters control station (either fog-2-station or multi-fog-2-station) where admins/operators can make decisions and arrangements. However, some disaster monitoring systems are delay tolerant and do not require the WSN sensed data to be transfer to the desired destination in real-time. These types of systems are normally collects the data for historical data archiving and disasters pattern creation/recognition. For example, systems that monitor infrastructure-health and environmental changes. In such scenarios, UAVs and fog computing can be use as data collectors from these distributed sensors to transfer them to the main stations [1, 52, 53] when they are not busy with higher priority tasks that requires real-time/instant attention. In flood disaster scenarios, multiple deployed WSN collect physical information, such as the water level at the monitored bank and vibration/displacement on the territory. Thereafter, the data gets transmitted to connected fog nodes, where the information is logged and processed.

In disasters monitoring events, the objective is to monitor certain areas in a given time-period and with a given update-frequency to assist rescue reams and operations. Hence, the UAVs establish communication links among UAVs and links with other higher level networks (e.g., fog nodes) and ground base stations. Some research to enhance communication links among UAVs, UAVs and WAS and/or fog can be found in nodes [1, 54, 55]. Thus, it is common to find UAVs-to-ground communication links in order to transmit data from the UAVs for fog nodes and/or ground stations. The UAVs can pass over WSN and wirelessly collect their sensed data. Thus, this way they can save the WSN energy by reducing the communications and extend the battery life of WSN [1, 56]. Although, the UAVs are efficient for monitoring purposes and situational awareness, there are different regulations that apply to the usage of UAVs, depending on the country [44]. However, during a disaster, a special authorisations are granted to UAVs to help first disasters monitoring and assessing the situation [44].

### 4.2.2 Preparedness and Early Warning

The preparedness processes for a disaster have no predefined duration and could start before or within the actual occurrence of a disaster. During the preparedness stage, the data acquisition from WSN is normally used by the connected fog nodes to perform some processing and analysis to assess the probability of disaster occurrences, thus, using UAVs as source of live data from the sky, such as live images. UAVs have limited use at this stage as the processes during this stage is more like identifying the suitable methods to achieve the minimal effects of a natural disaster, including the rescue operations required to elevate the hazards caused by a disaster. However, the WSN could have the most use for ground based environment measurements, because the operational time of WSN can be sufficient to capture the different trends in the sensed environment natural parameters that could help for disaster early warning.

Early Warning Systems (EWS) represent the essential part of the preparedness towards natural disasters [7], hence, there are lots of efforts focused on developing an efficient EWS. For example, the UrbanFlood [1] is a European project that aims to investigate the use of sensors within flood embankments to support an online EWS, and real-time emergency management. EWS uses the data from both UAVs and fog's connected WSN to predict and forecasting a natural disaster by processing and analysing the structural and environmental monitored data. Hence, the goal of most EWS is to create a connected service's platforms that can be used to link WSN data with a predictive models and emergency warning systems. Thus, the warnings and information produced by these platforms can be accessible by all people within an area that in a high-risk of a threaten natural disaster attack.

## 4.3 Situational Awareness, Logistics, and Evacuation

The start of this stage occurs as soon as a disaster take place in which parts of the environment and topographical region are damaged and become unusable for vehicular traffic or people habitation. The employment of UAVs and fog computing at this stage can be useful in reporting real-time data from the area affected by a hazard. The critical tasks carried by the UAVs during this stage involves the process of establishing ground communication processes with the affected people, then transferring the gathers data to the control station and/or rescue team raise awareness about vulnerable people. This monitoring processes at this time of the disaster will help in assessing the situation as UAVs and fog nodes are able to provide a real-time data for the surrounding that can help in accurate assessment of the situation/hazard. For example, the UAVs fly over an affected region by a flood and send live images to the rescue teams about any possible vulnerable people as per Figure 1.

### 4.3.1 Situational Awareness

Situational Awareness is part of the disaster management processes where the main goal is to gather enough information when a disaster is progressing. Gathered data will significantly help in providing safe and secure recommendations to the vulnerable people who are endanger from the disaster, as well as the rescue teams deployed on the disaster area [39]. Both UAVs and fog connected WSN can be used during this stage to transfer information about the affected areas as well as the vulnerable people. Although, some fog nodes and their connected WSN may also be affected by a disaster, they still used as indication that particular area might be affected by a disaster in which caused the damage for the planted fog nodes and WSN. The fog nodes and it connected WSN infrastructure that is partially in operational can be used in conjunction with the operated UAVs. Hence, video/images collected presents an overview of the situation. Also, affected people might also use various social-media or forward messages and/or images via the UAVs observing them, to the rescue team or control centre so they can get help.

[1] http://www.urbanflood.eu/

### 4.3.2 Logistics and Evacuation

UAVs could have more advantages at this stage cumbered with fog nodes and WSN. The UAVs can be significantly useful due to their ability of movement and flying to a targeted area. UAVs can be used for delivering first-aid equipment in very convenient way for all areas that are hard or not accessible due to the infrastructure damages caused by a disaster, also rural areas that are surrounded by forests. This will be significantly crucial to deliver the logistical services which are delay-sensitive [9] and it is important to deliver to affected people as soon as possible, such as delivering medication or medical resources. In addition, UAVs can maintain connectivity with vulnerable people and direct them to a safe areas and evacuation routes based on the information gathered during the disaster progression.

## 4.4 Search and Rescue Missions

The main goal to Search and Rescue (SAR) missions is to search for and to rescue the unfortunate people that happen to be lost, trapped by debris or injured during a natural disaster. The first 72h are after a disaster are the most critical [7, 39, 44] as SAR operations on its peak where the rescue teams need to safely finds the survivors in disaster situations as well as give them right assistance. Hence, the goal of SAR is to help in taken a quick actions to preserve peoples lives.

To increase the effectiveness of SAR missions and rescue teams, different technologies must be used at the same-time, such as WSN, social networks, autonomous UAVs, data processing mediums (e.g., fog nodes) and satellite observations [7]. Therefore, UAVs and fogs can be used to help in SAR operations significantly as the are able to provide instant and real-time data about the surrounding environment. UAV and fog connected WSN are used in disaster situations where continuous updates are needed to are where rescue teams cannot reaches easily and/or safely to the target area due to debris or other obstructions. UAVs provide a great surveillance tool as it can fly over the targeted area and relay information, such as capturing images and video for a specific target, back to the rescue workers to keep them updated. In such event, UAVs networks must maintain both connection and throughput between individual UAVs within the network and the ground station or the fog nodes forming the UAV-2-UAV, UAV-2-station and/or UAV-2-fog. However, the Videos or images footage collected by UAVs are different in substantially from images acquired on the ground [57], therefore, such aspect should be taken into account when designing the image processing algorithm for the UAVs use for SAR missions.

# 5 Conclusions

Smart Cities (SC) adopts and invests in smart solutions and recent technologies (e.g., UAVs and fog computing) to improve the Quality of Life for the citizens. SC main goal is to enhance the QoL by creating efficiency, improve sustainability, better services utilization as well as reducing the negative impacts on the environment, such as early warning systems for natural disasters. UAV and fog computing have been introduced recently to bring togather the power and advantages of fog computing and UAVs to better support IoE systems and application by utilizing UAVs services along with the support of fog nodes services. UAV-Fog computing can provide flexibility, mobility, and fast deployment features to support IoE systems in a smart cities. Also, UAV-Fog have a significant advantages for disasters management systems as it helps in disaster situations to deploy services supports for all pre-disaster monitoring, forecasting and all search and rescue operations. During disasters, UAVs fly over an affected regions to collect live images and videos to help in assessing the situation and relay to the rescue teams about any possible vulnerable humans. UAV in conjunction with fog computing presents a promising future technology for disaster management systems.

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