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Low-Altitude UAV-Based Internet of Things Services: Comprehensive Survey and Future Perspectives

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Abstract*—Recently, unmanned aerial vehicles (UAVs), or drones, have attracted a lot of attention, since they represent a new potential market. Along with the maturity of the technology and relevant regulations, a worldwide deployment of these UAVs is expected. Thanks to the high mobility of drones, they can be used to provide a lot of applications, such as service delivery, pollution mitigation, farming, and in the rescue operations. Due to its ubiquitous usability, the UAV will play an important role in the Internet of Things (IoT) vision, and it may become the main key enabler of this vision. While these UAVs would be deployed for specific objectives (e.g., service delivery), they can be, at the same time, used to offer new IoT value-added services when they are equipped with suitable and remotely controllable machine type communications (MTCs) devices (i.e., sensors, cameras, and actuators). However, deploying UAVs for the envisioned purposes cannot be done before overcoming the relevant challenging issues. These challenges comprise not only technical issues, such as physical collision, but also regulation issues as this nascent technology could be associated with problems like breaking the privacy of people or even use it for illegal operations like drug smuggling. Providing the communication to UAVs is another challenging issue facing the deployment of this technology. In this paper, a comprehensive survey on the UAVs and the related issues will be introduced. In addition, our envisioned UAV-based architecture for the delivery of UAV-based value-added IoT services from the sky will be introduced, and the relevant key challenges and requirements will be presented.

***Index Terms*—Drone, Internet of Things (IoT), machine type communication (MTC), machine-to-machine (M2M), unmanned aerial system (UAS), unmanned aerial vehicle (UAV), unmanned aerial vehicle data processing.**

I. INTRODUCTION

IN THE near future, millions of unmanned aerial vehicles (UAVs), also known as drones, are expected to be rapidly deployed in diverse sectors of our daily life performing wide-ranging activities from delivering a package to diving into water for a specific underwater operation [1].

For instance, the registered number of drones in use in the U.S. exceed 200 thousand [2] just in the first 20 days of January 2016, and that is after the USA Federal Aviation Administration (FAA) started requiring owners to sign up [3]. Regarding their utilization, UAVs' applications can be broadly divided into civilian and military models. The former can be utilized for governmental or nongovernmental purposes; e.g., employing UAVs in rescue operations to recover from large-scale disaster events, such as the great East Japan earthquake [4], the natural disasters of Indonesia [5], and the earthquake of Nepal [6]. UAVs were then used to distribute nutrition and medical items among the victims as well as to coordinate the operations of relief teams. Military UAVs have also been used in the past decade. Recently, a USA presidential candidate proposed using drones for monitoring USA borders as a countermeasure against illegal immigration.

However, in the near future, drones will be used not only for public protection and disaster relief operations [7], [8] but also for many other civilian, commercial and governmental services. Some good examples are surveillance and reconnaissance [9], public safety [10], homeland security [11], [12], forest fire monitoring [13], environmental monitoring [14], security and border surveillance [7], farming [8], or even Internet delivery [15], [16], architecture surveillance [17], goods transportations [18], [19] such as Amazon Prime Air [20] designed to safely deliver packages to customers within 30 minutes using small drones. With their countless applications, UAVs will soon be influentially a part of our daily life; a necessary technology similar to today's smartphones. Moreover, there are unique services that can be provided only from height (i.e., the sky). Drones are, therefore, highly useful for high-risk life-threatening operations such as flying over a volcano to inspect its activity level or above a radiation-contaminated region.

However, deploying a massive number of UAVs would bring important challenges. Ensuring collision-free and seamless operations of UAVs in the conventional air traffic is critical for the wide acceptance of this technology. Therefore, an effective collision avoidance (CA) system would be crucial, ensuring for the aviation authorities a seamless integration of UAV "flights" into the current air traffic control (ATC) procedures and maintaining safety-of-flight levels [21]. Public's apprehension, or maybe rejection, is also one of the issues that may impede the wide use of drones in the sky. This apprehension is logical as drones may disturb the privacy of individuals by passing above them and remotely monitoring their activities. Authentication, security, and trust are also important factors for the public acceptance of drone-based services. Effectively and for instance, when a drone is used to deliver a package to an individual, there should be a way to mutually authenticate the drone and ensure that the individual is the right recipient and the drone is the right one to deliver the package and not another malicious drone trying to invade the individual's pri- vacy. Thus, an efficient planning of the drone's routes in the sky should be carried out such that it ensures that people's privacy is not intimidated.

Another worth-pondering issue relates to sky pollution. Indeed, thousands of drones flying in the sky, following ran- dom paths, could be perceived as sky pollution that may impact the comfort of the society. Therefore, a good planning of the drones' flying paths should also consider minimizing sky pollution. For this purpose, standardization and regulation efforts are highly needed to overcome and regulate the afore- mentioned issues and more so that UAVs can fly safely in the sky without jeopardizing people's privacy.

Moreover, interestingly from the technology perspective, UAVs are foreseen as an important component of an advanced cyber-physical Internet of Things (IoT) ecosystem [22]. Based on the definition, IoT aims at enabling things to be connected anytime, anywhere ideally using any network and providing any service. The IoT concept allows UAVs to become an integral part of IoT infrastructure. This is due to the fact that UAVs possess unique characteristics in being dynamic, easy-to-deploy, easy-to-reprogram during run-time, capable of measuring anything anywhere, and capable of flying in a con- trolled airspace with a high degree of autonomy [23]. UAVs consist of different parts such as Avionics, sensors or pay- loads, software, and communication devices that provide links to the ground control station (GCS). The body of a UAV can be considered as the physical entity and the UAV con- troller is the related virtual entity. These two parts jointly form a whole entity, called smart object (i.e., vehicle or thing) [24], or alternatively UAV-IoT thing. Moreover, there are smart UAV management platforms capable of controlling multiple UAVs from anywhere using any device [25].

Generally, the drones are planned for specific applications and services. However, in addition to their original tasks, e.g., postal mail delivery, they can be simultaneously exploited for other value-added services, particularly those in the IoT spheres. Indeed, a drone, flying in the sky for a specific task, could be equipped with IoT devices like sensors and cameras that can be triggered by a third party. For example, Transport Safety Agency could request the current traffic status in spe- cific streets over which the drones will be flying, in order to, e.g., measure parameters of interest like air pollution. In this respect, drones can be used for diverse tasks requested by different stakeholders that do not necessarily have to invest into drones, a fact that would potentially generate additional sources of revenues for the actual owner of the drones.

However, offering value-added IoT services on a hetero- geneous platform of drones, originally destined for other tasks, is not as easy as one may anticipate. Assuming that the drones are equipped with IoT devices (e.g., sensors, cameras, etc.—alternatively known as machine-to-machine or machine type communication—M2M/MTC devices), collect- ing data from these heterogeneous MTC devices, processing the collected data and delivering them from height to a cellu- lar system (which is originally designed for communications from the ground) bring many challenges that need to be duly addressed. Furthermore, keeping the MTC devices constantly operating and connecting to the network will overwhelm the network from one side, and drains the battery of the drone from the other. Power consumption is generally a high con- cern for battery-equipped devices. For drones, it becomes even more significant as battery is critical for them to fly and carry out their tasks. For example, a drone may be programmed to deliver two objects at two distant places. After the deliv- ery of the first object, the battery level becomes low and the drone may not be able to deliver the second object and return safely. In this case, on-board sensors and cameras, for example, should be turned off/on as needed.

Another challenge pertains to cases when a drone deviates from its predetermined path, e.g., due to weather conditions. In this case, a special attention should be made to avoid any collision with the other flying drones. Consequently, many cri- teria should be considered for selecting a drone, or a cluster of drones, to carry out a particular task or value-added service. Therefore, algorithms and methods will be required to: 1) effi- ciently and remotely manage on-board sensors and cameras;
2) coordinate a group of drones; 3) select the right cluster of drones for a specific IoT service; 4) collect and process data; and 5) deliver data via different wireless communications tech- nologies. This is not only to offer the value-added services, but also to secure safe flights for the drones by preventing any collision among them.

To the best knowledge of the authors, no prior research work in the literature has addressed the above-mentioned points. In this paper, we will provide a comprehensive survey on UAVs, highlighting their potential for the delivery of IoT ser- vices from height. Relevant challenges will be also addressed and solutions devised for other purposes, yet relevant, will be described. The remainder of this paper is organized as follows. Section II classifies UAVs, portrays some UAV use cases, and reports on major regulations and standardization efforts relevant to UAVs. Section III introduces our envisioned architecture for the delivery of UAV-based IoT services and addresses key challenges and requirements. Section IV gives an overview on methods for

UAV CA and obstacle detection. It also addresses the public safety concerns with regard to UAVs. Section V provides a comprehensive survey on the different networks that can be formed with or by UAVs. Section VI presents a detailed overview on IoT equipment that can be put on board UAVs and provides a survey on methods for the col- lection of data. Section VII reviews different wireless access technologies applicable to UAVs and discusses issues relevant to machine-to-machine communications in the context of the envisioned architecture. Section VIII addresses aspects rele- vant to the processing of data collected by UAVs and reviews the potential of using cloudlets and computational offloading to suggest the solutions for the problem of UAVs resource restrictions. Finally, Section IX provides some future research directions and this paper concludes in Section X.

II. UAV CLASSIFICATIONS AND UAS

In this section, a quick overview on the classification of air space and UAVs, and the ongoing standardization efforts is presented. Then, some UAV use cases are introduced, based on which the envisioned UAV-based IOT platform is derived.

A. Air Space and UAV Classifications

According to the International Civil Aviation Organization classification [26], airspace can be broadly classified into two categories; namely controlled and uncontrolled airspace. The former is a controlled area within ATC, which is maintained by instrument flight rules (IFRs) and visual flight rules (VFRs). For every aircraft wanting to enter into a controlled airspace, a clearance should be obtained beforehand. Under this cat- egory, there are five classes; from A to E, whereby the difference between the classes depends on the types of allowed flights (i.e., IFR and VFR), and the flights that receive traf- fic information. Regarding the uncontrolled airspace, it is the area where ATC is not applied. Under this category, two classes exist; namely, F and G. ATC separation is provided in Class F, yet not in Class G.

Regarding the UAVs, their classification depends on the considered metrics. Based on their functionality in terms of communication, two broad classes can be envisioned:
1) provider and 2) user of the communication platform. The communication provider acts as a base station (BS), while the user connects through the BS. These drone-based communica- tion platforms can be categorized into low altitude platforms and high altitude platforms [27]–[29]. Based on their max- imum altitude and maximum range, UAVs can be classified into three classes: small, medium, and large [21]. The maxi- mum altitude of small drones is below 300 m, while it exceeds 5500 m for large ones. The altitude of medium ones is between these ranges. Regarding the maximum range, it is less than 3 km for small drones and between 150–250 km for the medium ones [30], both representing line-of-sight (LoS) communica- tions. However, the large drones are beyond LoS (BLoS). Therefore, the majority of IoT services would be provided, principally, by small drones. Another good classification of drones is given in [31] that is according to diverse metrics such as the size, flight endurance, and capabilities. From the opera- tional perspectives, UAVs can be classified into governmental, nongovernmental, or recreational (i.e., for hobby) [29].

B. Regulation and Standardization Efforts

Although unmanned aerial system (UAS) is a promising market that will certainly yield many benefits for differ- ent stakeholders—manufacturers, network operators, and end-users, several obstacles are yet to be tackled. Like many other technologies, UAS is a double-edged sword that can be used for good or bad objectives. One important issue pertains to privacy: UAVs can easily violate the privacy of people [32]. UAVs can be also used by criminals to physically assault peo- ple. There are also concerns with the sudden fall of UAVs or objects they carry. Although the objects could be lightweight, they could become seriously harmful when falling from high altitude. Besides, UAVs could be used for illegal operations such as drug smuggling [33], espionage, or simply flying over sensitive or dangerous sites such as governmental or nuclear locations. For these reasons and more, there is need to regu- late the market of UAVs. This regulation has already started in many countries around the world, such as in different coun- tries in the European Union (EU) [34]. In addition, a special committee SC-228 has been created for the development of requirements for UAS control and nonpayload communica- tions. Some regulation activities have been also carried out in the USA FAA [35]. Some new regulations including all pilot and operating rules, will be effective on August 29, 2016. For example, no drone zone has been already applied in some areas in USA for security issues [36], while some exemptions are given for drones for educational purposes [37].

C. UAV Use Cases

UAVs are being used in different scenarios. They are expected to impact different sectors of our everyday life. Given the expected wide usage of UAVs, it is difficult to introduce all possible use cases. Therefore, in the remainder of this sec- tion, we introduce some representative use cases and discuss the relevant challenges.

D. Earthquake Use Case

In case an earthquake hits a certain region, UAVs equipped with appropriate IoT devices, such as sensors/cameras, may be instructed to fly over that region to record videos of specific areas for assessing the damage, and sensing parameters such as wind speed, temperature, and air pollution level; e.g., compo- sition of gases such as methane if the monitored area includes a factory or a storehouse storing this gas. Information on the latter may assist rescue teams to avoid life-threatening areas, or to be adequately equipped when visiting them.

Flying over a target area, UAVs may connect to each other to facilitate the coordination and area surveillance. A real- time processing of the collected data is required in order to identify the most impacted areas, and to assess whether there are any beings that need help. In case there are any, UAVs can deliver beverages, food, and medicament to the persons in urgent need until the arrival of rescue teams. UAVs can also assist rescue teams to identify the exact geo- graphical locations of victims and guide the rescue teams on how to reach them. In such earthquake case, and if the underlying ground communications infrastructure is damaged, completely or partially, UAVs may act as hot spots or BSs to collect short messages from the affected people to be for- warded to their friends and family members [38]. Small UAVs, e.g., nano-UAVs, may be also used to check if there are any victims inside impacted buildings and provide the appropriate aid later.

E. Crowd Surveillance

During large-scale public events (e.g., sport tournament and musical parade), instead of sending large members of security agents to monitor each public place, drones, flying above the event areas and equipped with the appropriate IoT devices, could be leveraged. Accordingly, security agents can moni- tor the safety of the public areas from a centralized location nearby the event and would physically intervene only when a suspicious incident is detected. Until the agents reach the location, drones can be used to track the movement, or even take photos/video, of any suspicious person. As they are mon- itoring the places from the sky, drones are expected to identify any abnormal movement easily and quickly. Therefore, with the usage of drones, crowd surveillance, safety, and secu- rity will be improved, while, at the same time, reducing security/monitoring teams' size and highly saving people's lives.

F. Real Time Monitoring of Road Traffic Conditions and Other Events

Flying over a location, drones can send real-time informa- tion about road traffic that can be compiled into a central server and used by pedestrians and vehicle drivers to decide on their routes. As another application, drones can be simi- larly used in meteorology. Instead of using dedicated drones to collect the data about the weather of a particular city, any drone flying above the city can collect the desired informa- tion; e.g., temperature, wind speed, and humidity; and send it to a central server. Based on this "drone-sensing" approach, accurate weather prediction can be made, above all with less efforts and highly reduced costs.

Drones can also be used as rescue providers. Indeed, in case a person falls down on the street, any drone flying above that region could take a photo/video of the incident and send it to a central surveillance center, i.e., similar in spirit to the concepts presented in [39] and [40]. Until the arrival of a professional rescue team, an "ambulance" drone carrying a suitable medical kit can reach the location and suitable passersby may be selected and prompted to use the kit to provide first aid [39], [40].

G. Disaster Management—Applied Areas

When a natural disaster happens in an area, coordinat- ing disaster management operations is of vital importance. The operations must be done quickly and effectively to assist people, reduce the number of victims, and to avoid the economic consequences [41]. The humanitarian UAV net- work (UAViators) [42] provide many use-case examples on where and how UAVs can be deployed for humanitarian pur- poses and disaster management. Apvrille *et al.* [43] stated that information has the key role in disaster management and relief. UAVs can effectively assist in improving the situational awareness and assessment. They can provide assistance in communications and coordination of operations, terrain cov- erage and search operations. Regarding the latter, UAVs can support the identification of scattered groups of disabled per- sons and may also help locate the electromagnetic emissions of personal belongings of victims buried under ruined build- ings or hiding in dense forests. For example, UAVs were

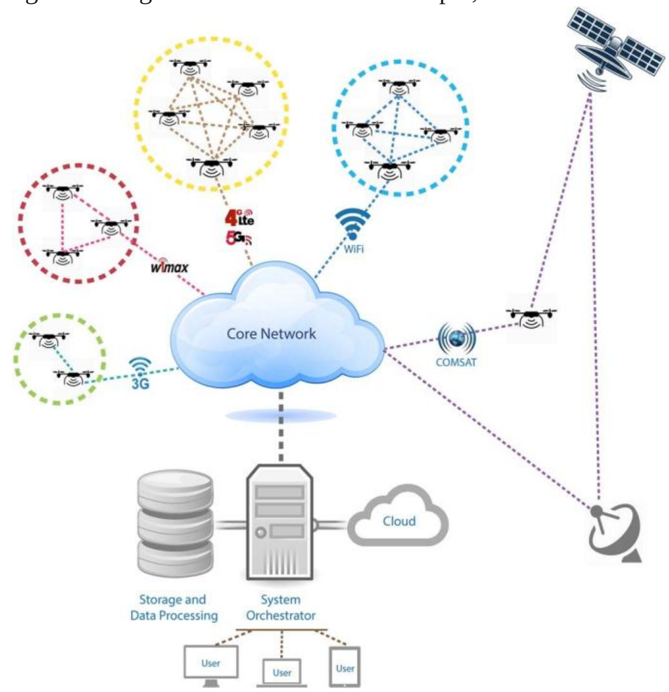

Fig. 1. High level view of the envisioned UAV-based Integrative IoT

Platform.

used during the Japan East great earthquake for the following purposes [44]–[47].

1) Assisting disaster relief efforts to recover from the earthquake and tsunami.
2) Capturing images of the damaged reactors at the Fukushima Daiichi nuclear power plant for site assess- ments.
3) Testing a twin tailed UAV to provide real time data of current radiation level at the nuclear power plant.
4) Assessing the state of the cleanup and reconstruc- tion efforts that were taking place in three areas in Fukushima prefecture.

In another disaster case, UAVs were applied in Port au Prince, Haiti in 2013 for surveying a surface of 45 km^2 in order to map urban shantytowns to count the number of tents and organize a census of the population [48], [49]. UAVs were, besides, used to deliver food, medicine and other necessities in developing regions and areas that are not accessible by roads. Moreover, UAVs were used to recover from the earthquake that hit Nepal in 2015 [50], to study the disaster risk reduc- tion, specifically due to flood, in Dar-es-Salam, Tanzania [51], and to rescue migrants in the Mediterranean [52].

III. UAS-Based Value Added Servicess

Inspired from the UAV use cases introduced in the previ- ous section, this section introduces our envisioned architecture of UAS and further discusses the associated challenges and system requirements.

A. *Vision of UAV-Based Architecture*

Fig. 1 illustrates a heterogeneous network of flying UAVs, each fulfilling a particular task and with specific characteristics

and equipment. Some UAVs are on the fly while others are ready to fly when commanded. These UAVs can be equipped with different IoT devices like sensors and cameras for col- lecting data to be processed for different objectives. UAVs are usually piloted based on predetermined routes, e.g., waypoint model, so they can fulfill their tasks in the right time and in the specific regions. They need to be self-organized in order to avoid physical collisions with other UAVs, or any unpre- dicted obstacles like, for example, birds and tower cranes. This is partly achieved by planning their routes. They must be remotely controllable in order to actuate the IoT devices (i.e., sensors or cameras) on board at the right time and in the right place and the right directions (for cameras). In the envisioned architecture, UAVs are spread over a large zone and may be organized in different UAV clusters. Each clus- ter has different objectives and specific tasks to carry on, and each applies different communication technologies, e.g., long term evolution for M2M communications (LTE-m), LTE, and narrow band-IoT. The UAV clusters may be formed based on the geographical proximity of their UAV members, the type of UAV application, flying altitude and geography of the flying zone, and the radio access technology, e.g., cellular system, Wi-Fi, or satellite. Furthermore, based on the appli- cation requirements and technology limitations, UAVs can be grouped in clusters with different sizes to accomplish their designated tasks.

On the other hand, by increasing the number of UAVs in clusters, the design of an efficient network architecture becomes an important issue. Thereby, establishing reliable communication paths among UAVs is an important challenge in multi-UAV systems. In the envisioned architecture, the wire- less communication is assumed to happen between UAV-to- ground, UAV-to-satellite, UAV-to-cellular infrastructure, and UAV-to-UAV (U2U), i.e., device to device (D2D) or alterna- tively drone to drone communications, in an *ad-hoc* manner. In some fly zones, however, there may exist connectivity and coverage limitations of cellular networks or satellite com- munications (SATCOM) to UAV systems. These restrictions can be alleviated by using flying *ad-hoc* networks (FANET) among UAVs. In the absence of a stable communication infrastructure, applying the delay tolerant networking (DTN) approach to these FANETs can be a solution to ensure end-to- end connectivity, but at the price of increased delay.

In each UAV cluster, a particular UAV could be elected as a cluster head (CH) serving as an aggregator point to transfer the data collected from other members to the system orchestrator (SO—whose functionalities are described below) via the core network sustaining connectivity to different wire- less access technologies (as depicted in Fig. 1). Data delivery from an UAV to the head of its cluster occurs using a suitable routing protocol for FANET. The core network interconnects UAVs, while the SO enables data exchange among different components of the network in a secure manner. The SO, as the brain of the whole system, employs a set of algorithms for collecting real-time and updated information about the cur- rent status of the UAVs, their routes, their battery conditions, and their equipment. SO is in charge of handling requests for IoT services from the clients/users of the architecture. Upon receiving a request from an IoT client, e.g., an environment monitoring agency desires knowing the air pollution level in a particular region, SO first sorts out the most adequate UAVs. This sorting is based on different criteria like: 1) flying paths of the drones (i.e., current or planned ones); 2) their geo- graphical proximity to the region of interest; 3) their on-board IoT equipment (e.g., air pollution meter); and 4) their bat- tery level (i.e., ensuring that if an UAV is commanded to perform an IoT service, its original tasks will not be ham- pered by depleting its battery). The elected number of UAVs for a certain task depends on the computation intensity of the

IoT service, the diversity of required IoT devices, or the size of the monitored/inspected area. Once the most adequate UAVs are selected, one or multiple UAVs will be instructed to carry out the IoT service by actuating their relevant IoT devices only when they are flying over the region of interest.

In this way, the UAV energy budget is highly conserved. Once the sensing is completed, SO instructs the UAVs on how (e.g., FANET fashion, DTN, UAV to cellular, etc.), where, and which access technology to use for delivering the sensed data. Additionally, SO ensures interoperability among UAVs using different access technologies. For example, in case of a disaster recovery operation whereby heterogeneous UAVs are used, UAVs using cellular technology operate within the coverage area of the cellular system, and outside that, UAVs using satellite connectivity operate. SO, then, coordinates and ensures reliable data exchange among them. SO is in charge of coordinating the routes of UAVs, preventing collisions among them or with any other obstacles. Besides, it may be interfac- ing to different other command and control systems that shall support further the operations and maintenance of UAS. SO may also connect to a local storage or a remote cloud for the storage and processing of data received from different UAVs regarding different IoT service requests. In this fashion, SO could regulate and support UAVs to have a ubiquitous, conve- nient, and on-demand access to a shared pool of configurable computing and storage platform.

B. Challenges and System Requirements

To realize the vision of the envisioned architecture as depicted in Fig. 1, a number of challenges need to be addressed. An important challenge pertains to the regulation of the airspace. The access to the airspace must be well orga- nized and controlled so the current air traffic would not be disturbed. Many other aspects should be also taken into con- sideration, such as the protection of the privacy and safety of people [53]. The spectrum regulation is also another important issue to be considered [21], [26], where the communication of UAVs should not affect the communication of current air traffic. The general agreement to support the communication of drones using current ground wireless networks has been referred in [54]–[56], as they are already widely deployed, especially the cellular networks.

However, supporting the communication of drones by the current ground wireless networks is an important challenge as they are originally designed to support communication from devices on the ground rather than on-board flying UAVs. There are also numerous challenges to establish reliable com- munications among drones (i.e., drone to drone or within FANET), and that is principally due to the frequently chang- ing topology of FANETs. Due to mobility features of UAVs (i.e., relative speed and moving direction), fast changes in the topology would happen, resulting frequent disconnections between adjacent UAVs.

Interference management is another challenging issue to be addressed. Indeed, as UAVs may have LoS to many BSs, even those that are multihops far away from each other. Large interference may be caused to neighboring BSs in uplink. UAVs may also suffer from interference from a large area in downlink. Another communication-relevant challenge consists in the selection of an appropriate wireless technol- ogy such as cellular, worldwide interoperability for microwave access (WiMAX) and Wi-Fi for the drone's communication. This selection depends on the UAV task type, its duration, and the operation environment, e.g., LTE-m for the delivery of sensed small data.

The send-and-receive signal strength is another challenge, which is principally due to the dynamic and high mobility feature of UAVs. This may be leveraged through automating antennas direction as per location/movement of an individual or a group of UAVs. Another issue corresponds to enhancing the mobile core network for the efficient support of UAV-based mobile communications. This requires investigating different attach/connectivity setup/mobility procedures in order to make them more suitable for connection of trusted/untrusted drones. The congestion problem, which can arise when multiple UAVs attempt connecting to the same BS, is also an impor- tant issue to be addressed. Indeed, in such a case, congestion becomes an inevitable issue unless the accesses of UAVs to the wireless system is efficiently coordinated. Energy efficiency is a crucial factor for the success and wide acceptance of the UAV technology. In this vein, it is important to minimize the energy consumed by UAVs in fulfilling a particular IoT task. This energy consumption must also be benchmarked for UAVs and that is when flying at different altitudes/distances from BSs while conducting a set of different task types, e.g., data sensing, data delivery, video streaming during certain time, etc. This energy consumption benchmarking is of vital importance for the planning, management, and orchestration of IoT tasks to be attributed to UAVs.

As stated earlier, UAVs are usually piloted based on predetermined routes. However, in some cases their routes need to be altered while UAVs are flying, e.g., for physical CA, change in mission, etc. In that case, it should be possible to command and control UAVs remotely using tools such as mission planner [57], or through the cellular systems if UAVs are within their coverage. For an efficient remote control of UAVs, they need to keep constantly updating the command-and-control system of their geographical coordinates. Frequent transmissions of such GPS coordinates at a fine granularity from a large number of UAVs may result in congesting the cellular system. To realize the envisioned UAV-based integra- tive IoT platform, there are numerous challenges to cope as well. These challenges relate to how to select suitable UAVs

for a given IoT task, how to remotely trigger IoT devices on board UAVs so they would collect the data required by the IoT task, how to process the data locally at UAVs, and how to deliver the collected data to remote cloud or a central server. Some of these challenges can be partially dealt with using of solutions existing in the literature. In the remainder of this paper, we provide a comprehensive survey on methods and technologies highlighting how they can be incorporated in the envisioned UAV-based IoT platform.

C. UAS Traffic Management

The initial challenge regarding the proposed architecture is to consider the increasing number of the drones in the sky and their associated fly routes and air traffic management. To find solutions for this challenge the National Aeronautics and Space Administration (NASA) is exploring prototype technologies for an UAS traffic management (UTM) system for enabling safe and efficient low-altitude civilian UAV operations [58]. UTM is designed to enable safe low-altitude civilian UAS operations by providing pilot information needed to maintain separation from other aircrafts by reserving areas for specific routes, with consideration of restricted airspace and adverse weather conditions [59].

To overcome to this challenge, NASA envisions two types of UTM systems: portable and persistent. The portable UTM system moves between geographical areas and supports oper- ations like disaster management and agriculture precision. Regarding the persistent UTM system, it supports low-altitude operations and provides continues coverage for an area. The requirements of both of the systems are persistent communi- cation, navigation, and surveillance coverage to track, ensure, and monitor conformance. In order to achieve these envisioned systems, NASA is leading the research, development and test- ing in collaboration with the FAA that takes place in four activity series called “technology capability levels (TCL)”; TCL1, TCL2, TCL3, and TCL4. In August 2015, the UTM TCL1 concluded the field testing and the additional test of this level is undergoing at an FAA site. However, UTM TCL2 and TCL3 are scheduled for October 2016 and January 2018, respectively. The date for UTM TCL4 will be determined in 2019. The activities will be enforced, where each activity will leverage previous level. The technologies in level 1 activity addressed operations for agriculture, firefighting and infras- tructure monitoring, with the focus on geo-fencing, altitude “rules of the road” and scheduling of vehicle trajectories. The level 2 activity will focus on beyond-visual LoS operations in sparsely populated areas. The focus of level 3 will be on testing technologies that maintain safe spacing between cooperative and noncooperative UAS over moderately populated areas. In addition, level 4 will explore UAS operations in higher-density urban areas for different task types, such as news gathering and package delivery.

Additionally, Airware acts as partner with NASA to develop a UTM system with the aim of enabling a safe and efficient low-altitude UAS operations [60]. Under this partnership, they will have the ability to operate and test a diverse set of UAVs, sensors, and custom software, such as CA and 4D trajectory

modeling [61]. Airware works on commercializing the use of the drones. It offers a common operating system that enables businesses to safely operate and manage the drones, and inte- grate aerial data into design, a robust flight control system, engineering, and asset management and decision workflows.

With regard to our proposed framework, it is aligned with UTM, as low-altitude UAVs are expected to be applied in our vision. Our framework shares with UTM the target of managing and enabling safe low-altitude operations. However, the main focus of our proposed framework is on the value-added services, which is not the case for UTM. This could be viewed as advantage, since more services could be achieved with the same number of UAVs and at the same time, and thus more revenue.

IV. Physical Collision

The flying UAVs carry IoT devices onboard and they pro- vide IoT services from the sky. In the envisioned UAV-based integrative IoT platform in Section III, one main concern relates to the deployment of massive number of UAVs. This is important because the probability of collisions among these UAVs and with other urban and nonurban obstacles such as buildings, mountains, and trees as well as flying birds in the sky increases. For the sake of UAS deployment and assuring a safe flight, the collision and obstacle avoidance becomes a big challenge. The importance of the safety rises if collision happens in urban and rural areas, and thus it would thread peo- ple and property safeties on the ground. The physical collision is one of the main concerns of the UTM which addressed in previous section. For the aforementioned reasons, this section reviews the physical CA methods and the routing of the UAVs.

A. Drone Safety for People on the Ground

One of the main requirements for the flight operations by UAS, is to preserve safety for the public by flight safety in the air and on the ground. To the safety level, the authors in [62] employed a method for an expected level of safety to calculate the UAV system reliability which is required to meet the safety level for different UAV classes, these classes differentiated by mass. The results of this research show that the ground impact risk varies significantly based on population density. It was significantly higher for high-mass and high-velocity UAVs. In addition, midair collision risk varied by two orders of magnitude between flight on airways, on major flight levels and away from airways, off major flight levels. Moreover, it was found that it is possible to operate small UAVs in the National Airspace System, such as those classified as Micro or Mini UAVs, away from only the most densely populous cities.

For achieving the required level of safety, the paper [63] presents a survey of CA approaches and explains that UAVs must be able to autonomously plan trajectories that are free from collisions with stationary obstacles such as mountains, trees and buildings on the ground. Additionally, the report in [64] has studied the CA requirements for unmanned air- craft systems (CAUSE). The outcome of the CAUSE is applied in the European Organization for the Safety of Air

Navigation and other regulatory bodies on how to integrate UAS into nonsegregated airspace. The CAUSE study considers the CA requirements of UAS in two phases: 1) identifica- tion of potential safety issue and the determination of the CA and 2) development of a methodology to quantify UAS CA performance. The report concludes that UAS operations are currently confined to specifically reserved areas of seg- regated airspace and it is likely that the increasing use of UAS for civil applications will create demand for UAS to be allowed to operate in nonsegregated airspace alongside manned aircraft. Furthermore, UAS must operate within the existing regulatory framework and should not pose greater risk to persons or properties on the ground or in the air than that presented by equivalent manned aircraft; and UAS will be treated by ATC as any other aircraft.

B. Collision Avoidance Methods

The CA control is one of the key technologies for UAV applications. UAVs must be able to autonomously plan trajec- tories that are free from collisions with ground obstacles and be able to sense-and-avoid (SAA) conflicts in the air. There are many approaches have been proposed to address this problem. Zeitlin and McLaughlin [65] examined the suitability of traf- fic alert and CA system (TCAS), which is used as part of safety provision in manned aircrafts like passenger and cargo carriers to use with UASs. In this work, TCAS is used as a safety system for UAS, considering that UAS safety case needs to address all of the same hazards that are dealt with manned aircraft. This study shows that the safety evaluations must be comprehensive and specific to the system and certain elements of the flight operation. In case of remote pilot, the communication link and the pilot response characteristics are both sensitive elements in the safety calculations.

Another research [66] discusses several methods and tools that have been accepted for modeling and evaluating the safety of CA for manned aircraft and uses these methods for UASs. They aim at developing UAS SAA standard based on the Aviation Gold Standard Science (RTCA SC-203) [67] and reg- ulations from FAA. The results of the research indicate that for a comprehensive evaluation of the safety of UAS CA, method- ological evaluations in several steps are required. Moreover the hazards need to be clearly specified and for each hazard the system performance should be evaluated. The statistical performance models of aircraft, CA systems (CASs) and pilots require development and integration for an accurate simula- tion. They recommend using a fault tree as a useful tool for combining separate risks and their mitigating elements.

In a study focusing on SAA method, Barfield [68] aims at creating a separate entity within each UAV to provide some of the "see-and-avoid" capability of manned aircraft. The work presents an autonomous CA system that provides safety and protection at the last instant before collision happens without causing any failure in the flight operation. The paper for- mulates a technique called time-to-collision Point, which is determined by dividing the distance from the present posi- tion to the predicted collision point along the projected future trajectory of the vehicle by the velocity along that trajectory.

The findings show that applying this technique yields to an accurate indication of the time before the collision, while the position uncertainty and data latency can definitely impact the system operation.

In a literature review, the UAV 3-D path planning [69] focuses on the path planning of UAVs for finding an opti- mal and collision free path in a 3-D cluttered environment by considering the geometric, physical and temporal constraints. To do so, the paper classifies the path planning methods into five categories as sampling-based, node-based, mathematical model-based, Bio-inspired and multifusion-based algorithms and then analysis each method; discusses each of the algo- rithms; and compares them.

Sharma and Ghose [70] have developed CA algorithms over several basic swarming laws. These algorithms are applied for two types of CA schemes, individual CA (ICA) in 2-D and Group CA (GCA) in the 3-D plane. UAV swarm refers to UAVs collaborating in order to perform a certain task. For sim- ulation, three different schemes are formulated for GCA in the 3-D plane. The results obtained from the simulations elucidate that in a conflict free scheme, group collision is achieved suc- cessfully for all the conditions. Additionally, the total deviation from the required path is very high compared to ICA scheme. It is also illustrated that the sensor range required to achieve the ICA is high, whereas the group collision can be achieved at low sensor range.

A fuzzy logic approach to CA as a solution for high- density UAVs is presented in [71]. For this purpose fuzzy logic is applied due to adaptability, ease of implementation, and

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robustness with inadequate sensing techniques. The method works by using a simple determination mechanism to check if a UAV is in a collision situation, and it applies fuzzy logic to specify a suitable avoidance maneuver after a pos- sible collision detection. The paper suggests that fuzzy logic systems should be considered as a valid solution for UAV CA. Furthermore, the other study in [72] discusses the advan- tages and disadvantages of different CA methods, including predefined CA, protocol-based decentralized CA, optimized escape trajectory, potential field methods, geometric methods, trajectory estimators, and hybrid CAS systems.

C. Obstacle-Collision Avoidance Methods

Different researches [73]–[75] have investigated the CA control law for air vehicles under uncertain information. The control law applies the information amount as one of the physical parameters for control system.

The proposed control law by [73] provides new performance by enabling the aircraft to obtain informa- tion for ensuring the certainty of the information. This work studies two cases of CA control to test the effect of the information amount as parameter control. The first case indicates to the problem of uncertainty of the information changes by the relative position of the evader and the target for example flight in fog or smoke. The second case refers to the uncertainty of the information as absolute position, where in this case the position can or cannot be obtained by the position itself like flight around urban buildings or mountains. The two cases have proved to have smoother and safer trajectories than the conventional laws, and the results from the simulations have demonstrated that the control law using information amount does not rely on the coordinates.

In an approach for obstacle CA, the work in [76] points that quadrotors are suitable for indoor flight operation because of their ability to hover and maneuver in confined spaces. This work seeks a possible solution for the use of force feedback to give the pilot haptic information about the quadrotor envi- ronment, where the main purpose of haptic feedback is to assist the pilot in avoiding obstacles while approaching at any direction. The study presents the development of three force feedback algorithms for use in piloting quadrotor UAVs in indoor environments, including time-to-impact (TTI), dynamic parametric field and virtual spring. The paper concludes that the TTI algorithm considerably decrease the amount of colli- sions compared to the other algorithms without requiring an extra operation time.

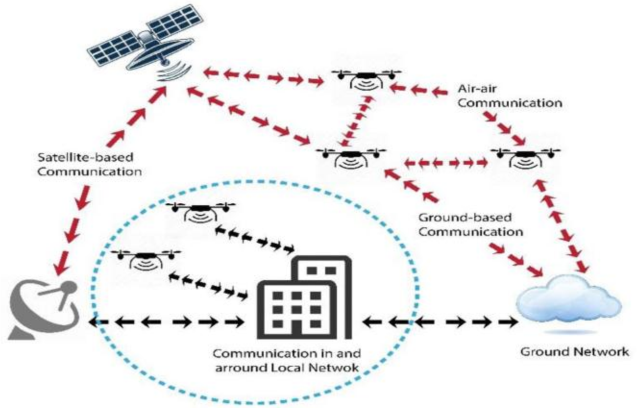
In a different method, Israelsen *et al*. [77] presented an algo- rithm for manually teleoperated unmanned aerial robots for automatic CA with obstacles. The algorithm continually esti- mates the future trajectory of the vehicle given its dynamics, current state and the current operator's input. It checks the present time horizon to examine avoidance of a collision by selecting a new control input.

D. Routing of UAVs

Path or route planning is one of the fundamental objectives for UAVs for maximizing the safety of the vehicles. Route planning is needed to reach to an optimal or suboptimal route for satisfying the desired flight performance [78]. Based on the studies [79]–[82], A* is the most common search algorithm for the route planning due to its applicability to a wide range of routing problems and its efficient performance.

Tulum *et al*. [83] introduced an agent-based approach for UAV mission route planning problem, using situa- tion awareness algorithms. They consider target, threat, ter- rain, and airspace restrictions to compute the "best" set of waypoints for the UAV mission. As a different study, Hernández-Hernández *et al*. [84] applied graph-based meth- ods for multiobjective route planning of a simulated UAV aerial platform considering scenarios with danger zones or prohibited areas, civil airspace characteristics and other required safety restricted considerations. The paper presents the functionality of NAMOA* multiobjective optimization graph-search algorithm due to automatic plan and routing of simulated UAV in civil airspace by minimizing the traveling distance, angle change, flight time duration, fuel consump- tion and deviation from the straight path. They argue that NAOMA* is superior to weighted A*, as it is able to achieve a set of nondominated solutions.

In another study [85], deterministic and probabilistic path planning strategies for an autonomous UAV network is examined by exploring a given area of obstacles and providing an overview image. The paper presents algorithms for online and offline implementations. It concludes that the applied approach can provide a solution with minimum number of



. Illustration of airborne network.

pictures. This approach requires more knowledge and time to generate a plan, while the probabilistic approaches are more flexible and adaptive.

V. UAV Communication Networks

An airborne network (AN) is a cyber-physical system (CPS) in which there is an intense interaction between physical and cyber components [86]. The synergy between the cyber and physical components significantly enhances the safety and security capabilities of next generation air vehicle systems. Namuduri *et al.* [86] indicated that the fundamental design principles required to explore this synergy between physical and cyber dimensions do not exist. Their work demonstrates the CPS perspective on an AN with four design principles: 1) control system; 2) information sharing; 3) situational awareness; and 4) networks and communications. The latter principle refers to communication link connectivity, coverage area and data throughput.

Many studies exist on communication network of UAVs [87]–[90]. This network consists of terrestrial, satellite, and wireless links to connect to control stations on the ground and other air vehicles. Fig. 2 illustrates the idea of an AN. In this network, node altitudes and distances between the nodes are highly variable. These nodes may be static or moving at some speed in a way that leads to dynamic topological changes in the network. For a good designing of an AN, the timeliness and integrity of information, high bandwidth usage and scalability are the most considerable parameters.

Frew and Brown [91] explained that there are four basic types of communication architectures that can be used for small UAS applications; direct link, satellite, cellular, and mesh networking. Regarding the communication systems and networking among UAVs, the collaborative communication in UAV systems is an important part, as they can be equipped with different communication technologies [92]. This collaborative communication can be between UAVs themselves, or between UAVs and other nodes such as GCS, wireless sensor networks and other ground moving vehicles. UAV systems have a wide range of applications and apply different networking technologies such as mesh, mobile *ad-hoc*, fly *ad-hoc*, and delay-tolerant. In the following, some of these technologies are explored.

A. Node-to-Node Communication

A direct link or an LoS communication between UAVs to ground station (GS) is the simplest architecture [91]. The study in [92] presents different networking architectures for U2U and UAV-to-infrastructure (U2I) communication that can be applied at the various layers of open system interconnection networking model. Since in-flight UAVs are highly mobile, mobile *ad-hoc* network (MANET) protocols are used for U2U communication where each UAV consists a mobile node in MANET. Besides, U2I refers to data exchange between UAVs and the infrastructure and the Internet. For this purpose, one of the UAVs plays the role of a gateway, where it collects the data from other UAVs (through U2U) and then relays the collected data to the GCS.

Li *et al.* [93] introduced two types of communication: 1) centralized and 2) decentralized. Centralized communication includes the most common topology that has a GS as the central node to which all the UAVs are connected. In this architecture, UAVs are not directly connected. The communication between two UAVs needs to be routed through the GS. On the other hand, a central node is not required in the decentralized architecture, where two UAVs can communicate either directly or indirectly employing a UAV as a relay. The authors introduce three groups for decentralized communication architecture.

1) *UAV Ad-Hoc Network:* Each UAV participates in data forwarding for other UAVs of the network.
2) *Multigroup UAV Network:* UAVs within a group construct a UAV *ad-hoc* network with its perspective backbone UAV connecting to the GS.
3) *Multilayer UAV Ad-Hoc Network:* UAVs within an individual group construct a UAV *ad-hoc* network which corresponds to the lower layer of the multilayer *ad-hoc* network architecture. The upper-layer is composed of the backbone UAVs of all groups.

The findings of the study is that a flat UAV *ad-hoc* network is more appropriate for a homogeneous group of UAVs, while a multilayer *ad-hoc* network is more suitable for connecting multiple groups of heterogeneous UAVs.

B. Mesh Networking

Mesh networking can be defined as an architecture, where every node, i.e., UAV or a GS, can act as a data relay. Besides, communication among multiple UAVs and GS can occur over several hops through intermediate nodes [91]. Some of the advantages of mesh networking are as follows.

1) The shorter range simplifies the link requirement, and the bandwidth is reused more frequently and efficiently.
2) U2U communication becomes direct, in addition to maintaining the communication links thanks to mesh routing protocols.

3) Mesh approach is promising if there is lack of infrastructure.
4) Any node connected to a direct, cellular or satellite link enables communication with the other nodes.
5) Meshing combined with mobility feature of UAVs extends the communication range.

Many works such as [94]–[96] have investigated the deployment of wireless technologies like wireless local area network (WLAN) to build low-cost aerial wireless mesh network for the use of UAVs. Other studies like [55] analyze the performance of four available mesh routing protocol implementations: 1) open80211s; 2) better approach to mobile *ad-hoc* networking (BATMAN); 3) BATMAN advanced; and 4) optimized link state routing (OLSR). This study recommends using open2011s and BATMAN-Advanced for the reliable establishment of multihop mesh network for swarming applications.

C. Delay Tolerant Network

The Delay Tolerant Network architecture aims to provide interoperable communications between a wide range of networks that may have poor and disparate characteristics [97]. DTN architecture has been designed to address the needs of networks characterized by link intermittent connectivity, lack of end-to-end connectivity between end-users as well as high latency [98]. In order to mitigate these problems, DTNs rely on store-and-forward message switching.

For establishing and maintaining reliable communications within IP-based AN, Johnson *et al*. [99] addressed the related challenges. The study indicates that intermittent links, high latency, low bandwidth and *ad-hoc* connections are common features of ANs. This study provides a sample AN-based use-case scenario and illustrates the applicability of DTN within the current ANs.

Le *et al*. [100] focused on the design and evaluation of a routing strategy using UAVs as carriers in order to provide network connectivity in highly partitioned *ad-hoc* networks. The DTN part of the protocol utilizes the UAVs as message ferries to store, carry and forward messages to the destinations where there is no possibility to send the data through intermediate nodes. This work applies *ad-hoc* on demand distance vector as an underlying routing protocol.

One of the considerations of DTN is the flying UAVs with IP wireless networks. The experiment [101] introduces autonomous flight wireless node (AFW) for the delivery of data under poor network conditions such as disasters and areas with no broadband network. This paper discusses data connection with DTN and autonomous UAV flight for searching possible encounters. For the proposed method, the data transmission is carried by DTN and AFW that is equipped with wireless interfaces and cameras. The UAV provides autonomous flight, seeks the wireless nodes, sends and receives disaster information by DTN and returns to the stations with power charging ability. The results of this experiment demonstrate the effectiveness of applying AFW with DTN.

Kwon and Hailes [102] used UAVs as communication relays. Further, they discuss dynamic positioning of UAVs for maximizing communication efficiency by means of packet delivery rate and signal to noise ratio between the UAVs. This study refers to the possibility of creating a DTN in order to analyze the scheduling UAVs using real-time response techniques. It provides a scheduling framework to illustrate whether a UAV can cover a given set of distributed nodes.

D. MANET/VANET Data Routing

An MANET is a collection of independent mobile nodes connected among them with wireless links. Using these mobile nodes as hosts and relays, MANET configures an infrastructure-less network dynamically. These nodes have free movement and their network topology changes rapidly over time. On the other hand, for vehicular applications, the mobile nodes are embedded in vehicles that leads to another concept namely vehicular *ad-hoc* network (VANET). VANET extends the range of MANET and enables its usage in new application areas. From the UAV viewpoint, the traditional MANETs and VANETs do not address the unique characteristics of the UAV networks. Setting up an *ad-hoc* network for UAVs is a challenging issue because these can have stationary, slow moving or highly mobile nodes. Besides, UAV networking requirements such as connectivity, routing process, applications, and services are different from the traditional MANETs and VANETs.

Addressing the aforementioned challenges, Gupta *et al.* [103] compared the characteristics of MANETs, VANETs and UAV networks. They discuss the challenges related to, for example, link establishment and topology of the UAV networks. However, Mesh networking is seen to be the most appropriate for UAVs but the architecture of multi-UAV networks is still an open study area. Besides, routing demands of UAVs exceed the requirements of MANETs and VANETs, and therefore new protocols are required for adapting high mobility, fluid topology, intermittent links, power constraints, and link quality changing. As UAVs are battery-equipped, these protocols should take a special attention on the power consumption, moving toward greening of the network. Another issue to be considered about UAVs is that they may fail and thus the network may be divided. As a result, delay and disruption tolerance are important metrics to be noted, in addition to other issues like limited life of the UAV and network dynamicity. However, there are many routing protocols, and they will be briefly explored here.

1) Static routing protocols that include load carry and deliver routing, multilevel hierarchical routing and data centric routing.
2) Proactive routing protocols that include OLSR, destination sequenced distance vector, BABEL that is based on

distance-vector routing protocol and BATMAN.

3) Reactive routing protocols that consist of dynamic source routing and ad hoc on demand distance vector.
4) Hybrid routing protocols that include zone routing pro- tocols and temporarily ordered routing algorithm.
5) Geographic 2-D and 3-D protocols.

The challenging issues relative to the deployment of UAVs as mobile nodes in an *ad-hoc* network are discussed in [104]. However, existing MANETs and slowly moving VANETs do not address the unique features of UAV networks, such as path planning and the high mobility of nodes. Furthermore, devel- oping a fully autonomous and cooperative multi-UAV system requires new networking model in an *ad-hoc* manner.

Biomo *et al.* [105] and Shirani [106] explored unmanned aeronautical *ad-hoc* networks (UAANET) that are self- organizing networks and a type of MANETs applied for UAVs. UAANETs utilize geographical routing that relies on greedy forwarding, also called greedy geographic forwarding (GGF). The problem of GGF is that it fails when a packet arrives at a node that has no neighbor closer to the destination than it is. The work proposes a low-complexity and low-overhead recovery strategy for GGF failure that is complied with the reality of UAANETs.

Huo *et al*. [107] studied the improvement of network con- nectivity, throughput and data flow of MANET. In order to improve the network performance, the authors define a system model with a UAV as a relay node and ground nodes that can connect with both the UAV and other ground nodes. By the formulation of mobility strategy of the UAV as an optimiza- tion problem, the authors propose a load and priority weighted center track update strategy algorithm. Simulation results show that this strategy can improve the network characteristics com- pared to existing center-based cooperative trajectory update, static and random walking strategies.

From the security perspective, MANET applications have a highly secure nature because of their dynamicity and change of their topology at any time. The paper [108] explores an efficient group key management (GKM) scheme for MANET communication system. The GKM protocol includes node authentication, key generation and distribution, key update protocol and the consistency of group key. This work presents GKM architecture for a heterogeneous MANET model with UAV-aid. Due to the high changes in the MANET network topology and membership, in addition to other factors like node computing power and storage capacity, the performance of GKM becomes significantly important. Performance anal- ysis of the architecture, from the point of the overload values of key storage and rekey computing, shows that the presented algorithm suits the heterogeneous MANET environment.

The study in [109] indicates that the use of a standard syn- thetic mobility model can result in incorrect conclusions. It presents the mobility properties for the movement of UAVs in a reconnaissance scenario by providing two mobility models for the scenario. In the first model, the UAVs move indepen- dently and randomly, while in the second model a pheromone model guides their movement. Simulation results elucidate that the random model is very simple but the coverage is worse and it achieves mediocre results. The result of pheromone model has significant scanning properties, but it has problems with network connectivity. The authors conclude that the cover- age and the connectivity of communications are two different conflicting objectives.

Guo *et al.* [110] presented UAV-aided cross-layer rout- ing protocol (UCLR) for improving the cross-layer routing performance of a ground MANET network that proposes a UAV load balancing algorithm. This work is executed by implementing UCLR using Linux Quagga routing suite along with open shortest path first MANET designated routing. The results demonstrate that USLR significantly improves the throughput and delivery ratio of both TCP and UDP and its overall performance improvement compared to the original MDR. In addition, through the proposed UAV load-balancing algorithm, this work presented how UCLR could intelligently utilize the limited resources of a UAV in order to avoid for- warding packets over poor quality ground links. Moreover, their proposed load-balancing algorithm effectively reduces the congestion level at the UAV, and thus achieving an optimal deployment of the UAV.

Zhu *et al*. [111] tried to find the minimum number of UAVs to maintain the connectivity of ground MANETs while some UAVs have already been deployed in a field. The problem is formulated as minimum Steiner tree problem with existing mobile Steiner points under edge length bound constraints, and it is proven that the problem is NP-complete. Then the authors propose an existing UAVs aware (EUA) algorithm to solve the mentioned problem. Simulations results show that the proposed EUA method provides better performance than a non-EUA method in terms of deploying newly added UAVs. Moreover, EUA method can achieve a reduction of at most 60% of the new UAVs number compared to non-EUA.

E. Flying Ad-Hoc Network

FANETs basically represent a new class of *ad-hoc* net- works composed of aerial vehicles [112]–[118]. FANET is a new network family whose requirements are highly dif- ferent from the traditional MANETs and VANETs [114]. It is a new networking paradigm developed based on the con- cept of MANETs [113]. FANET is considered as a subtype of VANET, but the nodes in FANET have greater degree of mobility and the distance between nodes are often higher than that in VANETs [117]. FANET requires both peer-to-peer communication and converge cast traffic at an equivalent time for the synchronization of UAVs.

FANET resolves several design limitations with the infrastructure-based architecture approach. It solves the range restriction among the UAVs and the GS and reliability of the communication [114]. FANET is capable of sending informa- tion quickly and accurately in a situation where the generic *ad- hoc* networks are not able to do so. In addition, due to high

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mobility and rapid topology change, routing in FANET is a big challenge [113] and mobility models have impor- tant role in optimizing the performance of routing protocol in FANET. Sahingoz [112] identified the challenges of using UAVs as relay nodes in an *ad-hoc* manner. They state that FANET requires scalable, reliable, real-time and peer-to-peer MANET among UAVs and GS.

Singh and Verma [113] studied OLSR in FANETs under different mobility models in terms of packet delivery ratio, average throughput, and end-to-end delay with varying speed of nodes. Different mobility models of Random Waypoint, Manhattan-Grid, RPGM and Pursue are used to demonstrate

the effectiveness of OLSR protocol. Simulation results demonstrate that performance of OLSR depends on the different UAV speed and mobility models. However, OLSR has better performance compared to other models.

Tareque *et al*. [114] explored the challenges of FANETs compared to the traditional *ad-hoc* networks. Regarding the FANET protocols, they are classified into six major categories: 1) static; 2) proactive; 3) reactive; 4) hybrid; 5) position/geographic-based; and 6) hierarchical. The outcome of this comparison assists the selection of appropriate routing protocols based on a specific scenario where the FANET will be deployed.

Bekmezci *et al*. [118] compared the current *ad-hoc* networks and FANETs and then present an FANET architecture test bed implementation. This work develops four network architecture designs including FANET. In the first design, all UAVs communicate with a GS where in this case the operation area is limited to the communication range between UAVs and GS. In the second design, UAVs can establish communication link to satellite instead of GS, but this would be expensive, and heavy hardware devices should be mounted on every UAV.

The third design is to use multiple GSs for multi-UAV systems. However, this architecture is not a suitable for military and disaster application scenarios, as the infrastructure cannot be trusted in such situations. The fourth one is to communicate UAVs in an *ad-hoc* manner (i.e., FANET), while some of UAVs communicate with GS or via satellite. The important features of applying FANETs are overcoming the range restriction problem and providing real-time communication without requiring any infrastructure. The findings of the study show the advantages of FANET architecture by report to other architecture. From the secure routing protocol perspective, Maxa *et al.* [119] presented an approach to secure a swarm of UAVs, namely secure UAV *ad-hoc* network. The authors used model driven development approach to be compliant with the certification requirements.

VI. Data Collection

The basic task of UAS is collecting data using onboard IoT devices and utilities. UAVs can utilize intelligent interfaces for connecting devices, machines, smart objects, smart environments, services and persons [120] so they share their collected data from embedded sensors, actuators and other IoT member utilities [121]. UAVs collect the data from remote locations and share them with a GS. There are a variety of applica- tions that require a suitable technology for their data collection system. UAS is recognized as the best candidate to fill this gap. These applications could be specified in the following areas [122].

1) Geoscience (geography, geomorphology, geophysics, and meteorology).
2) Environmental and planning disciplines (vegetation science, landscape ecology, environmental monitoring, settlement dynamics, agriculture and forestry, and archaeology).
3) Surveying and geographic information industry (low cost photogrammetry and topographic mapping). Furthermore, based on the use-cases mentioned in Section II, data collection and reporting methods can be classified into the following.

1) *Time Driven:* In this reporting mode, the sensors will be activated at a certain time to collect the intended data, e.g., sensing the temperature at specific times or periodically.
2) *Space Driven:* The drones flying above a certain region will collect the intended data regardless of time. For example, drones flying above an industrial zone will sense the level of CO_2 and report it to an environment-monitoring agency.
3) *Space-Time Driven:* The drones flying above the city, for example, during the busy hours will sense many parameters, like the level of CO_2 and recording video to know the status of the traffic.
4) *Event Driven:* Whenever an event occurs, the on-board sensors of the drones flying above the concerned region will be activated to collect the intended data.
5) *Query Driven:* A customer or the owner of the drones requests certain information. For example, the owner of drones would want to know the status of the equipment of the drones and the drones themselves. It should be noted that Query driven events could be delay-sensitive or delay-tolerant.
6) *Space-Query Driven:* This relates to a query rele- vant about a certain location. For example, a customer requests certain information, e.g., temperature or traffic status, from certain location.

On the other hand, equipment selection for data collection is an important issue in a UAV operation system. The selection can be accomplished based on the envisioned UAS application. UAS could be equipped with a variety of multiple and interchangeable imaging devices including day and night real-time video cameras in order to capture real-time video. Some of these devices are video camera, digital camera, infrared cameras, multispectral and hyperspectral sensors, biological and radiological sensors [123]. Note that some requested data needs to be collected from more than one type of sensors, like the heat index that is calculated from the temperature and humidity.

Cameras are indispensable IoT components of UAVs, where they are application-specific. Among diverse applications, they are applied for autonomous vision system for safe land- ing. Using aerial imagery, the works [124]–[127] describe landing approach by the experiment and introduce a design and implementation of a real time vision-based algorithm. In addition, cameras enable UAVs for trajectory, path plan- ning, environment monitoring, tracking and other purposes. Sharp *et al.* [124] reviewed the UAVs for traffic surveil- lances with the purpose of traffic management and concludes that they are useful and successful for traffic surveillance. Another research [128] indicates that airborne cameras offer many benefits such as mobility to cover a large area and greater speed than surface vehicles. The work describes that UAVs may provide a "bird's eye view" for traffic surveillance, road conditions and emergency response. This is due to UAVs data collection capabilities, because some of them have the real-time data transfer ability and others are able to store high quality video or images on-board. In order to cover the pos- sible spectrum of UAV applications, Microdrones [129] offers some application specific cameras, such as tetra-cam miniature multiple camera array, multispectral camera, thermal camera, HQ photo, and video camera.

Sensors are the fundamental IoT utilities of any data col- lecting devices. They have an integral role in subsequent data transmission and data processing. Sensors and their associated circuits are applied to measure various physical properties [130]. There are different types of physical quantity sensors [131].

1) *Mechanical Sensors:* Pressure, movement, position, speed, acceleration, vibration, force, and momentum.
2) *Heat Sensors:* Temperature, heat, and heat flow.
3) *Radiation Sensors:* Visible light, infrared, ultraviolet, and nuclear.
4) *Chemical Sensors:* Solution concentration, polarography sensors, and substance composition sensors/detectors.
5) *Other Types of Sensors:* Touch, contactless, lin- ear (analog), digital (numeric), compound, and integrated.

These sensors increase the ability to measure, analyze, and aggregate data at a much localized level.

Actuators are other IoT devices applied with the UAVs. They are mechanical devices that convert energy into motion, i.e., digital data into physical actions. Some of these devices are electric servo-actuators [92], high performance low-weight compact servo actuator that is applied for flap control and other UAV applications [93]. Moreover, these actua- tors and servo-actuators can be used for a variety of high performance applications, and they are standard building blocks that could be used in ruggedized systems. An exper- iment by Reti *et al*. [132], which is the development of a smart actuator used on a small scale UAV, proves that the actuators with their controlling microprocessors are capable of establishing two-way communication via controlled area network.

Thermal infrared (TIR) remote sensing is a powerful tool for collecting, analyzing, and modeling of energy fluxes and temperature variations. The traditional TIR sensing plat- forms are satellites, aircrafts and balloons that provide valu- able data about the regional scale environments. UAVs have numerous advantages in TIR remote sensing compared to the traditional platforms, because they are inexpensive and easy-to-use.

Sheng *et al*. [133] introduced a small, low-cost and flexible UAV-based TIR remote sensing platform called "AggieAir-TIR," aiming at collecting remote TIR image data. This platform is used for agriculture field and water area detec- tion. It accomplished the mission successfully and showed clear advantages over the traditional TIR remote sensing platforms.

Radio frequency identification (RFID) technologies are applied for tracking, localization, and environmental monitor- ing. RFIDs [134] consist of tags and readers. There are two types of tags, high frequency and ultra high frequency (UHF) tags. RFID systems can include many readers where all these readers can be constructed on a single network using one con- troller. Furthermore, the same design is possible for a single reader that can communicate with many tags simultaneously, reminding that nowadays simultaneous communication of 1000 tags per second is possible. In an application of RFIDs with UAVs, Dubai-based age steel is using RFID reader drone for inventory and locating tagged bundles of pipes, plates, and other items in storage yard [135].

The paper [136] studies the feasibility of using RFID with UAVs to improve construction supply chain management. This research aims at improving workers productivity by identify- ing location of construction materials. The paper addresses the RFID reader detection range and UAV battery life as the technical restrictions. In conclusion, this application offers considerable promise in the construction industry.

The study in [137] explores an indoor localization technique for a UAV using passive UHF far-field RFID system in an indoor monitoring area. This study aims at achieving a simple, accurate and cost effective tracking and localization method for UAVs. Due to shortage of accurate localization in passive UHF RFID systems, the research presents UAV-based interfer- ence location sensing method. The outcome is that first, the existence of UAV in a monitoring area induces RF shadowing and received signal strength indicator (RSSI) interference from deployed tags. Second, it proposes a localization method using observation of RF shadowing and RSSI interference under indoor environments.

The experiment in [138] seeks a solution for monitoring operation in harsh environments using RFID with a UAV. The work proposes a system in which RFID tags that equipped with measuring sensors are distributed on a territory and a reader installed on UAV. The UAV flies over RFID tags and down- loads the measured data by the sensors and sends them to GCS. The work indicates an operator can control the reader through a graphical user interface console. In addition, it is

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possible to clear the RFID tags memory after downloading the sensor data. The results show that tags can be powerful moni- toring instruments, especially where the monitoring is needed for a large area or a harsh environment.

Another experiment [139] evaluates the energy consumption of an RFID tag in an environmental monitoring operation. It tests the possibility of recharging multipurpose RFID tags using a UAV equipped with a wireless power transfer system "rectenna." It works so that the UAV reaches a point at the vertical of the "rectenna" on the RFID tag at a height of about 5 m. By computing the energy balance, the experiment proves the feasibility of this technique.

VII. DATA DELIVERY

One of the significant issues of the deployment of value-added services is the way these IoT devices are activated; sensed or captured data is collected and delivered in an effi- cient way. Our assumption is that the drones are equipped with 4G or beyond technology to connect to the deployed cellular networks. Further, they are also equipped with short- range communication like Wi-Fi so they can connect among themselves directly in D2D manner. Generally, data deliv- ery depends on the application type, i.e., whether it requires real-time action or it is a delay tolerant one.

As discussed in previous section, data collection can be done in different ways. The straightforward way is that each device will send the collected data to the network. However, it is not an efficient way when there is a large number of drones (and each one hosts many MTC devices), where a net- work congestion is expected. As the delay is not a concern in the delay-tolerant applications, an efficient way to trans- fer the data to the network is to store the collected data, and then sent it whenever the drone detects a good network, i.e., high link quality and less congested network as the drone is flying. In other words, this method of data collection will be at three stages; store, wait, and forward. In addition to the minimization of the power consumption, the other advan- tage of this method is optimization of network congestion. Minimizing power consumption is achieved by the fact that the drone will attach to the network with a high link quality and less congestion, and thus less energy is needed to con- nect to the network (as the transmitted power depends on the distance between the transmitter and the receiver).

Another efficient and powerful way is to organize the flying drones into many clusters. However, the creation of clusters consisting of always moving devices, i.e., drones, is not an easy task, where many challenges could be expected. In the case of monitoring a plaza crowded with people, all the drones monitoring this plaza will be grouped in one cluster if they are equipped with the same technology, i.e., homogeneous drones, otherwise many clusters should be created. These clusters can be interconnected if the CH of each cluster is equipped with the required interfaces, otherwise the connection would be done via the network. Another challenging issue is the choice of CH. For many flying drones, the CH should be chosen that all (or the majority) of the members of the cluster could be connected to it for a certain time. That is, the longer period the drone stays in the cluster, the probability of selection as CH increases.

In addition, CH should also be equipped with the interface by which it could interconnect with other CHs. Another impor- tant concern in the creation of the cluster is whether the created network is a mesh one, or another form of networks. Depending on the type of the network, which one is the effi- cient way to relay the data to the CH and then to the network? Besides, the interference between the moving clusters is of paramount issue that should be efficiently solved too. The cluster mechanism could be used for real and nonreal-time applications, but the difference would be the location where the collected data is stored and processed.

A. Communication Technologies for UAVs

For communicating the MTC devices among them and also to the network (or the Internet), an appropriate access net- work should be chosen. These access networks can be divided into two categories: short and wide range communications. Wide range communications provide coverage over a large area such as cellular (e.g., LTE), broadband (e.g., Wimax), and SATCOMs. The other category, i.e., short range commu- nication, is used (as expected from its name) for short distances communications, such as Zigbee and Bluetooth.

Advances in telecommunication technologies enable con- trolling the UAVs flying at high altitudes from considerable distances [140]. 4G LTE systems as well as the upcoming 5G system have the ability to provide reliable mobile con- nectivity to UAVs for aerial data collection, processing and analysis [141]. The communication among these IoT devices on board of UAVs requires flexibility, fast and reliable com- munication. These advance communication technologies will support reliability, connectivity and high mobility of the drones flying in the air. For example, UAVs will gain benefits using 5G for real-data and high resolution video streaming such as 4k capacity.

With the deployment of UAVs, different new business mod- els will emerge such as sensing and services applications. These businesses will utilize these flying vehicles as a plat- form that works in parallel to the ground Internet or to complement the coverage of 5G. For instance, UAVs can be equipped with communication relays and can operate as high altitude communications relay platform which is a technology that can deliver mobile, persistent connectivity over different regions [142]. For example, Google tests multiple prototypes of solar-powered Internet drones to ensure security for deliv- ering Internet from the sky. On top of this, Google's project SkyBender uses the drones to deliver next generation 5G wire- less Internet, up to 40 times faster than 4G systems [143]. In the following sections, many candidates of access networks for

UAVs will be explored.

1) Cellular Systems: The recent development in remotely controlling the flying vehicles via wireless has enabled to con- trol the UAVs even Beyond Visual Line of Sight. Definitely, one of the possibilities that enables this feature for UAVs is the application of cellular networks. In these networks, each cell obtains a fixed location transceiver known as BS. These cells provide radio coverage over the areas. A User Equipment in the coverage area is able to communicate to the network while moving. Cellular architecture has several advantages [91], such as coverage can be extended over large areas by multiple BSs. Multiple BSs provide a natural redundancy in a way that if one link is poor, another link may perform better. A limited bandwidth can be reused many times over a region and capac- ity can be increased as required. Popular cellular technologies include global system for mobile communication (GSM), uni- versal mobile telecommunication system or 3G, and LTE or 4G.

Lee *et al*. [144] indicated that in most of UAV civil appli- cations, the industrial, scientific and medical (ISM) frequency bands are applied for air-ground communications. The trans- mission power of these bands is strictly limited, and this results in a limited flight coverage. For avoiding the band- width and coverage limitations, this paper considers cellular networks for the communication. The reason is that cellular networks can provide a wide coverage with high throughput rate, communication devices are small in size, low power con- sumption and mass production that can accelerate its usage in practical UAV implementations. The work in [145] presents

a scenario in which UAVs serve as flying GSM BSs and can provide network coverage to users within their vicinity. In the case of a failure in the infrastructure of cellular network, this work applies a UAV-based software defined radio platform for emergency communication and SAR operations.

The field-test experiment [146] analyzes the potential of applying a 3G small UAVs (SUAVs) as wireless relays for assisting cellular network performance to provide network connectivity for rural areas. The results of this experiment both in rural and urban environments demonstrate a simi- lar trough-to-peak throughput and ping time improvements. Besides, after comparing the SUAVs relay performance with alternative load balancing and static relaying methods, the work shows improvement over existing methods in both mean throughput and Quality of Service (QoS).

Qazi *et al*. [147] studied the UAV-based real-time video surveillance and streaming over 4G-LTE system. The study evaluates the performance of this video streaming by applying many metrics like throughputs, loss rates and the delay in rela- tion to the physical aspects of wireless propagation; multipath propagation loss, shadowing, and fading models. They present an architecture for closed circuit monitoring framework for streaming real-time video using encoded MP4 video format. The architecture consists of multiple indoor femto cells and outdoor macro vantage points, where its efficiency is validated by simulations carried out in network simulator-3.

2) WiMAX (802.16): WiMAX is a wireless technology that aims at delivering broadband access over a large area. It provides wireless broadband access at a low cost and covers longer distances than Wi-Fi [148]. Depending on the frequency band, this technology applies frequency division duplex or time division duplex configurations. The data rate for the fixed standard supports up to 75 Mb/s (typically 20 to 30 Mb/s) per subscriber, while the mobile applications sup- ports 30 Mb/s (typically 3 to 5 Mb/s) per subscriber [149]. WiMAX is developed to handle high-quality voice, and video stream while providing high QoS.

Rahman [150] considered UAV-based rescue system as a viable solution for saving lives in alpine environment. According to the network requirements, the work discusses the challenges of existing wireless technologies for enabling UAV communications and finds WiMAX as an appropriate technology for this hostile environment. The reason to choose WiMAX is due to: 1) the flexibility, i.e., it supports point- to-point and mesh systems; 2) service differentiation, i.e., it applies different management methods based on the types of traffic; 3) higher safety, i.e., it implements several methods of encryption, authentication and security; 4) higher throughput;
5) wide coverage; 6) mobility, i.e., it allows connections up to 120 km/h; and 7) the easy installation and the low cost.

The study in [151] focuses on determining how far the mobile WiMAX performance meets the strong requirements on a communication system used for command-and-control of UAVs. To do so, the work investigates the mobile WiMAX system performance under different channel conditions by means of throughput, round trip time (RTT), jitter and packet error rate for different uplink and downlink modulation and coding schemes and channel attenuations. The results of this evaluation show that the mobile WiMAX is very promising due to its low RTT and jitter in combination with a low packet error rate even under difficult channel conditions.

Dalmasso *et al*. [152] use wireless mesh networking as a solution to create adaptive networks during emergency situ- ations. They propose a network solution without fixed access points, based on UAVs to realize the network backbone in emergency scenarios. The analysis of the work is per- formed considering space, random, and Manhattan scenarios. Random-scenario is characterized by the presence of obstacles of random dimensions and positions, while Manhattan sce- nario reminds the typical perpendicular streets of Manhattan in New York. This work analyzes coverage properties of UAV nodes and provides a methodology for the network planning in terms of number and positions of UAVs by determining a sin- gle cell radius setting and the desired modulation scheme. The authors consider the UAV height as an important parameter in accordance to the topological features of the obstacles on the terrain, in addition to the radius. Simulations results elu- cidate the possibility of determining the position and height of each UAV over the emergency area and ensure a certain communication quality using WiMAX.

Dusza and Wietfeld [153] indicated that for a reliable control of micro unmanned aerial vehicles using IP-based networks, it is highly important to assure certain QoS for the transmission of control data. This work presents a novel QoS aware packet scheduling scheme which is parametrized in a very flexible and simple way. The mobile WiMAX defines five QoS classes, which present different require- ments concerning data rate and delay. This is important since WiMAX is used for untypical applications like controlling the UAVs. The authors equip UAV swarm with gas measurement equipment in order to measure the contamination in the atmo- sphere. They apply the defined scheduling algorithm scheme to ensure that UAV control information such as flight routes and telemetry is transmitted under each circumstance and also the gas measurement values are not completely suppressed by scheduling scheme. The overall achievement of this work shows a performance improvement and an increase in QoS by applying mobile WiMAX and the proposed scheduling scheme.

3) Satellite Communications: When UAVs fly outside the range of direct link due to distance or environmental obstruc- tions, SATCOMs are applied for BLoS communication [154]. Besides, during UAV operations the existence of satel- lite link is required at all times to assure mission critical communications.

Skinnemoen [155] pointed out that SATCOM(s) is required either in UAV itself or as a relay via ground. They present the key challenges of applying SATCOM for live photo and video communications through micro and mini UAS. They point out that there are two main challenging issues: 1) limited bandwidth and 2) high cost for data transfer. This work intro- duces adaptive system for image communications in global networks. This is proposed to solve several challenges for mission-critical UAV operations. Additionally, a study in [156] refers to UAV image transmission system based on satellite relay. The paper discusses the key specifications such as UAV uplink transmission power, image transmission rate and satel- lite downlink transmission power. In comparison to UAV aerial data-relay with satellite data-relay, it is indicated that satellite relay obtains larger overlay range, where it has stable wire- less channel performance and provides long distance image transmission with a good image quality.

4) Wi-Fi (IEEE 802.11): Wi-Fi is a wireless technology that includes a set of standards for implementing WLAN commu- nication in 2.4, 3.6, 5, and 60 GHz frequency bands [157]. It specifies an over-the-air interface between a wireless client and a BS or between two wireless clients. This technology is used in flight control and real-time data such as photo and video transmission between UAVs and devices on the ground [158]. The research in [159] has developed a UAV-carried, on-demand Wi-Fi prototype system where the UAV carries the Wi-Fi signal to the emergency areas. The traditional Wi-Fi signal is transmitted around 100 m but this UAV-carried system can extend the signal up to 25 km. It can focus on the energy in one direction with the use of directional antennas. In addition, a smart heading control mechanism is used to ensure the link connectivity. The system has the real-time video transmission ability. This prototype approves the feasibility of establishing on-demand Wi-Fi service through the aerial layer using a flexible UAV platform. The field experiments in [160] address the issue of configuring 802.11 antennas in UAV-based networking. It reports the performance mea- surement of wireless link from a UAV to GS by means of RSSI, distance, raw link-layer throughput, and ground-station elevations. This experiment compares the performance of 32 simultaneous pairs of UAV and ground configurations, and concludes that for achieving the highest throughput, both the UAV and GS should use omnidirectional antennas positioned horizontally. The results of applying 802.11a wireless links for UAV and GS demonstrate that it is useful in UAV network- ing. The study in [161] addresses the enhancing impedance bandwidth of a capacitive antenna for 1.575 GHz GPS and 2.4/5.2 GHz Wi-Fi applications for communications between UAV and GS.

5) Bluetooth (IEEE 802.15): Bluetooth (IEEE 802.15.1) is a standard and a communication protocol with a low power consumption and designed for ranges between 10 to 100 m. It operates in 2.4 GHz frequency band and uses frequency hopping spread spectrum for the transmission. There are three versions of this technology with different data rates of 1 and 3 Mb/s and the maximum data rate can reach up to 24 Mb/s. This wireless technology is applied in different applications such as file transfer, Ad-hoc networking, device synchronization, peripheral connectivity, etc. [162].

The experiment in [163] involves the design and prototype development of an aerial “fly-by-wireless” UAV platform and describes the onboard wireless distributed data acquisition and control system. The developed onboard wireless system is composed by one master node, connected to the flight con- troller and six slave nodes spread along the aircraft structure and connected to several sensors and actuators. The results of this experimental work demonstrate that, for a slave-to-master direction, the system prototype has the ability of supporting a sampling rate of up to 200 Hz for each of the six slaves simultaneously without significant performance degradation in terms of throughput, loss or delay. Furthermore, a differ- ent study [164] introduces a robotic system named unmanned ground-air vehicle, which consists of two semi-autonomous robot platforms, an unmanned ground vehicle (UGV) and a UAV. This work proposes three inspection topics with com- bined UGV and UAV: 1) the operator control unit (OCU) by means of cell or smart phones; 2) the camera and vision system with the focus on real-time-feature extraction; and 3) the archi- tecture and hardware of UAV. It applies Free2move Bluetooth module for remote software debugging, parameter transfer, and future remote control using mobile devices. The work mentions that the OCU is able to use Bluetooth and supports searching for the best communication channel.

Afonso *et al*. [165] described the implementation of a short range wireless network platform using Bluetooth and on a round robin scheduling algorithm. This implementation proposes an approach to build an application independent plat- form for supporting distributed sensing and actuation control system, which is applied for a UAV. The aim of this work is to achieve an autonomous flight that is capable of carrying on different flight missions. The established Bluetooth network includes one master station, containing the flight controller and up to seven slave stations, which are speared along the UAV structure. The results of the work demonstrates that apply- ing the round robin scheduling algorithm together with the proposed platform result in an efficient behavior with low computational power and provides reliable communication. Furthermore, based on this technology Hoffmann *et al*. [166] developed a testbed for multiple UAVs control. This work out- lines the design and development of a miniature autonomous waypoint tracker flight control system and the creation of a multivehicle platform for experimenting and validation of multiagent control algorithm. The work points out that the development of this testbed paves the way for real-world implementations such as autonomous collision and obstacle avoidance, task assignment formation flight, by applying both centralized and decentralized techniques.

6) Zigbee (IEEE 802.15.4): Zigbee (IEEE 802.15.4) sup- ports high-level communication protocols used to create per- sonal area networks, since it is low-power and low-cost. This technology is typically used in low data rate applications that require battery life and secure networking. The low- power consumption feature enables it to have longer life, and having mesh networking enables it to have high reliabil- ity and larger range. This technology operates in ISM bands and it applies direct sequence spread spectrum (DSSS) to increase the robustness against interference, and provide gross data rates of 20/40 kb/s at the 868/915 GHz, and 250 kb/s at the 2.4 GHz. There are 16 channels, where each one requires 5 MHz of bandwidth. Zigbee is the best choice for intermit- tent data transmissions from a sensor or input device. There are increasing applications of this technology in wireless control and monitoring applications, including traffic system manage- ment, electrical meters, pollution control, as well as home and factory automations [167].

Regarding Zigbee in the deployment of UAVs, Yu *et al*. [168] presented developing a system of general use in quadrotor UAV indoor localization in a known envi- ronment. This development is made by the combination of Zigbee and inertial navigation system, where inertial sensors, e.g., airspeed meter and accelerometer are used to increase the accuracy. By applying an accurate extended Kalman filter model, the data is stabilized and substantial improvements are made. The results elucidate that the localization system is viable, effective, flexible, and easily adaptable to various sit- uations. In another work, [169] presents UAV landing, where Zigbee is used for communication and position estimation. The outcome of the paper shows considerable decrease of error's amount for position calculation.

B. Machine-Type-Communications Perspective

Machine-type-communications (MTC), or alternatively machine-to-machine (M2M) communications, refers to data communication among IoT devices without any human intervention [170], [171]. M2M devices cover a broad variety of applications; e.g., eHealth, surveillance, and security, intelligent transport system, city automation, etc.; in a wide range of domains, influencing different markets and envi- ronments. M2M is considered as the key enabler of the IoT vision. MTC is expected to connect an enormous number of devices, where it is expect to reach 50 billion M2M devices by 2020 [172]. Usually, M2M devices can communicate either among each other directly, i.e., D2D communication, or through the network, such as 3G/4G networks. In this paper, UAVs can be considered as machines communicating among them without, or with a little, human intervention. As a result, the communications between UAVs is either D2D, or M2M, depending on whether the communication is direct or via the network, respectively. These communications need to be reliable, secure, scalable, and manageable. Generally, the M2M applications have noticeable features, such as low cost, low/no mobility, the presence of a large number of devices, time-controlled, small data transmission, and group-based communications. In most cases, they are delay tolerant and small, and have infrequent data transmission [141], [173].

1) Small MTC Data Delivery: The small data deliv- ery is one of the MTC features. It is intended to be applied for the MTC devices that send or receive small amount of data. The technical specification group services and system aspects [174] refers to three considerations for small data delivery. First, the system shall support delivery of a small amount of data with minimal network impact, e.g., signal- ing overhead, network resource, and delay for reallocation. Second, before the delivery of a small amount of data, the MTC device may be attached or detached to/from the net- work. Third, the definition of a small amount of data shall be configurable per subscription or by network operator pol- icy. There is a variety of MTC applications that apply small data delivery such as security, tracing and tracking, payment, health, remote maintenance/control and metering.

Tyagi *et al*. [175] mathematically analyzed the delay of ran- dom access procedure with simulations for an efficient delivery of frequent small data for ubiquitous-healthcare (u-healthcare) applications over LTE-Advanced network. They pointed out that the presented model for delay analysis can be used as a basis for network management mechanism that ensure reli- able delivery of small frequent u-healthcare data sets within small delays.

The transmission of a small amount of data in the presence of a large number of MTC devices causes signaling overhead in the random access procedure stage. To enable an efficient small data transmission, Liao *et al*. [176] proposed a direct access scheme using code division multiplexing (CDM) with pseudo-random resource selection for small data delivery in cellular networks. Instead of the transmission on resource blocks assigned by eNB, the UEs randomly select resource blocks for direct data transmission, where CDM is used to resolve the collision problem. The performance of this scheme is close to the random selection scheme with much lower complexity, in addition to the feasibility of the proposed CDM-based system for direct access in cellular networks.

The study in [177] addresses the emerging concept of MTC where unattended wireless devices send their infrequent and small data over LTE cellular network. In order to improve the efficiency of small data access, the authors suggest a novel contention-based LTE transmission (COBALT) mechanism. Simulation results demonstrate that COBALT improves net- work resource utilization and device energy efficiency, in addition to the reduction of the mean data access delay.

2) MTC Congestion Problem: A massive deployment of MTC IoT devices, without an adequate engineering of their associated traffic and signaling, results in a congestion problem [178]. This is because in M2M communication, some applications like remote surveillance and monitoring systems generate simultaneous data at periodic time intervals or due to the existence of an event like the detection of the fire in a forest. This consequently causes overload at the same time interval. In addition, when a massive amount of con- nection/activation requests comes from a large area in a time interval, it leads to congestion problem in both radio access network (RAN) part and core network part.

Generally, congestion and system overload can take place for many reasons [179]: 1) malfunction in the MTC appli- cation or MTC server, e.g., devices are trying to reconnect multiple times to a server which is down; 2) massive attempts from MTC devices to attach or connect to the network simultaneously; 3) transmission and reception a high vol- ume of activate/modify/deactivate connection requests all at once; and 4) synchronized applications, e.g., MTC devices are simultaneously activated at a certain time.

Regarding the MTC signaling congestion avoidance and overload control methods, they can be classified into two main classes: 1) push- and 2) pull-based methods. In the push-based methods, the RACH procedure is initiated by the terminals (UEs or MTC devices), which yields to consider them also as a decentralized control scheme. Under this category, we can find many methods [180], [181]: Separate RACH resources, Dynamic allocation of RACH resources, access class barring scheme. Regarding the pull-based scheme, the network (eNB) itself initiates the RACH procedure. This scheme can be considered also as centralized control one, as the control is totally held by the network. Paging and group paging are good examples on this category [181]. Another classification

is introduced by Ksentini *et al*. [182], where they classified the existing solutions into proactive and reactive ones. The proactive solution is applied beforehand in order to alleviate the congestion problem. Many mechanisms exist under this class; for instance, grouping and clustering of MTC devices, aggregating the MTC requests either at RAN or by creating profile ID. On the other hand, the reactive solutions are reac- tive to the congestion, i.e., they are applied when a problem takes place. The methods under this class take many actions, such as rejecting or delaying the requests at RAN.

VIII. DATA PROCESSING

Data processing mainly depends on the type of application whether it is a real-time one or not. For nonreal-time applica- tions where there is no constraint on the delay, i.e., delay- tolerant applications, the collected data can be stored and processed in a remote cloud (i.e., cloud computing), and then the user can request the post-processed information (the results of processing of the collected data) from the cloud. Regarding the real-time applications where the post-processed informa- tion is needed for the following tasks, the concerned data is stored and processed in a local Cloud that is in the vicinity of the monitored location, e.g., monitoring a plaza crowded with people. For crucial cases where the delay is critical, specific UAV(s) acting as a moving "cloudlet" can be used. Cloudlets are the techniques that propose the augmentation of mobile computational resources with the adjacent servers. Cloudlets are the solutions for connecting the high latency remote servers by bridging the cloud to the mobile [141]. Cloudlets increase the processing capacity, conserve the energy resource, and ease the deployment.

For an application of cloudlet, the technical report [183] presents a strategy for overcoming the challenges of cyber- foraging mobile platforms at the tactical edge. In the strategy, for instance, the mobile apps can locate a different cloudlet, e.g., in a UAV and have the apps running in a short time with no need to any configuration on the app or the cloudlet. This runtime flexibility enables employing all the opportunistic available resources and the replacement of lost cyber-foraging resources by the newly obtained cyber-foraging resources.

The experiment in [184] explores the use of UAVs for surveillance and security related tasks through a cloud com- puting infrastructure. The work proposes "dronemap," a cloud- based architecture for Internet of drones (IoD). Dronemap integrates UAVs with the cloud and aims at virtualize access to UAVs, and offload heavy computations from the UAVs to the cloud. The virtualization emphasizes the concept of IoD as specific thing of IoT connected to the Internet through abstract interfaces. The computation offloading (CO) solves the com- puting and storage resource restrictions of the UAVs as the intensive computation is not performed on-board UAVs and it is offloaded to the cloud.

The paper [185] proposes a cloud-supported UAV application framework for disaster sensing applications in disconnected, intermittent and limited environments and implements the prototype of the framework. This is suitable for the scenarios which have a large amount of video data requiring real-time processing which is a significant factor in

disaster management applications. It integrates video acquisition, data scheduling, data offloading and processing, and network state measurement to deliver an efficient and scalable system. The prototype of the framework consists of a client- side which is the set of components hosted on the UAV that selectively offloads the captured data to a cloud-based server. The server which is hosted within the cloud infrastructure provides real-time data processing and information feedback services to the control center and the operator. For the result of the paper, the developed prototype proves the feasibility of the proposed framework in the paper.

The report [186] studies the collaboration between the fleet of UAVs to work autonomously from the central command center which is hosted in the cloud. The report studies the use of UAVs within cloud computing in emergency situations in Smart Cities. Emergency situations are unpredictable and often involve incomplete information that might variate over time. This variation generates unpredictable complex and multiob- jective functions. For solving these problems, the study uses evolutionary methods for the optimization and performs the computation using cloud computing. The study concludes that for keeping the system in an optimal state, the multiobjective functions should be evaluated continuously over time.

CO improves the performance of embedded systems by offloading some of the computational tasks, especially computation-intensive tasks to servers or clouds. Besides, CO reduces the power consumption of the UAV, since most of the tasks, especially the computation-intense ones, would be per- formed in the cloud and not in the UAV. Since there would no need for powerful computation hardware (when using CO), the hardware design and thus the cost of UAVs would be lowered, making the feasible deployment of a lot of UAVs in various domains. In this regards, 5G networks would be the best tech- nology for the efficient deployment, as the virtualization and cloud computing would be inherently supported.

To cover the concept of computational offloading, Kumar *et al.* [187] provided an overview on different algorithms, architectures, and technological enablers. This work describes some infrastructure and solutions that address the related research areas. The paper uses common approaches to make offloading decisions and classifies these approaches according to different factors such as improving performance by saving the energy, when to decide offloading, i.e., static versus dynamic, the type of mobile systems using offload- ing, types of applications, and offloading infrastructure. The paper aims to emphasize on the importance of CO for resource constraint devices.

Reference [188] reviews a series of computational offloading mechanisms and then formulates the equations of the CO problem with the goal of optimizing the communication and computation resources with the focus on latency and energy constraints. The paper indicates that mobile cloud comput- ing (MCC) has three main advantages. First, MCC enhances the battery life-time by offloading energy-consuming tasks from the mobile device to the cloud. Second, it enables mobile devices to run complicated applications and provides higher data storage capabilities. Third, it improves reliability, as the data can be stored and backed up from the mobile device to a set of reliable fixed storage devices.

Toma and Chen [189] indicated that in CO mechanisms, most of the approaches decide whether a task is executed locally or is offloaded without scheduling the execution order. For this purpose, the study explores the timing constraints of real-time tasks as well as deciding which tasks should be offloaded to receive the results in time. This problem is an NP-complete and to solve it the authors develop and study a pseudo-polynomial-time algorithm for deriving feasi- ble schedules.

The paper [190] proposes a framework for energy effi- cient computational offloading (EECOF) for computational offloading in MCC. The framework aims at leveraging appli- cation processing services of cloud datacenters with minimal instances of application migration at runtime. This work is examined first, by performing the execution of offloading techniques for running the mobile applications in real MCC environment. Second, by employing EECOF for computational offloading, and third by measuring energy efficiency in terms of reducing the energy computation cost. The findings of these experiments illustrate that both the size of data trans- mission over wireless link and energy consumption cost have prominent reduction.

The work in [191] proposes the mobile cloud with smart offloading system (MCSOS). This is an adaptive CO system with an optimization problem and aims at minimizing the energy consumption in cloud-assisted mobile computing. This smart system allows the resource-poor mobile devices to offload their computation to the devices with idle resources in the vicinity. The results of the proposed MCSOS, with dif- ferent simulation cases, demonstrate eminent improvement on the energy efficiency.

The study in [192] formulates an optimization problem subject to delay constraints. The study introduces two algorithms:
1) deterministic delay constrained task partitioning (DTP) and
2) probabilistic delay constrained task partitioning (PTP). DTP solves the offloading decision problem with delay constraints and provides near-optimal solution runs in polynomial time in the number of tasks. PTP offers stronger QoS guarantees. Simulation results of this study illustrate that the proposed algorithms are accurate and robust, and have flexible scale with different numbers of assigned tasks.

Moreover, recently code offloading from the mobile devices to the cloud has become one of the popular techniques to reduce the energy consumption. The research in [193] explains the code

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offloading as the process that depends on remote servers to execute the code delegated by a mobile device. To do this, the mobile device is assigned by a local decision logic for detecting resource-intensive portions of the code in a way that when there is network communication, the device can estimate the amount of the energy that needed for executing the code. This estimation leads to less computation effort and thereby less energy consumption. The code offloading methods are addressed in [194].

IX. Future Research Areas

The advancement in UAVs technology, namely drones, is growing rapidly. It is expected to enter nearly every sector of our life, such as search and rescue, surveillance, monitoring (e.g., Oil and gas pipeline, and road traffic), disaster manage- ment, and crop management (e.g., agricultural activities and crop dusting). Moreover, it could provide new services never imagined before, in addition to presenting a new revenue and business market.

However, the efficient and safe deployment of this new technology is faced by many challenging issues. These issues comprise not only technical issues, such as physical collision, path planning, data collection, communication and network- ing of UAVs, and data delivery, but also regulation issues as this nascent technology can be associated with problems like breaking the privacy of people. However, we preview here and highlight some of them for future research: management and control, power consumption, and security and privacy.

Regarding the first challenging issue, it is a big challenge to manage and control a massive number of drones. The rea- son is that each UAV may host more than one IoT device, such as different types of sensors and cameras. In addition, managing and control of many devices on board and some- times with conflict of interest (e.g., taking a video and photos from two different angles from one fixed location) becomes a problem for the efficient introducing of UAV-based value- added services. Therefore, efficient methods and algorithms to solve the concurrence on the IoT devices on-board should be dully proposed in order to realize and validate our vision on the value-added services.

Another significant open issue pertains to the power con- sumption in UAVs. This power consumption can be due to three main tasks: 1) the power consumed by the drone itself; 2) the power consumed by the IoT devices on-board like sensors and cameras; and 3) the power consumed for the com- munication to deliver the collected data and other tasks like the command and control. Giving a certain UAV consuming a certain power level, the power consumption of the two other tasks, i.e., for the IoT devices and the communications, should be highly controlled in order to minimize the power consump- tion as much as possible, and thus achieving many value-added services other than the main task of the UAV. In this vein, algo- rithms and methods to control and manage the IoT devices as well as the communication to the network (or the Internet) are indispensable for the efficient deployment of UAVs.

The security and privacy is one of the most critical issues to think about it when talking about UAVs. This is because of the dangerousness of this technology if it is applied for bad issues. Let us take the example of drone delivering pizza to the consumer. On its way to the destination, this drone is tam- pered with another malicious drone, i.e., drone to bad task. In this case, the consumer would be easily attacked if there is no a way for mutual authentication between the drone and the consumer. Another security issue is network security. It is also an important concern to be tackled with in UAV communica- tions. For example, the jammers may intend jamming of the GPS signal that navigates the path of the UAV. In the case of jamming, the UAV communication will be disrupted, and thus it will lose its ability to determine its location, altitude, and its travel direction. Therefore methods to evade the aerial jammer on the communications are needed. Depending on more than one navigation system may be also a good idea to avoid the concerned problem.

X. Conclusion

In this paper, a comprehensive survey on UAVs is presented. It highlighted the UAVs' potential for the delivery of IoT ser- vices from height and addressed the relevant challenges. In addition, we described our envisioned UAV-based architecture for the delivery of UAV-based IoT services from the sky and we presented the relevant key challenges and requirements.

This paper addressed the regulations and standardization efforts, and public safety concerns on the ground. It also overviewed the concerns regarding the physical CA and obsta- cle detection methods. Additionally, a detailed overview on IoT equipment such as sensors, cameras, and RFID that are applied with UAVs is presented, and the data collection by each of discussed equipment is studied.

Furthermore, to address the challenging issue concerning the adoption of different communication technologies among UAVs and the ground infrastructure, this paper explored possi- ble solutions by reviewing different wireless technologies such as cellular (3G, 4G LTE), WiMAX, and Wi-Fi.

To obtain an efficient UAV networking, the drones are con- structing FANET in which they communicate among them in an *ad-hoc* manner. They establish device-to-device or alter- natively drone-to-drone communications. In order to portray possible solutions for this type of communication, this paper discussed issues relevant to machine-to-machine communica- tions in the context of our envisioned architecture. This paper addressed the node-to-node, mesh, DTN, and the data routing (MANET/VANET) perspective as well.

Moreover, in order to overcome the problem with the lim- ited energy resources of the UAVs and to process the collected data by the UAVs, considering the cloudlets and the CO might be of best solution. This is because cloudlets increase the pro- cessing capacity, conserve the energy resource and the CO is a considerable technique to handle the data processing by the

UAVs as the mobile devices.

REFERENCES

[1] D. Nield, "Boeing's latest patent reveals a drone that can transform into a submarine," *ScienceAlert*. Accessed on Mar. 7, 2016. [Online]. Available: http://www.sciencealert.com/boeing- s-latest-patent-reveals-a-drone-that-can-transform-into-a-submarine

[2] A. F. B. Hanscom and M. A. Bedford, "Unmanned aircraft system (UAS) service demand 2015–2035, literature review & projections of future usage," Res. Innov. Technol. Admin., U.S. Dept. Transp., Washington, DC, USA, Tech. Rep. DOT-VNTSC-DoD-13-01, Sep. 2013.

[3] A. Garcia, "300,000 drones registered in 30 days," *FOX News—CNN WIRE*, Jan. 2016. [Online]. Available: http://money.cnn.com/2016/01/22/technology/faa-drone-registrations/

[4] Economic Research Office. (2011). Information and Communications in Japan, Ministry of Internal Affairs and Communications (MIC), Japan. [Online]. Available: http://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2011/2011-index.html

[5] A. Qiantori, A. B. Sutiono, H. Hariyanto, H. Suwa, and T. Ohta, "An emergency medical communications system by low altitude platform at the early stages of a natural disaster in Indonesia," *J. Med. Syst.*, vol. 36, no. 1, pp. 41–52, 2010.

[6] J. Rogers, "How drones are helping the Nepal earthquake relief effort," *FoxNews.Com*. Apr. 2015. [Online]. Available: http://www.foxnews.com/tech/2015/04/30/how-drones-are-helping-nepal-earthquake-relief-effort.html

[7] R. Debra and C. McCullough, *Unmanned Aircraft Systems (UAS) Guidebook in Development*. Accessed on Mar. 7, 2016. [Online]. Available: http://cops.usdoj.gov/html/dispatch/08-2014/UAS_Guidebook_in_Development.asp S. W. Loke, "The Internet of Flying-Things: Opportunities and chal- lenges with airborne fog computing and mobile cloud in the clouds," Dept. Comput. Sci. Inf. Technol., La Trobe Univ., Melbourne VIC, Australia, Jul. 2015, accessed on Jun. 4, 2016. [Online]. Available: https://arxiv.org/abs/1507.04492

[8] B. J. O'Brien, D. G. Baran, and B. B. Luu, "Ad hoc networking for unmanned ground vehicles: Design and evaluation at command, control, communications, intelligence, surveillance and reconnaissance on-the-move," ARL, Adelphi, MD, USA, Army Res. Lab. Tech. Rep. ARL-TR-3991, Nov. 2006.

[9] IAFC (International Association of Fire Chiefs). (Jan. 2014). *Use of Unmanned Aerial Vehicles in Public Safety Emergency Response, Adopted by IAFC Board of Directories*. [Online]. Available: http://www.iafc.org/IAFC-position-Use-of-Unmanned-Aerial-Vehicles-In-Emergency-Response

[10] C. C. Bolkcom, "Homeland security: Unmanned aerial vehicles and border surveillance," Federation Amer. Sci., Congr. Res. Service (CRS), Washington, DC, USA, Tech. Rep., Jul. 2010.

[11] M. T. McCaul, "Using unmanned aerial systems within the homeland: Security game changer?" House Committee Homeland Security, Washington, DC, USA, Tech. Rep. 112-107, Jul. 2012.

[12] W. Staff, "Fighting forest fires before they get big—With drones," *WIRED*, Jun. 2015. [Online]. Available: http://www.wired.com/2015/06/fighting-forest-fires-get-big-drones/

[13] J. K. Hart and K. Martinez, "Environmental sensor networks: A revolution in the earth system science?" *Earth Sci. Rev.*, vol. 78, nos. 3–4, pp. 177–191, Oct. 2006.

[14] P. Dockrill, "Facebook is preparing its Internet-beaming drone for maiden launch," *ScienceAlert*. Accessed on Mar. 7, 2016. [Online]. Available: http://www.sciencealert.com/facebook-is-preparing-its-internet-beaming-drone-for-maiden-launch

[15] D. Sahota, "Internet.org building drones to connect remote communities," *Telecoms.com*, Mar. 2014. [Online]. Available: http://telecoms.com/239252/internet-org-building-drones-to-connect-remote- communities/

[16] T. Skinner, "Nokia and Du launch network testing drones in Dubai," *Telecoms.com*, Jul. 2015. [Online]. Available: http://telecoms.com/430141/du-and-nokia-launch-network-testing-drones-in-dubai/

[17] G. Kimchi *et al.*, "Unmanned aerial vehicle delivery system," U.S. Patent 20 150 120 094, Apr. 2015.

[18] D. Lee, "Google plans drone delivery service for 2017," *BBC News*. Accessed on Mar. 7, 2016. [Online]. Available: http://www.bbc.com/news/technology-34704868

[19] Amazon, "Amazon prime air," Accessed on Mar. 7, 2016. [Online]. Available: http://www.amazon.com/b?node 8037720011

[20] ITU, "Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in nonsegregated airspace," Mobile, Radio Determination, Amateur Related Satellite Services, Geneva, Switzerland, Tech. Rep. M.2171, 2010. [Online]. Available: http://www.itu.int/pub/R-REP-M.2171/fr

[21] O. Vermesan and P. Friess, *Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems* (River Publishers Series Commun.). Aalborg, Denmark: River, 2013.

[22] C. Snow, "Why drones are the future of the Internet of Things," Dec. 2014, Accessed on Mar. 10, 2016. [Online]. Available: http://droneanalyst.com/2014/12/01/drones-are-the-future-of-iot/

[23] Slange. *Internet of Things-Architecture—IOT-A: Internet of Things Architecture*. Accessed on Jun. 4, 2016. [Online]. Available: http://www.iot-a.eu/public

[24] DroneDeploy. *Powerfull Cloud-Based Software*. Accessed on Jun. 4, 2016. [Online]. Available: https://www.dronedeploy.com/

[25] *Europe Control Manual for Airspace Planning*, Eur. Org. Safety Air Navig., Brussels, Belgium, Oct. 2003.

[26] L. Reynaud and T. Rasheed, "Deployable aerial communication networks: Challenges for futuristic applications," in *Proc. 9th ACM Symp. Perform. Eval. Wireless Ad Hoc Sens. Ubiquitous Netw.*, Paphos, Cyprus, 2012, pp. 9–16.

[27] G. Avdikos, G. Papadakis, and N. Dimitriou, "Overview of the application of high altitude platform (HAP) systems in future telecommunication networks," in *Proc. 10th Int. Workshop Signal Process. Space Commun. (SPSC)*, 2008, pp. 1–6.

[28] J. Gavan and S. Tapuchi, "The potential of high altitude plat- forms (HAPS) for low interference and broadband radio services," in *Proc. 5th Asia–Pacific Conf. Environ. Electromagn. (CEEM)*, Xi'an, China, 2009, pp. 17–25.

[29] UVS International. *Remotely Piloted Systems: Programming International Cooperation & Coordination, RPAS Related Documents*. Accessed on Jun. 4, 2016. [Online]. Available: http://uvs-international.org/

[30] A. C. Watts, V. G. Ambrosia, and E. A. Hinkley, "Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use," *Remote Sens.*, vol. 4, no. 6, pp. 1671–1692, 2012.

[31] D. Umhoefer. (Apr. 2014). *Bird-Sized Drones Could Record You Inside Your Home, Chris Taylor Says*. [Online]. Available: http: / / www.politifact.com / wisconsin / Statements / 2014 / apr / 09 / chris-taylor/bird-sized-drones-could-record-you-inside-your's-hom/

[32] S. Berger, "Mexico drug trafficking: Drone carries 28 pounds of heroin across border to US," *International Business Times*, Aug. 2015. [Online]. Available: http://www.ibtimes.com/mexico-drug-trafficking-drone-carries-28-pounds-heroin-acrossborder-us-2051941

[33] "Proposal to create common rules for operating drones," EASA: European Aviation Safety Agency, Cologne, Germany, Sep. 2015. [Online]. Available: http://easa.europa.eu/newsroom-and-events/News/easa-regulatory-approach-remotely-piloted-aircraft-rpas

[34] *Unmanned Aircraft Systems*. Accessed on Mar. 7, 2016. [Online]. Available: https://www.faa.gov/uas/

[35] "Federal aviation adminstration (FAA)," *DC is a No Drone Zone*. Accessed on Jun. 4, 2016. [Online]. Available: http://www.faa.gov/uas/no_drone_zone/dc/

[36] *FAA Administrator Makes Two Major Drone Announcements*. Accessed on Jun. 4, 2016. [Online]. Available: https://www.faa.gov/news/updates/?newsId=85528

[37] T. Sakano *et al.*, "Disaster-resilient networking: A new vision based on movable and deployable resource units," *IEEE Netw.*, vol. 27, no. 4, pp. 40–46, Jul./Aug. 2013.

[38] T. Taleb, D. Bottazzi, M. Guizani, and H. Nait-Charif, "Angelah: A framework for assisting elders at home," *IEEE J. Sel. Areas Commun.*, vol. 27, no. 4, pp. 480–494, May 2009.

[39] T. Taleb, D. Bottazzi, and N. Nasser, "A novel middleware solution to improve ubiquitous healthcare systems aided by affective informa- tion," *IEEE Trans. Inf. Technol. Biomed.*, vol. 14, no. 2, pp. 335–349, Mar. 2010.

[40] T. Tanzi, L. Apvrille, J.-L. Dugelay, and Y. Roudier, "UAVs for humanitarian missions: Autonomy and reliability," in *Proc. IEEE Glob. Humanitarian Technol. Conf. (GHTC)*, San Jose, CA, USA, 2014, pp. 271–278.

[41] Case Studies of Humanitarian UAV Missions. (Sep. 2015). *Docs, Humanitarian UAV Network, UAVIATORS.* [Online]. Available: http://uaviators.org/docs

[42] L. Apvrille, Y. Roudier, and T. J. Tanzi, "Autonomous drones for disasters management: Safety and security verifications," in *Proc. 1st URSI Atlantic Radio Sci. Conf. (URSI AT-RASC)*, Las Palmas, Spain, 2015, pp. 1–2.

[43] M. Smith. *Flying Drone Peers Into Japan's Damaged Reactors.* Accessed on Mar. 8, 2016. [Online]. Available: http://edition.cnn.com/2011/WORLD/asiapcf/04/10/japan.nuclear.reactors/

[44] *Case Studies of Disaster Management for Different Countries*, Nat. Inst. Technol., Durgapur, India, Mar. 2011.

[45] J. Siminski, "Fukushima plant's radiation levels monitored with an UAV," *The Aviationist*, Jan. 2014. [Online]. Available: http://theaviationist.com/2014/01/29/fukushima-japan-uav/

[46] T. Torii and Y. Sanada, "Radiation measurement by unmanned aircraft after Fukushima Daiichi nuclear power plant accident," in *Proc. Symp. ICAO*, Montereal, QC, Canada, Mar. 2015, accessed on Mar. 15, 2016. [Online]. Available: http://www.icao.int/Meetings/RPAS/RPASSymposiumPresentation/Day%201%20Session%202%20Massaki%20Nakadate.pdf

[47] A. Klaptocz. (May 2013). *Drone Adventure in Haiti*. [Online]. Available: http://blog.droneadventures.org/post/85864746895/drone-adventure-in-haiti

[48] O. Andrade, "Flying aid drones tested in Haiti and Dominican republic," *The Guardian*, Jan. 2013. [Online]. Available: http://www.theguardian.com/global-development/2013/jan/09/flying-aid-drones-haiti-dominican-republic

[49] P. Meier, "Humanitarian UAV missions in Nepal: Early observations (updated)," *iRevolutions*, May 2015. [Online]. Available: http://irevolutions.org/2015/05/03/humanitarian- uav-missions-nepal/

[50] P. Meier, "World bank using UAVs for disaster risk reduction in Tanzania," *iRevolutions*, Aug. 2015. [Online]. Available: http://irevolutions.org/2015/08/19/world-bank-using-uavs/

[51] E. Mavropoulou. "The success of the migrant offshore aid station (MOAS)," *Human Rights at Sea*. Accessed on Mar. 8, 2016. [Online]. Available: https://www.humanrightsatsea.org/the-success-of-the-migrant-offshore-aid-station-moas/

[52] R. M. Thompson, II, "Drones in domestic surveillance operations: Fourth amendment implications and legislative responses," CRS Tech. Rep. R42701, Apr. 2013.

[53] K. Gomez, T. Rasheed, L. Reynaud, and S. Kandeepan, "On the performance of aerial LTE base-stations for public safety and emergency recovery," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, Atlanta, GA, USA, 2013, pp. 1391–1396.

[54] J. Pojda, A. Wolff, M. Sbeiti, and C. Wietfeld, "Performance analysis of mesh routing protocols for UAV swarming applications," in *Proc. 8th Int. Symp. Wireless Commun. Syst. (ISWCS)*, Aachen, Germany, 2011, pp. 317–321.

[55] E. Yanmaz, R. Kuschnig, and C. Bettstetter, "Channel measurements over 802.11a-based UAV-to-ground links," in *Proc. IEEE GLOBECOM Workshops (GC Wkshps)*, Houston, TX, USA, 2011, pp. 1280–1284.

[56] M. Oborne. *Ground Station, Mission Planner*. Accessed on Mar. 15, 2016. [Online]. Available: http://planner.ardupilot.com/

[57] V. D. L. Santos and J. Rios. (Dec. 2015). *NASA UTM: Home.* [Online]. Available: http://utm.arc.nasa.gov/index.shtml

[58] S. Lozano. *First Steps Toward Drone Traffic Management*, NASA. Accessed on Nov. 19, 2015. [Online]. Available: http://www.nasa.gov/ feature/ames/first-steps-toward-drone-traffic-management

[59] Airware. *The Operating System for Commercial Drones*. Accessed on Mar. 10, 2016. [Online]. Available: http://www.airware.com

[60] Airware News, "Airware partners with NASA to develop a UAS traffic management system," Unmanned Syst. Technol., Sep. 2014, accessed on Mar. 15, 2016. [Online]. Available: https://www.airware.com/news_items/airware-partners-with-nasa-to-develop-uas-traffic-management-system/

[61] R. E. Weibel, "Safety considerations for operation of different classes of unmanned aerial vehicles in the national Airspace System," M.S. thesis, Dept. Aeronaut. Astronaut., Massachusetts Inst. Technol., Cambridge, MA, USA, 2005.

[62] B. M. Albaker and N. A. Rahim, "A survey of collision avoidance approaches for unmanned aerial vehicles," in *Proc. Int. Conf. Tech. Postgraduates (TECHPOS)*, Kuala Lumpur, Malaysia, 2009, pp. 1–7.

[63] G. Dean and M. Griffin, *Unmanned Aircraft Systems—ATM Collision Avoidance Requirements*, document CND/CoE/CNS/09-156, Eur. Org. Safety Air Navig., Brussels, Belgium, May 2010.

[64] A. D. Zeitlin and M. P. McLaughlin, "Safety of cooperative colli- sion avoidance for unmanned aircraft," in *Proc. IEEE/AIAA 25th Digit. Avionics Syst. Conf.*, 2006, pp. 1–7.

[65] A. D. Zeitlin and M. P. McLaughlin, "Modeling for UAS colli- sion avoidance," MITRE Corporation, Center for Adv. Aviation Syst. Develop., Doc. 06-1008, McLean, VA, USA, Aug. 2006.

[66] *The Aviation Gold Standard Since 1935, TRCA, Inc.* Accessed on Mar. 8, 2016. [Online]. Available: http://www.rtca.org/content.asp?pl=108&sl=33&contentid=121

[67] F. Barfield, "Autonomous collision avoidance: The technical requirements," in *Proc. IEEE Nat. Aerosp. Electron. Conf. (NAECON)*, Dayton, OH, USA, 2000, pp. 808–813.

[68] L. Yang, J. Qi, J. Xiao, and X. Yong, "A literature review of UAV 3D path planning," in *Proc. 11th World Congr. Intell. Control Autom. (WCICA)*, Shenyang, China, 2014, pp. 2376–2381.

[69] R. K. Sharma and D. Ghose, "Collision avoidance between UAV clusters using swarm intelligence techniques," *Int. J. Syst. Sci.*, vol. 40, no. 5, pp. 521–538, 2009.

[70] M. Hromatka, M. Holt, S. Biaz, and J. West, "A fuzzy logic approach to collision avoidance in smart UAVs," Dept. Comput. Sci., College Saint Benedict, Saint John's Univ., St. Joseph and Collegeville, MN, USA, Tech. Rep. CSSE12-05, 2013.

[71] H. Alturbeh, "Collision avoidance systems for UAS operating in civil airspace," Ph.D. dissertation, School Eng., Cranfield Univ., Cranfield, U.K., Nov. 2014.

[72] S. Ueno and T. Higuchi, "Collision avoidance law using infor- mation amount," in *Numerical Analysis—Theory and Application*, J. Awrejcewicz, Ed. Rijeka, Croatia: InTech, 2011.

[73] D. Toratani, T. Higuchi, and S. Ueno, "Terrain following flight of UAV using information amount feedback," in *Proc. SICE Annu. Conf. (SICE)*, Nagoya, Japan, 2013, pp. 1503–1508.

[74] S. Ueno, T. Higuchi, and K. Iwama, "Collision avoidance control law of a helicopter using information amount feedback," in *Proc. SICE Annu. Conf.*, Tokyo, Japan, 2008, pp. 2118–2121.

[75] A. M. Brandt and M. B. Colton, "Haptic collision avoidance for a remotely operated quadrotor UAV in indoor environments," in *Proc. IEEE Int. Conf. Syst. Man Cybern. (SMC)*, Istanbul, Turkey, 2010, pp. 2724–2731.

[76] J. Israelsen *et al.*, "Automatic collision avoidance for manually tele-operated unmanned aerial vehicles," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, Hong Kong, 2014, pp. 6638–6643.

[77] B. Capozzi and J. Vagners, "Evolving (semi)-autonomous vehicles," in *Proc. AIAA Guid. Navig. Control Co-Located Conf.*, Montreal, QC, Canada, 2001, pp. 1207–1217, accessed on Mar. 15, 2016. [Online]. Available: http://tdl.libra.titech.ac.jp/journaldocs/en/recordID/ article.bib-02/ZR000000045233?hit=-1&caller=xc-search

[78] M. S. Gudaitis, "Multicriteria mission route planning using a paral- lel A* search," M.S. thesis, Graduate School Eng., Air Force Inst. Technol., Wright-Patterson AFB, OH, USA, Dec. 1994.

[79] R. J. Szczerba, P. Galkowski, I. S. Glicktein, and N. Ternullo, "Robust algorithm for real-time route planning," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 36, no. 3, pp. 869–878, Jul. 2000.

[80] P. Sanders and D. Schultes, "Engineering fast route planning algo- rithms," in *Experimental Algorithms*, C. Demetrescu, Ed. Heidelberg, Germany: Springer, 2007, pp. 23–36.

[81] D. Schultes, *Route Planning in Road Networks*. Saarbrücken, Germany: VDM Verlag, 2008.

[82] K. Tulum, U. Durak, and S. K. Yder, "Situation aware UAV mission route planning," in *Proc. IEEE Aerosp. Conf.*, 2009, pp. 1–12.

[83] L. Hernández-Hernández, A. Tsourdos, H.-S. Shin, and A. Waldock, "Multi-objective UAV routing," in *Proc. Int. Conf. Unmanned Aircraft Syst. (ICUAS)*, Orlando, FL, USA, 2014, pp. 534–542.

[84] E. Yanmaz, R. Kuschnig, M. Quaritsch, C. Bettstetter, and

B. Rinner, "On path planning strategies for networked unmanned aerial vehicles," in *Proc. IEEE Conf. Comput. Commun. Workshops (INFOCOM WKSHPS)*, 2011, pp. 212–216.

[85] K. Namuduri, Y. Wan, M. Gomathisankaran, and R. Pendse, "Airborne network: A cyber-physical system perspective," in *Proc. 1st ACM MobiHoc Workshop Airborne Netw. Commun.*, Hilton Head, SC, USA, 2012, pp. 55–60.

[86] K. Namuduri, Y. Wan, and M. Gomathisankaran, "Mobile ad hoc net- works in the sky: State of the art, opportunities, and challenges," in *Proc. 2nd ACM MobiHoc Workshop Airborne Netw. Commun.*, Bengaluru, India, 2013, pp. 25–28.

[87] C. Witefeld, "Communication-aware service platform for collabora- tive UAV applications," Talk at UAV-g, Commun. Networks Inst., Faculty Elect. Eng. Inform. Technol., TU Dortmond Univ., Dortmund, Germany, Sep. 2013.

[88] R. Austin, *Unmanned Aircraft Systems: UAVS Design, Development and Deployment*. Chichester, U.K.: Wiley, Apr. 2010.

[89] J. Chuck, J. Griner, K. Hayhurst, and J. Shively, "Unmanned aircraft systems (UAS) integration in the national airspace system (NAS) project subcommittee final," presented at the NASA Advisory Council Aeronaut. Committee, UAS Subcommittee, Jun. 2012, accessed on Mar. 20, 2016. [Online]. Available: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120015471.pdf

[90] E. W. Frew and T. X. Brown, "Airborne communication networks for small unmanned aircraft systems," *Proc. IEEE*, vol. 96, no. 12, pp. 2008–2027, Dec. 2008.

[91] I. Jawhar, N. Mohamed, J. Al-Jaroodi, and S. Zhang, "Data com- munication in linear wireless sensor networks using unmanned aerial vehicles," in *Proc. Int. Conf. Unmanned Aircraft Syst. (ICUAS)*, Orlando, FL, USA, 2014, pp. 43–51.

[92] J. Li, Y. Zhou, and L. Lamont, "Communication architectures and protocols for networking unmanned aerial vehicles," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, Atlanta, GA, USA, 2013, pp. 1415–1420.

[99] T. Jonson, J. Pezeshki, V. Chao, K. Smith, and J. Fazio, "Application of delay tolerant networking (DTN) in airborne networks," in *Proc. IEEE Milit. Commun. Conf. (MILCOM)*, San Diego, CA, USA, 2008, pp. 1–7.

[100] M. Le, J.-S. Park, and M. Gerla, "UAV assisted disruption tolerant routing," in *Proc. IEEE Milit. Commun. Conf. (MILCOM)*, Washington, DC, USA, 2006, pp. 1–5.

[101] N. Uchida, N. Kawamura, T. Ishida, and Y. Shibata, "Proposal of seeking wireless station by flight drones based on delay tolerant net- works," in *Proc. 9th Int. Conf. Broadband Wireless Comput. Commun. Appl. (BWCCA)*, 2014, pp. 401–405.

[102] J. Kwon and S. Hailes, "Scheduling UAVs to bridge communications in delay-tolerant networks using real-time scheduling analysis tech- niques," in *Proc. IEEE/SICE Int. Symp. Syst. Integr. (SII)*, Tokyo,Japan, 2014, pp. 363–369.

[103] L. Gupta, R. Jain, and G. Vaszkun, "Survey of important issues in UAV communication networks," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 2, pp. 1123–1152, 2nd Quart., 2016.

[104] O. K. Sahingoz, "Mobile networking with UAVs: Opportunities and challenges," in *Proc. Int. Conf. Unmanned Aircraft Syst. (ICUAS)*, Atlanta, GA, USA, 2013, pp. 933–941.

[105] J.-D. M. M. Biomo, T. Kunz, and M. St-Hilaire, "Routing in unmanned aerial ad hoc networks: A recovery strategy for greedy geo- graphic forwarding failure," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Istanbul, Turkey, 2014, pp. 2236–2241.

[106] R. Shirani, "Reactive-greedy-reactive in unmanned aeronautical *ad-hoc* networks: A combinational routing mechanism," M.A.Sc. thesis, Dept. Syst. Comput. Eng., Carleton Univ., Ottawa, ON, Canada, 2011.

[107] J. Huo, Z. Xu, Y. Zhang, and X. Shan, "A UAV mobile strategy in mobile ad hoc networks," in *Proc. Int. Conf. Electron. Commun. Control (ICECC)*, Las Vegas, NV, USA, 2011, pp. 686–690.

[108] W. Chu-Yuan, "A hybrid group key management architecture for het- erogeneous MANET," in *Proc. 2nd Int. Conf. Netw. Security Wireless Commun. Trusted Comput. (NSWCTC)*, vol. 2. Wuhan, China, 2010, pp. 537–540.

[109] E. Kuiper and S. Nadjm-Tehrani, "Mobility models for UAV group reconnaissance applications," in *Proc. Int. Conf. Wireless Mobile Commun. (ICWMC)*, Bucharest, Romania, 2006, p. 33.

[110] Y. Guo, X. Li, H. Yousefi'zadeh, and H. Jafarkhani, "UAV-aided cross- layer routing for MANETs," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Paris, France, 2012, pp. 2928–2933.

[111] M. Zhu, Z. Cai, D. Zhao, J. Wang, and M. Xu, "Using multiple unmanned aerial vehicles to maintain connectivity of MANETs," in *Proc. 23rd Int. Conf. Comput. Commun. Netw. (ICCCN)*, Shanghai, China, 2014, pp. 1–7.

[112] O. K. Sahingoz, "Networking models in flying *ad-hoc* net- works (FANETs): Concepts and challenges," *J. Intell. Robot. Syst.*, vol. 74, nos. 1–2, pp. 513–527, Oct. 2014.

[113] K. Singh and A. K. Verma, "Applying OLSR routing in FANETs," in *Proc. Int. Conf. Adv. Commun. Control Comput. Technol. (ICACCCT)*, Ramanathapuram, India, 2014, pp. 1212–1215.

[114] M. H. Tareque, M. S. Hossain, and M. Atiquzzaman, "On the routing in flying ad hoc networks," in *Proc. Federated Conf. Comput. Sci. Inf. Syst. (FedCSIS)*, Łódź, Poland, 2015, pp. 1–9.

[115] K. S. Singh, "A comprehensive survey on fanet?: Challenges and advancements," *Int. J. Comput. Sci. Inf. Technol.*, vol. 6, no. 3, pp. 2010–2013, 2015.

[94] A. Ryan *et al.*, "Modular software infrastructure for distributed control of collaborating UAVs," in *Proc. AIAA Conf. Guidance Navig. Control*, 2006, Accessed on Mar. 20, 2016. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.101.2959&rep=rep1&type=pdf

[95] T. X. Brown *et al.*, "Ad hoc UAV ground network (AUGNet)," in *Proc. AIAA 3rd Unmanned Unlimited Tech. Conf.*, Chicago, IL, USA, 2004, accessed on Jun. 4, 2016. [Online]. Available: http://citeseer.ist.psu.edu/viewdoc/download?doi=10.1.1.118.8768&rep=rep1&type=pdf

[96] D. Hague, H. T. Kung, and B. Suter, "Field experimentation of cots-based UAV networking," in *Proc. IEEE Milit. Commun. Conf. (MILCOM)*, 2006, pp. 1–7.

[97] K. Fall, "A delay-tolerant network architecture for challenged Internets," in *Proc. Conf. Appl. Technol. Architect. Protocols Comput. Commun.*, 2003, pp. 27–34.

[98] K. Fall *et al. Delay-Tolerant Networking Architecture*. Accessed on Mar. 8, 2016. [Online]. Available: https://tools.ietf.org/html/rfc4838

[116] R. B. Chiaramonte and K. R. L. J. C. Branco, "Collision detection using received signal strength in FANETs," in *Proc. Int. Conf. Unmanned Aircraft Syst. (ICUAS)*, Orlando, FL, USA, 2014, pp. 1274–1283.

[117] S. Temel and I. Bekmezci, "On the performance of flying ad hoc net- works (FANETs) utilizing near space high altitude platforms (HAPs)," in *Proc. 6th Int. Conf. Recent Adv. Space Technol. (RAST)*, Istanbul, Turkey, 2013, pp. 461–465.

[118] I. Bekmezci, I. Sen, and E. Erkalkan, "Flying ad hoc net- works (FANET) test bed implementation," in *Proc. 7th Int. Conf. Recent Adv. Space Technol. (RAST)*, Istanbul, Turkey, 2015, pp. 665–668.

[119] J.-A. Maxa, M. S. B. Mahmoud, and N. Larrieu, "Secure rout- ing protocol design for UAV ad hoc networks," in *Proc. 34th IEEE/AIAA Digit. Avionics Syst. Conf. (DASC)*, Prague, Czech Republic, 2015, pp. 4A5-1–4A5-15.

[120] O. Vermesan and P. Friess, *Internet of Things: From Research and Innovation to Market Deployment*. Aalborg, Denmark: River, 2014.

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 14
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[121] "Connected living: Mobilising the Internet of Things," *Connected Living*, Jun. 2014. [Online]. Available: http://www.gsma.com/connectedliving/

[122] R. Bill, "Unmanned aerial systems (UAS)—Attractive extensions to spatial data collection methods," *Photogrammetrie Fernerkundung Geoinformation*, vol. 2014, no. 4, pp. 225–226, Aug. 2014.

[123] A. Puri, *A Survey of Unmanned Aerial Vehicles (UAV) for Traffic Surveillance*, Univ. South Florida, Tampa, FL, USA, Jan. 2005.

[124] C. S. Sharp, O. Shakernia, and S. S. Sastry, "A vision system for landing an unmanned aerial vehicle," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, vol. 2. Seoul, South Korea, 2001, pp. 1720–1727.

[125] P. J. Garcia-Pardo, G. S. Sukhatme, and J. F. Montgomery, "Towards vision-based safe landing for an autonomous helicopter," *Robot. Auton. Syst.*, vol. 38, no. 1, pp. 19–29, Jan. 2002.

[146] W. Guo, C. Devine, and S. Wang, "Performance analysis of micro unmanned airborne communication relays for cellular networks," in *Proc. 9th Int. Symp. Commun. Syst. Netw. Digit. Signal Process. (CSNDSP)*, Manchester, U.K., 2014, pp. 658–663.

[147] S. Qazi, A. S. Siddiqui, and A. I. Wagan, "UAV based real time video surveillance over 4G LTE," in *Proc. Int. Conf. Open Source Syst. Technol. (ICOSST)*, Lahore, Pakistan, 2015, pp. 141–145.

[148] Worldwide Interoperability for Microwave Access (WIMAX). *WIMAX Forum*. Accessed on Mar. 25, 2016. [Online]. Available: http://www.wimaxforum.org/

[149] S. Banerji and R. S. Chowdhury, "Wi-Fi & WiMAX: A comparative study," *Indian J. Eng.*, vol. 2, no. 5, Feb. 2013.

[150] M. A. Rahman, "Enabling drone communications with WiMAX

[126] S. Hrabar and G. S. Sukhatme, "Omnidirectional vision for an autonomous helicopter," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, vol. 1. Taipei, Taiwan, 2003, pp. 558–563.
[127] S. Saripalli, J. F. Montgomery, and G. S. Sukhatme, "Vision-based autonomous landing of an unmanned aerial vehicle," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, vol. 3. 2002, pp. 2799–2804.
[128] B. Coifman, M. McCord, R. Mishalani, and K. Redmill, "Surface trans- portation surveillance from unmanned aerial vehicles," in *Proc. 83rd Annu. Meeting Transp. Res. Board*, 2004, pp. 1–9.
[129] Microdrones. *Drone Equipment: Multispectral Camera, Thermal Imaging, GPS*. Accessed on Mar. 8, 2016. [Online]. Available: https://www.microdrones.com/ en/products/equipment/
[130] J. D. Irwin, *The Industrial Electronics Handbook*. Boca Raton, FL, USA: CRC Press, 1997.
[131] J. Fraden, *Handbook of Modern Sensors*, 4th ed. New York, NY, USA: Springer, 2010.
[132] I. Reti *et al.*, "Smart mini actuators for safety critical unmanned aerial vehicles," in *Proc. IEEE Conf. Control Fault Tolerant Syst. (SysTol)*, Nice, France, Oct. 2013, pp. 474–479.
[133] H. Sheng *et al.*, "Low-cost UAV-based thermal infrared remote sensing: Platform, calibration and applications," in *Proc. IEEE/ASME Int. Conf. Mechatronics Embedded Syst. Appl. (MESA)*, Qingdao, China, 2010, pp. 38–43.
[134] Frequently Asked Questions. *RFID Journal*. Accessed on Mar. 15, 2016. [Online]. Available: http://www.rfidjournal.com/ site/faqs#Anchor-46384
[135] C. Swedberg, "RFID-reading drone tracks structural steel products in storage yard," *RFID Journal*, Sep. 2014. [Online]. Available: http://www.rfidjournal.com/
[136] B. Hubbard, H. Wang, and M. Leasure, "Feasibility study of UAV use for RFID material tracking on construction sites," in *Proc. 51st ASC Annu. Int. Conf.*, College Station, TX, USA, 2015, accessed on Jun. 4, 2016. [Online]. Available: http://ascpro0.ascweb.org/archives/cd/2015/paper/CPRT367002015.pdf
[137] J. S. Choi, B. R. Son, H. K. Kang, and D. H. Lee, "Indoor localization of unmanned aerial vehicle based on passive UHF RFID systems," in *Proc. 9th Int. Conf. Ubiquitous Robots Ambient Intell. (URAI)*, Daejeon, South Korea, 2012, pp. 188–189.
[138] G. Greco, C. Lucianaz, S. Bertoldo, and M. Allegretti, "A solution for monitoring operations in harsh environment: A RFID reader for small UAV," in *Proc. Int. Conf. Electromag. Adv. Appl. (ICEAA)*, Turin, Italy, 2015, pp. 859–862.
[139] M. Allegretti and S. Bertoldo, "Recharging RFID tags for environmen- tal monitoring using UAVs: A feasibility analysis," *Wireless Sensor Netw.*, vol. 7, no. 2, pp. 13–19, 2015.
[140] R. Kumar, "Tactical reconnaissance: UAVs versus manned aircraft. Air command and staff college," Res. Dept., ACSC Air Command and Staff College, Air Univ., Montgomery, AL, USA, Mar. 1997.
[141] H. Shariatmadari *et al.*, "Machine-type communications: Current status and future perspectives toward 5G systems," *IEEE Commun. Mag.*, vol. 53, no. 9, pp. 10–17, Sep. 2015.
[142] D. E. Zheng and W. A. Carter, "Leveraging the Internet of Things for a more efficient and effective military," Center Strategic Int. Studies (CSIS), Washington, DC, USA, Sep. 2015.
[143] M. Harris, "Project Skybender: Google's secretive 5G Internet drone tests revealed," *The Guardian*, London, U.K., Jan. 2016.
[144] B. Lee, J. Lee, Y.J. Lee, and S. Sung, "Development of cellular data network enabled autonomous rotary UAV," in *Proc. 13th Int. Conf. Control Autom. Syst. (ICCAS)*, Gwangju, South Korea, 2013, pp. 719–722.
[145] K. Guevara *et al.*, "UAV-based GSM network for public safety com- munications," in *Proc. SoutheastCon*, Fort Lauderdale, FL, USA, 2015, pp. 1–2.
Technology," in *Proc. 5th Int. Conf. Inf. Intell. Syst. Appl. (IISA)*, 2014, pp. 323–328.
[151] B. Dusza and C. Wietfeld, "Performance evaluation of IEEE 802.16e mobile WiMAX for long distance control of UAV swarms," in *Proc. IEEE Int. Conf. Wireless Inf. Technol. Syst. (ICWITS)*, Honolulu, HI, USA, 2010, pp. 1–4.
[152] I. Dalmasso, I. Galletti, R. Giuliano, and F. Mazzenga, "WiMAX net- works for emergency management based on UAVs," in *Proc. IEEE 1st AESS Eur. Conf. Satellite Telecommun. (ESTEL)*, Rome, Italy, 2012, pp. 1–6.
[153] B. Dusza and C. Wietfeld, "QDV—A QoS enabled packet scheduling scheme for mobile WiMAX in UAV swarms," in *Proc. 20th Int. Conf. Comput. Commun. Netw. (ICCCN)*, Maui, HI, USA, 2011, pp. 1–5.
[154] (Jul. 2014). *Satcom Relay for Manned and Unmanned Airborne Platforms*, UAV, UAS & Manned Aircraft—Newtec. [Online]. Available: http://www.newtec.eu/article/application-note/ uav-uas-manned-aircraft
[155] H. Skinnemoen, "UAV & amp; satellite communications live mission- critical visual data," in *Proc. IEEE Int. Conf. Aerosp. Electron. Remote Sens. Technol. (ICARES)*, 2014, pp. 12–19.
[156] D. Ma and S. Yang, "UAV image transmission system based on satellite relay," in *Proc. 4th Int. Conf. Microw. Millimeter Wave Technol. (ICMMT)*, Nanjing, China, 2004, pp. 874–878.
[157] *IEEE 802 LAN/MAN Standards Committee, LMSC, LAN/MAN Standard Committeee (Project 802)*. Accessed on Mar. 28, 2016. [Online]. Available: http://www.ieee802.org/
[158] C. Zhu, X. Wang, and Z. Liu, *Commercial UAV Positioning Use Case*, IEEE document IEEE 802.11-15/0907r1, Huawei Technol., Shenzhen, China, Jul. 7, 2015.
[159] S. Fu and Y. Wan, "Spotlight: UAVs for disaster area communication," *HDIAC*, Jul. 2015. [Online]. Available: https://www.hdiac.org/
[160] C.-M. Cheng, P.-H. Hsiao, H. T. Kung, and D. Vlah, "Performance measurement of 802.11a wireless links from UAV to ground nodes with various antenna orientations," in *Proc. 15th Int. Conf. Comput. Commun. Netw. (ICCCN)*, Arlington, VA, USA, 2006, pp. 303–308.
[161] J. Chen, K.-F. Tong, and J. Wang, "A triple band arc-shaped slot patch antenna for UAV GPS/Wi-Fi applications," in *Proc. Int. Symp. Antennas Propag. (ISAP)*, vol. 1. Nanjing, China, 2013, pp. 367–370.
[162] Bluetooth. (2003). *Bluetooth Technology*. [Online]. Available: https://www.bluetooth.com/
[163] P. Carvalhal, C. Santos, M. Ferreira, L. Silva, and J. Afonso, "Design and development of a fly-by-wireless UAV platform," in *Aerial Vehicles*, T. Mung, Ed. Rijeka, Croatia: InTech, 2009.
[164] H. Surmann *et al.*, "Teleoperated visual inspection and surveillance with unmanned ground and aerial vehicles," *Int. J. Online Eng.*, vol. 4, no. 4, pp. 26–38, Oct. 2008.
[165] J. A. Afonso *et al.*, "Distributed sensing and actuation over Bluetooth for unmanned air vehicles," in *Proc. IEEE Int. Conf. Robot. Autom.*, Orlando, FL, USA, 2006.
[166] G. Hoffmann *et al.*, "The Stanford testbed of autonomous rotorcraft for multi agent control (STARMAC)," in *Proc. 23rd Digit. Avionics Syst. Conf. (DASC)*, vol. 2. Salt Lake City, UT, USA, pp. 12.E.4–12.1.10.
[167] (2002). *The ZigBee Alliance, Control Your World*. [Online]. Available: http://www.zigbee.org/
[168] L. Yut, Q. Fei, and Q. Geng, "Combining Zigbee and inertial sensors for quadrotor UAV indoor localization," in *Proc. 10th IEEE Int. Conf. Control Autom. (ICCA)*, Hangzhou, China, 2013, pp. 1912–1916.
[169] Y. Jiang, J. Cao, and Y. Du, "Unmanned air vehicle landing based on Zigbee and vision guidance," in *Proc. 6th World Congr. Intell. Control Autom.* (*WCICA*), vol. 2. 2006, pp. 10310–10314.
[170] O. Arouk, A. Ksentini, and T. Taleb, "Group paging optimiza- tion for machine-type-communications," in *Proc. IEEE Int. Conf. Commun. (ICC)*, London, U.K., 2015, pp. 6500–6505.
[171] R. Ratasuk, J. Tan, and A. Ghosh, "Coverage and capacity analysis or achine type communications in LTE," in *Proc. 75th Veh. Technol. Conf. (VTC Spring)*, Yokohama, Japan, 2012, pp. 1–5.
[172] L. Changwei, *Telco Development Trends and Operator Strategies*, Huawei Technol., Shenzhen, China, Jul. 2012.
[173] R. Ratasuk, S. Iraji, K. Hugl, L. Wang, and A. Ghosh, "Performance of low-cost LTE devices for advanced metering infrastructure," in *Proc. IEEE 77th Veh. Technol. Conf. (VTC Spring)*, Dresden, Germany, 2013, pp. 1–5.
[174] 3GPP TS22.368 V10.4.0, *3rd Generation Partnership Project;*

Technical Specification Group Services and System Aspects; Service Requirements for Machine-Type Communications (MTC), Mar. 2011.

[175] R. R. Tyagi, K.-D. Lee, F. Aurzada, S. Kim, and M. Reisslein, "Efficient delivery of frequent small data for U-healthcare applications over LTE-advanced networks," in *Proc. 2nd ACM Int. Workshop Pervasive Wireless Healthcare*, 2012, pp. 27–32.

[176] K.-T. Liao, C.-H. Lee, T.-M. Lin, C.-M. Lee, and W.-T. Chen, "Non- orthogonal direct access for small data transmission in cellular MTC networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, London, U.K., 2015, pp. 2264–2270.

[177] S. Andreev *et al.*, "Efficient small data access for machine-type com- munications in LTE," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Budapest, Hungary, 2013, pp. 3569–3574.

[178] A. Amokrane, A. Ksentini, Y. Hadjadj-Aoul, and T. Taleb, "Congestion control for machine type communications," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Ottawa, ON, Canada, 2012, pp. 778–782.

[179] L. Ferdouse, A. Anpalagan, and S. Misra, "Congestion and over-load control techniques in massive M2M systems: A survey," *Trans. Emerg. Telecommun. Technol.*, Mar. 2015. [Online]. Available: http://dx.doi.org/10.1002/ett.2936

[180] 3GPP, "Study on RAN improvement for machine-type-communications," 3GPP Mobile Competence Center, Sophia Antipolis, France, Tech. Rep. 3GPP TR 37.868 V11.0.0, Sep. 2012.

[181] O. Arouk, A. Ksentini, and T. Taleb, "Group paging-based energy sav- ing for massive MTC accesses in LTE and beyond networks," *IEEE J. Sel. Areas Commun.*, vol. 34, no. 5, pp. 1086–1102, May 2016.

[182] A. Ksentini, T. Taleb, X. Ge, and H. Honglin, "Congestion-aware MTC device triggering," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Sydney, NSW, Australia, 2014, pp. 294–298.

[183] S. Simanta, G. A. Lewis, E. J. Morris, K. Ha, and M. Satyanarayanan, "Cloud computing at the tactical edge," Softw. Eng. Inst., Carnegie Mellon Univ., Tech. Rep. CMU/SEI-2012-TN-015, Oct. 2012.

[184] B. Qureshi, A. Koubaa, M.-F. Sriti, Y. Javed, and M. Alajlan, "Poster: Dronemap—A cloud-based architecture for the Internet-of-Drones," in *Proc. Int. Conf. Embedded Wireless Syst. Netw.*, Graz, Austria, 2016, pp. 255–256.

[185] C. Luo, J. Nightingale, E. Asemota, and C. Grecos, "A UAV-cloud system for disaster sensing applications," in *Proc. IEEE 81st Veh. Technol. Conf. (VTC Spring)*, Glasgow, U.K., 2015, pp. 1–5.

[186] M. Cochez, J. Periaux, V. Terziyan, K. Kamlyk, and T. Tuovinen, *Evolutionary Cloud for Cooperative UAV Coordination*, Univ. Jyväskylä, Jyväskylä, Finland, 2014.

[187] K. Kumar, J. Liu, Y.-H. Lu, and B. Bhargava, "A survey of computation offloading for mobile systems," *Mobile Netw. Appl.*, vol. 18, no. 1, pp. 129–140, Apr. 2012.

[188] S. Barbarossa, S. Sardellitti, and P. Di Lorenzo, "Communicating while computing: Distributed mobile cloud computing over 5G heteroge- neous networks," *IEEE Signal Process. Mag.*, vol. 31, no. 6, pp. 45–55, Nov. 2014.

[189] A. Toma and J.-J. Chen, "Computation offloading for real-time sys-tems," in *Proc. 28th Annu. ACM Symp. Appl. Comput.*, Coimbra, Portugal, 2013, pp. 1650–1651.

[190] M. Shiraz, A. Gani, A. Shamim, S. Khan, and R. W. Ahmad, "Energy efficient computational offloading framework for mobile cloud computing," *J. Grid Comput.*, vol. 13, no. 1, pp. 1–18, Jan. 2015.

[191] W. T. Su and K. S. Ng, "Mobile cloud with smart offloading system," in *Proc. IEEE/CIC Int. Conf. Commun. China (ICCC)*, Xi'an, China, 2013, pp. 680–685.

[192] Y.-H. Kao and B. Krishnamachari, "Optimizing mobile computational offloading with delay constraints," in *Proc. IEEE Glob. Commun. Conf. (GLOBECOM)*, Austin, TX, USA, 2014, pp. 2289–2294.

[193] K. Kumar and Y. H. Lu, "Cloud computing for mobile users: Can offloading computation save energy?" *Computer*, vol. 43, no. 4, pp. 51–56, Apr. 2010.

[194] H. Flores, "Service-oriented and evidence-aware mobile cloud com-puting," Ph.D. dissertation, Inst. Comput. Sci., Faculty Math. Comput. Sci., Univ. Tartu, Tartu, Estonia, 2015.