Drones in IoT-enabled Spaces

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Sometimes you can find words to fill in a 250 pages' book,
but you can't find a word to thank somebody without whom
the book itself wouldn't be realized... Thanks Sinem.

Thanks to my parents, my brother, my sisters, and
my kids... Thanks to all who standby...

Fadi Al-Turjman

"Great things in business are never done by one
person. They're done by a team of people."

Steve Jobs

Contents

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Prof. Fadi Al-Turjman received his Ph.D. degree in computer science from Queen's University, Canada, in 2011. He is a professor at Antalya Bilim University, Turkey. He is a leading authority in the areas of smart/cognitive, wireless and mobile networks' architectures, protocols, deployments, and performance evaluation. His record spans more than 200 publications in journals, conferences, patents, books, and book chapters, in addition to numerous keynotes and plenary talks at flagship venues. He has authored/edited more than 12 published books about cognition, security, and wireless sensor networks' deployments in smart environments with Taylor & Francis and Springer (top-tier publishers in the area). He was a recipient of several recognitions and best paper awards at top international conferences. He also received the prestigious *Best Research Paper Award* from Elsevier *COMCOM Journal* for the last 3 years prior to 2019, in addition to the *Top Researcher Award* for 2018 at Antalya Bilim University, Turkey. He led a number of international symposia and workshops in flagship IEEE ComSoc conferences. He is serving as the lead guest editor in several journals, including the *IET Wireless Sensor Systems*, *Springer EURASIP*, *MDPI Sensors*, *Wiley & Hindawi WCM*, *Elsevier Internet of Things,* and *Elsevier Computer Communications.*

Chapter 1

UAVs in Intelligent IoT-Cloud Spaces

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The wireless cellular communications infrastructure mainly depends on base station systems (BSS) that are responsible for ensuring communications of associated nodes and user equipment (UE). Under normal circumstances, the cellular and infrastructure-based systems work effectively. However, in events of unexpected conditions and natural disasters, such systems are relatively fragile and can easily be disrupted. During a natural calamity, the wireless communications infrastructure can be severely affected, where one or more BSS can stop working. The disruption in the operation of BSS affects the communications of interconnected devices. In such circumstances, flying ad hoc networks can assist as a substitute to provide structureless communications framework for communicating emergency and safety information using unmanned aerial vehicles (UAVs).

Recent developments in microelectromechanical systems (MEMS) technology and very large-scale integration have been influential in transforming large BSS to minute structures, which enables the adaptation of small-sized drones (or UAVs). UAVs are capable of the replicating technology features of BSS and can be used to form a small coverage area. UAVs, with the ability to move autonomously and to hover over the affected area, can function as a small cell to establish communications with the active UE in the designated emergency coverage area. Hypothetically, with the presence of sufficient UAVs, the communications outage area in vulnerable regions can be fully covered. The restoration of a communication network in such areas using UAVs provides a rapid and reliable alternative to reconfigure and replicate necessary functionalities of the affected BSS. These drone small cells (DSCs) can also be used to enhance and extend communication coverage in disaster areas where on-ground repairs are not feasible. The ability of DSCs to reposition itself and respond to the UE by reducing distance extends coverage, decreases outage probability of the UE in coverage zones, improves bandwidth efficiency, and optimizes system throughput.

However, due to the nature of sensitivity of such situations, additional constraints such as delay and reliability are required, which are very challenging. Moreover, the incorporation of appropriate information-based urgency index in ad hoc networks is also very important. In fact, communications in emergency networks can be classified into a number of precedence levels, where alerting messages, well-being messages, control messages, distress calls, and data collection schedules can be characterized separately to optimize the ongoing communications between UAVs. Therefore, a suitable *intelligent* mechanism is needed to associate priority levels with these calls, messages, and schedules. Providing multihop collaboration among UAVs in an attempt to reach possible urgent services that can be provided by the cloud facilities, where machine learning (ML)-based approach is employed for the adaptation of existing configuration can significantly improve the services that DSCs can provide. Automating the collection and analysis of data has the potential to lead to more robust and intelligent systems that can save lives and time for the emergency and rescue teams involved.

1.1 Intelligence in UAVs

Recently, artificial intelligence, specifically ML, showed an outstanding performance in complicated tasks that require human-like intelligence and intuition to perform. ML is suited for the situations where there are no defined rules for performing a task, and instead, the rules are learned from real data. ML is capable of detecting hidden structures in the data to make smart decisions. ML techniques can be classified in general into three main categories. This classification is mainly based on the kind of data and the objective of the task. The three categories are as follows.

1. Supervised learning: This is the well-established and most used technique. Supervised learning techniques use data to make accurate predictions and learn the mapping between the input and its corresponding output while receiving a feedback during the learning process to identify things based on similar features. Approaches in this category are used to predict an outcome or the future or to classify the input to a set of desired classes. Most common approaches in this category can be regression algorithms, support vector

machine, and neural network approaches. In order to introduce the training employed in these techniques, usually a function (linear, nonlinear, polynomial, fully connected neural network, etc.) that can best approximate the relation between the input and output data is defined. Then, a cost function is set to tell the learner how much it is far from the best answer, so it acts as a feedback signal. In turn, this signal is used to update the parameters of the function at each iteration. At the end, this function is used to make the prediction of future input or classify unseen data.
2. Unsupervised learning: Unlike supervised learning that uses labeled data, unsupervised learning has no labels and no feedback signal. This technique is mostly used to find the hidden structure of the data and move it into similar groups. So, they are mainly used for pattern detection and descriptive modeling. These types of algorithms are promising to achieve general artificial intelligence, but they usually lack behind supervised learning in terms of accuracy and computation time. K-means and autoencoder are the most known unsupervised algorithms.
3. Reinforcement learning (semisupervised): This technique resembles to highly extend the way humans learn and navigate through their daily life tasks. Reinforcement learning is neither fully supervised nor unsupervised, but it's a kind of hybrid approach.

Appling any of these ML techniques in a DSC-based coverage network can restore the necessary links in the communications outage area while ensuring minimal delay for emergency communications and maximum network throughput for better bandwidth/resource utilization. Further improvements in ML techniques design for infrastructureless UAV-based communications in emergency personal sensor networks (PSNs) can also support in disaster communications, using new technologies such as device-to-device (D2D), machine-to-machine, internet of things (IoT) communications. For example, authors in Refs. [1,2] examined how the in-coverage UE deliver the elementary network services to out-of-coverage UE by relaying their data to eNB (evolved NodeB) as base station. The study investigated the selection of an in-coverage UE in PSN. The findings suggested that there is no centralized entity in PSN to assist the discovery and synchronization of UE and should separately be addressed, which results in high energy consumption and delay. In addition, authors in Ref. [3] outlined that UE selection process was also highly critical because both in- and out-of-coverage UE have very limited energy and processing capability. There was limited reliability in terms of availability, throughput, and traffic handling capabilities of UE and cannot concurrently handle PSN demands. Therefore, the use of DSCs is well suited for PSNs. The suitability of DSCs in PSNs is primarily attributed to self-organization, mobility, and delay minimization abilities of DSCs.

In Refs. [4,5], UAVs are proposed as a part of a system targeting postdisaster scenarios. The subsystems running on each UAV are explained and evaluated using a prototype helicopter to prove the efficiency of the navigation subsystem. The long-term evolution-unlicensed (LTE-U) technology is proposed in Ref. [6] for DSCs to enhance the achievable broadband throughput for postdisaster assistance. An ON/OFF game-based mechanism is employed for effective use of LTE-U, and to reach a correlated equilibrium. Numerical simulations are employed in Ref. [7] to study the coverage that can be provided by UAV-based base stations. The study attempts to minimize the number of stops and amount of delays for a single UAV that needs to visit various positions to completely cover the potential disaster area. This study is further extended in Ref. [8] for multiple UAVs. A framework is proposed for optimizing the 3D placement and the mobility of UAVs. Simulations performed using MATLAB® provide results that show significant enhancements using the proposed approach, especially in terms of reductions in transmission power of IoT devices and system reliability. Through these results, the significance of intelligent decisions in terms of UAV deployment and repositioning has been emphasized.

1.2 Collaborative UAVs in Cloud

The decision-making and evaluation processes of cloud-based studies in this area are mainly dependent on high-level analytical abstractions of scenarios considered. We believe that there are factors above the physical and data link layers that can affect the optimization of heterogeneous infrastructures that can involve conventional base stations, D2D communications of UEs, and DSCs. For incorporating the potential complexities of more realistic scenarios, it is possible to provide communication between UAVs and the existing cloud facilities to use more sophisticated approaches such as ML for the analysis [9].

In Ref. [10], the authors propose a framework to use UAV support for wireless powered communication (WPC) techniques that mainly focus on providing energy to the UEs of potential victims in disaster areas. The mobility features of UAVs are employed to improve the conventional WPC techniques that are mainly dependent on a static access point responsible for charging a set of wireless nodes in the downlink. A distributed resource management mechanism is proposed in this study to optimize the public safety IoT (PS-IoT) devices' uplink transmission powers and UAV positioning. However, considering allocation of uplink and downlink resources and optimization using various methods based on game theory may not be sufficient, since higher level of simulations where traffic conditions, mobility-related issues, and availability of other facilities should also be considered together with facilities provided by UAVs. Furthermore, considering the limited flying time mainly due to the limited energy resources of UAVs, the optimum configuration for the transmission of safety critical information becomes even more critical.

A drone cooperation scenario is considered in Ref. [11]. The UAV-based base stations are employed together with conventional base stations in an attempt to aid the disaster-struck regions where terrestrial infrastructure is damaged. The main focus of this study is efficient power allocation strategies for the microwave base station as well as smaller UAV-based base stations. The power control strategy presented is self-adaptive depending on the interference threshold employed as well as data rate requirements. Factors such as UAV altitude and number of ground users are considered with an analytical abstraction for simulations. The importance of incorporation of UAVs in the multitier heterogeneous networks for better network coverage and capacity is emphasized in this study as well [12].

1.3 Conclusion

Research in DSC is still in its infancy, and many practitioners and academics are keen to pursue their research in this scholarly area. The use of DSC-based solutions, where an infrastructure can be made available very rapidly, particularly, for emergency communications in disaster-affected areas, is a very promising solution.

The research work on this topic mainly advocates the following reasons for the employment of DSC-based solutions in PSNs: (1) UAVs are able to hover at higher altitude to provide a suitable height gain; (2) through energy sustainability, UAVs can be made suitable for PSNs, since the main aim is to exchange emergency-related information for short durations; (3) while hovering, UAVs improve connection reliability and offer better connectivity and efficiency for UE; (4) the usage of DSCs can allow efficient use of bandwidth and improve frequency reusability; and (5) the use of DSCs will result in rapid deployment of communication network in disaster-affected areas where early involvement is essential. The utilization of DSCs in critical scenarios has the potential of introducing significant advantages, since due to their mobility, flexibility, and adaptability, the DSCs are able to provide coverage and capacity exactly where and when it is needed even under such circumstances that other means of communication services are not available.

The main areas of interest that requires improvements for development of DSCs are as follows: (1) optimized on-demand communications should come with enhanced throughput to support highly resilient networks within critical and emergency scenarios; (2) ad hoc on-demand formation of small cells should support enhancement of the number of users to be served by and at the same time prioritize the communications of rescue workers and first responders, reporting from the disaster-affected areas; (3) A priority-wise channel access establishment should also be provided for emergency-related communications, which reduces channel access delay within DSCs; (4) the deployment, mobility, and coverage-based issues, such as potential areas with higher numbers of victims, should be addressed.

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