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Handover Management of Drones in Future Mobile Networks: 6G Technologies

Joana Angjo[1], Ibraheem Shayea[1], Mustafa Ergen[1], Hafizal Mohamad[2], Abdulraqeb Alhammadi[3], and Yousef Ibrahim Daradkeh[4]
[1] Faculty of Electrical and Electronics Engineering, Istanbul Technical University, 34469, Maslak, İstanbul, Turkey.
[2]Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, 71800 Bandar Baru Nilai, Negeri Sembilan, Malaysia.
[3]Department of Electronics and Communication Engineering, College of Engineering, A'Sharqiyah University (ASU), 400 Ibra, Oman.
[4]Department of Computer Engineering and Networks, College of Engineering at Wadi Addawasir, Prince Sattam Bin Abdulaziz University, Saudi Arabia.

Corresponding author: Joana Angjo (e-mail: angjo16@itu.edu.tr).

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ABSTRACT Drones will be a significant part of future mobile communication networks, serving as mobile users or acting as mobile base stations at sky. Although they will provide several solutions related to mobile communication networks and other non-communication services, drones also possess numerous challenges, especially when it comes to their handover management. Unlike terrestrial networks, drones are mobile devices that move in a three-dimension (3D) environment, which further complicates mobility issues. Therefore, this paper provides an overview on the handover management for connected drones in the future mobile networks. The study summarizes how current research efforts approach the issues that characterize drones, with special focus on the handover process. This work also provides a general concept of drone integration in heterogeneous networks and discusses specific solutions for addressing possible problems. This survey further offers a brief discussion and guidance for upcoming research directions related to connected drones in future heterogeneous networks.

INDEX TERMS Connected Drones, Unmanned Aerial Vehicles, UAV, Handover, Mobility Management, Drones, Heterogeneous, 6G Networks

I. INTRODUCTION

The technology of drones (also known as Unmanned Aerial Vehicles (UAVs)) introduces abundant advantages to wireless communication networks. However, several demands are required for drones to successfully meet the targeted objectives. A number of smart solutions, which can be served by connected drones in future, have been proposed in the literature. In the next-generation of mobile networks, connected drones will be widely implemented to serve in various environments as delivery systems, surveillance networks, and military networks. Therefore, connected drones will significantly alter the main concept of surveillance including the mechanisms and mindsets related to acquiring information. The use of drones will be implemented by governments, businesses, and citizens [1]. The deployment of drones as part of future cellular networks will significantly contribute to enhanced communication reliability and stability as well as the efficient usage of system bandwidths. They will also provide good coverage, especially for areas with high density connections. Drones can ensure connection in cases where terrestrial devices fail to do so since in disaster scenarios, it is rather hard to build a network at short notice [2], [3]. Although drones will create numerous benefits for future wireless communication networks, their Handover (HO) management is a major issue that must be efficiently addressed [4].

HO is one of the key processes in wireless communication networks that guarantees seamless connection and reliable communication services during the mobility of users. The HO mechanism is a process of switching the user equipment (UE) communication from one cell to another during its mobility without any disruptions (in the ideal case). Several factors lead to the occurrence of HO procedures such as the loss of serving signal level, load balancing, or high packet error rates. When one or more of these factors reach an undesirable level, the connection must be switched to another cell site for more reliable, stable, and rapid communication [5]. This procedure frequently occurs and becomes more challenging when the UE is a drone.

The HO procedure is difficult to manage in wireless communications, and it will be even more complicated with drones due to their characterization. The drone's flight is dominated by Line-of-Sight (LoS) paths, but the interference level from other communication links is higher than in the usual terrestrial networks. It was also proven that the coverage probability of a UAV-UE is less than that of a UE on the ground. This is due to the drone's downward tilted antennas and the interference dominated by LoS for the UAV-UEs [6]. Moreover, the speed of a drone is much higher than ground users, indicating that the HO rate for a drone would be much higher. Drones are also served by the antennas' side-lobes, therefore, more frequent HOs will possibly occur [7]. As a result, the Quality of Service (QoS) will be remarkably degraded [8].

Several studies in the literature have been conducted to address various types of HO issues, from the First Generation (1G) to the Sixth Generation (6G) [9-24]. In [9], the authors proposed a prediction mechanism based on UE history information to decide the target Base Stations (BSs). This algorithm has been proven to reduce the rate of HO failure and ping-pong effect. The authors of [10] proposed an optimizing methodology for setting the best possible HO parameters so that delay is minimized and the system's throughput is maximized. In [11], the network's hierarchical structure and location information are utilized to perform faster handoffs. The authors of [12] focused on an algorithm for predicting the best network to perform HO based on the user's trajectory in heterogeneous networks. Another study on Heterogeneous Networks (HetNets) is presented in [13]. Nevertheless, there is still room for improvement when it comes to HO in future HetNets since it is an essential factor yet, simultaneously, a very challenging issue.

Other studies have focused on the mobility management of drones in various scenarios. One study suggested an HO mechanism algorithm to adjust the height of the drones as well as the distance between them [3]. The authors in [25] also discussed the UAV challenges in cellular Long-Term Evolution (LTE) networks. It was mentioned that the uplink interference is relatively high for the UAV-UEs compared to the ground UEs. The presented simulation results further indicated that the performance of UAV-UEs is greatly influenced by the downlink interference which can be improved by adapting the factors of mobility when the drone reaches a specific height. Drones also face an issue regarding coverage. When the altitude increases, the frequency of cell change becomes higher due to the very high mobility speeds of drones. It will become more complicated with the implementation of Fifth Generation (5G) and 6G networks since they will work based on millimeter wave (mm-wave) bands [26-30].

Overall, the HO of drones should be managed more carefully and efficiently than what is generally needed for terrestrial UEs. Conventional HO procedures and techniques may not be functional for use in drones. Several related solutions have been proposed in the literature, however, the issue must still be further addressed. Since it is expected that future mobile networks will be autonomous, node mobility prediction is a key solution for the enhanced service of UAV networks. A large number of existing solutions are based on predictions derived from distance measurements. Algorithms that work upon machine learning solutions have been developed to train UAV-based networks to learn specific patterns in order to improve HO management performance, such as in [8, 31]. Conventional transmission protocols, such as the Transmission Control Protocol/Internet Protocol (TCP/IP), will be inapplicable for drones since drones are mobile. For such protocols, a source and destination must exist rather than selected during movement. Thus, packet-based solutions must be considered. Even mobile IP will be inefficient since drones have different trajectories and characterizations compared to terrestrial UEs. Another set of solutions for drone BS is based on regulating each drone's coverage by adjusting its height and the separation distance in between. Algorithms based on Received Signal Strength (RSS) values can achieve this task. Further approaches have also been inspired by the irregular spread and trajectories of drones. As a result, deploying tools from stochastic geometry in drone analyses may provide good insight into the network design. Several survey research in the literature have focused on the integration of UAV into existing networks. The authors of [32] discussed the standardization and security issues of UAV cellular communications. In [33], the design challenges and experimental advancements of cellular-connected UAVs have been discussed. Although several conducted studies are present in the literature, the issues related to the mobility management of drones are still a challenge for future wireless networks.

This paper provides a survey on HO management in networks where drones have been integrated, granting much attention to the networks' optimization solutions. It mainly focuses on answering two questions. Why is the HO of drones challenging? What are the existing solutions proposed to address it? The latest simulation examinations, experimental-based works, and proposals are outlined. Since drones are receiving much attention lately, summarizing the fundamental research for their management is necessary. All ideas are explored, and the key points of present issues and ongoing research are highlighted. Special cases of drone usage are also examined, providing full insight into the importance of incorporating drones into today's networks. Directions for future research are provided as well. This survey will be useful for upcoming research works. Overall, this study lists the challenges of HO management for HetNets where drones have been integrated and lists several directions for optimizing the HO process for future research in this area.

This paper is organized as follows. Section II provides a background of the HO concept, focusing on the HO of drones. Section III discusses the drones' applications. Section IV lists and explains the challenges regarding the HO of drones. Section V presents summaries of related works. Section VI explains the proposed solutions for the challenges, and Section VII discusses the performance metrics. Section VIII lists the future directions of drone communication. Finally, Section IX concludes the paper.

II. RESEARCH BACKGROUND

Connected drones will be a significant technology that offers a wide range of services in various environments. However, the need for stable connection during their mobility is the main issue that must be sufficiently addressed. The principal aim of this study is to understand the concept and HO management of drones. Therefore, this section provides the general concepts of connected drones, the HO technique, and the HO management. The following subsections briefly discuss the various subtopics.

A. CONNECTED DRONES

The use of drones has rapidly increased in recent years due to their capability of offering numerous solutions in several environments. Drone usage is also profitable for service providers and customers. Drones can efficiently serve wireless communications by acting as BSs to connect mobile users. They can be employed in non-communication services as well. If drones are used as BSs, they will offer very low latency, enhanced energy efficiency, and improved communication reliability for the served mobile user. This will also enable several fast solutions for different environments. Currently, research and targeted services offered by drones are heading toward the connected drone, which is what we wish to cover in this paper.

Connected drones involve the integration of drones as moving BSs, relays, or UEs in the sky for existing networks. For instance, in the latter, the uplink connection from a drone to a BS can transmit data to the ground for further analysis. In contrast, the downlink path can be utilized for the control and supervision of a drone's flight. Drones will collect data to serve connections while simultaneously be controlled in such a way that they can reach remote zones or handle dense connectivity areas. A drone-assisted network is analyzed in [34] where drones serve as relays for the information between users and the BS. In [35], the authors examined HetNets where drones act as the BS. The study focuses on a solution for maximizing wireless coverage for ground users. A model of connected drones in HetNets is illustrated in Fig. 1. In most existing applications, drones are supplied with communication equipment or specific sensors to allow a range of services such as low altitude surveillance, post-disaster rescue, logistical application, and communication support [13].

B. HANDOVER CONCEPT

HO is a key technique needed to support mobile connection during movement in wireless communication networks. By enabling this technique, the communication link is kept while the UE moves, then switches from one BS to another when required [4, 17]. The HO procedure was developed to manage mobile connections during UE's mobility, guaranteeing seamless communication and higher reliability throughout the movement of users. The HO procedure enhances the UE's throughput, reduces the Radio Link Failure (RLF), and decreases the interruption time. Therefore, a better HO management approach will lead to a better quality offered by the serving network [36]. That is why telecommunication service providers and research centers place much attention on this technique.

The HO procedure in any wireless communication system is generally performed through several steps. For instance, in the LTE network, this process follows three consequent phases. The first is the preparation phase where the UE periodically sends the Measurement Report (MR) to the BS, which is called eNodeB (eNBs) in LTE technology. Based on the MR, the target eNB is selected to the eNB that the UE connection will be switched to. Next, the HO request is initiated. The second phase is known as the execution phase which follows up with a message sent to the UE regarding the switching of eNBs. The UE then disconnects from the serving eNB and requests a connection to the target eNB. The third phase is known as the completion phase which concludes this procedure. The resources assigned to the UE from the source eNB are released, and the system layers are alerted to change the information path for the UE. This step is performed from the hosting (serving) eNB. A message of successful completion will be sent when the HO has been efficiently completed [37]. If this process is successfully accomplished, the buffered information is transmitted to the UE through the new eNB (target eNB) which becomes the new serving eNB. This process will guarantee seamless communication during UE mobility. However, not all phases are ideally performed at all times. False HO triggering and the ping-pong effect are examples of the most common HO related problems. Moreover, additional HO procedures can cause more overheads and extra signaling costs [38].

Several HO techniques have been employed to support user mobility, including accurate HO decision algorithms (how and when exactly the UE should perform the HO to a new AP/BS), HO optimization techniques [39], selection of suitable target AP/BS, and choosing routing protocols. However, the use of mm-waves in 5G and 6G networks further increases HO issues. The new technologies support higher mobility speed scenarios. While 4G supports speeds of up to 350 km/h, 5G is expected to surpass it by up to 500 km/h, and 6G technology will support higher speeds. This leads to the need for more efficient HO techniques since UEs move faster. Information on location and RSS must be obtained in a shorter time frame, therefore increasing computational complexity.

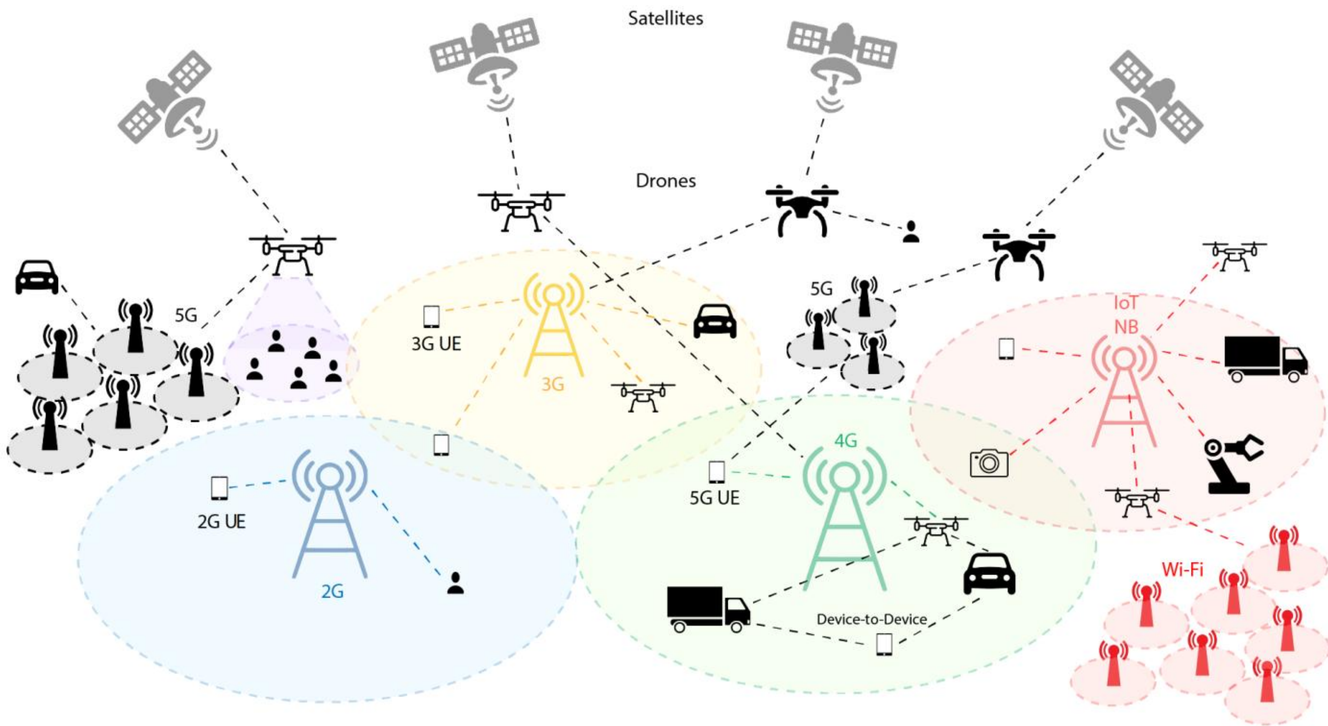

FIGURE 1. **Connected drones in future HetNets**

Another issue is the need for load balancing between cells. If connections overcrowd the serving BS, some UEs will need to switch connections to other BSs for better service and lower delay [40]. HO can also be used to reduce cost by connecting the session to a closer BS where the transmitted power is lower, saving the battery of devices by controlling the transmitted power [36]. Therefore, the deployment of connected drones will further raise the number of HO scenarios. Fig. 2 illustrates two HO scenarios of a drone, the HO between two cellular networks, and the HO between a cellular network and an access point of Wide Area Network (WAN). Since the technology does not change in the former, this HO type is known as horizontal HO and the latter is known as vertical HO. These are the two main HO scenarios in general, but multiple types of scenarios can be performed under each one.

C. HO OF DRONES

Drones are the prominent solution to several issues related to the future of communication, which is mainly due to their low cost and high speed. However, unlike terrestrial devices, a drone's mobility is in 3D since it moves in the sky, prompting the rise of additional challenges. Fig. 3 illustrates the biggest challenge that mobile UAVs face. The side lobes of the antennas assist drones; however, they are tilted downwards while serving ground users, leading to the poor performance of drone-based communication. Moreover, drones move at a high altitude due to the effect of LoS paths, causing higher interference levels which come from other UAVs. In short, several parameters affect the HO of these devices; from altitude, coverage, density, etc. In order to mitigate these challenges and achieve seamless communication, several studies have focused on the mobility management of drones. Nevertheless, the mobility management of connected drones is still a major challenge for future networks.

III. DRONES APPLICATIONS

A. DRONES IN E-COMMERCE

Nowadays, people use E-Commerce for almost everything. The expansion of this industry leads to an increase in the delivery of orders as well as the need for shorter delivery time. A decreased transportation flux is also required. The integration of autonomous mobility and drone delivery can immediately solve all these problems [41]. However, similar works are somewhat limited in the literature.

B. DRONES IN PEOPLE'S LIVES WITH SPECIAL NEEDS

Drones can be equipped with sensors for encouraging different research fields. They can be integrated into the lives of people with special needs to provide visual information. This will enable them to experience what they usually cannot experience, increasing their sense of belonging [42].

C. DRONES AS FLYING ROBOTS

- The authors in [43] claimed that telepresence robots should make use of drone technologies. A prototype design for a flying robot based on a drone was thus built. An octocopter is used to keep all the weight of the robot. The robot is 110 cm tall and weighs 10.47 kg.

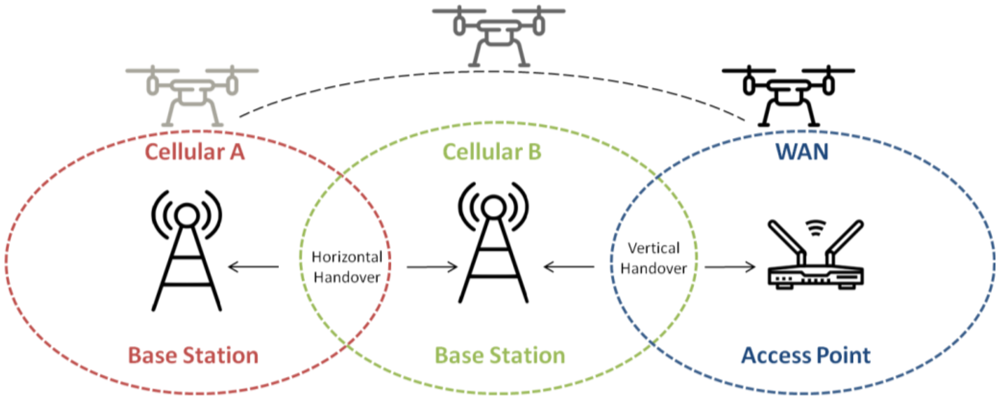

FIGURE 2. Illustration of horizontal HO and vertical HO for drones

- The concept proposed in [41] is named Drone-Delivery using Autonomous Mobility (DDAM). The idea is that the drone picks up the package from the delivery center, flies to the autonomous mobility vehicle, and then connects to its roof. After the vehicle has travelled some distance, the drone disconnects and flies to the delivery destination where the package is dropped.

D. DRONES FOR INTELLIGENT TRANSPORTATION

- An intelligent transportation system is one of the future technologies that employ drones to help monitor and control traffic, accidents, and other unexpected scenarios. In [44], a framework was created for this emerging application. Two algorithms were proposed for its enhancement, and future directions have been specified.
- The recommended solution in [42] is a system in which an unmanned semi-autonomous quadrotor is combined with a Virtual Reality (VR) based scheme. The user can move the quadrotor through head movements understood by the VR headset and sent to the ARD. It is then converted into six degrees of freedom. The use case is an alpine expedition in which the user will virtually be part of the team. The experiment includes flying the quadrotor in a way where it follows some pre-specifications. For evaluation, the user's stability and the ease of flying the drone have been considered.

IV. RESEARCH CHALLENGES

According to 3rd Generation Partnership Project (3GPP) [45], aerial drones have a higher possibility of experiencing weakened Signal-to-Interference-plus-Noise Ratio (SINR) than terrestrial UEs. More HO failures and frequent HOs occur in the air. Thus, it is essential to address these issues since further implications can reduce the network's reliability. In order to fully benefit from the advantages that drones present, special attention should be given to the effects of the environment, routing protocols, channel effects, antenna configurations, and HO management. These concerns and problems require extensive discussions to effectively solve the challenges of connected drones.

In this section, the introductory issues related to drone operations and HO management are briefly discussed. Since drones are exceptionally mobile in a 3D pattern, their usage areas have been limited until now. Due to this, research works are still in the development stage. This section provides a constructive overview of what is absent in the literature regarding the HO problems of connected drones. Finally, several areas in which drones can indeed be beneficial are introduced.

A. MOBILITY IN 3D

Drones for network services differ from conventional networks because their mobility is performed in a 3D pattern rather than 2D. Drones are exceptionally mobile, making their control and decision-making processes very challenging [46], [47], [48]. Thus, advanced mobility solutions must be developed.

B. TRANSMISSION PROTOCOLS

Many companies have patented several drone communication technologies describing how the scanning and collection of data occur while drones drop off information packets. However, the conventional transmission protocols, such as TCP/IP, will not adequately work for drones [49]. As a consequence, new protocols should be designed based on drones' mobility characteristics.

C. DOMINANCE OF LOS

As the altitude increases, challenges may also rise since the radio environment is different from the terrestrial case. Drones also cause severe interference to BSs when aerial and terrestrial users coexist in cellular networks. This is problematic for the uplink communication service of terrestrial users. The channel characteristics of drone communication follow dominant LoS. Since obstacles are not present in the sky, their effect on the HO mechanism is unavoidable [8], [50]. The design of drone-based networks should consider this peculiarity.

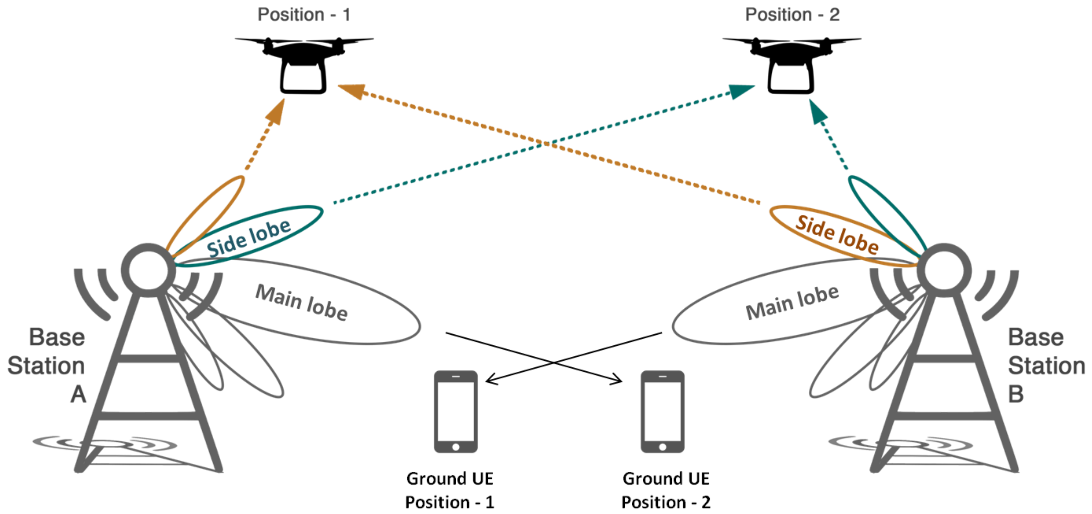

FIGURE 3. HO of drones in the sky and UE in the ground

D. HIGH HANDOVER PROBABILITY

Drones experience fast channel fluctuations due to their high mobility speed, prompting the occurrence of frequent HOs and ping-pong effects. A few studies have proposed solutions to prevent drones from colliding in urban areas and reduce mobility issues. The challenges of these solutions have been highlighted, such as unexpected situations or missions that may face drones in smart cities. Several shortcomings are emphasized in the current literature regarding the HO of drones. Some are listed in the following subsections.

E. COORDINATED MULTI-POINT TRANSMISSION

There is a lack of research that investigates drones' Coordinated Multi-Point (CoMP) transmission in order to provide a smooth connection. Existing studies only dealt with scenarios that include static UAV-UEs [6]. CoMP is an innovative approach for drone communication, and it should be considered to further enhance the network. However, additional research is required to sufficiently investigate communication efficiency.

F. DRONES INTEGRATED IN UDNs

5G technology comes with various requirements that must be met due to increased data transmission density and the exponential increase of connected devices. While 6G networks will have further requirements and the number connected devices will increased massively with new further applications were not available in the previous generations. Ultra-Dense Networks (UDNs) are a prominent solution for the demands of the new generation in which drones can also be integrated. However, numerous challenges are present which must be overcome, such as interference problems, energy consumption limitations, and front and backhauling issues [51], [52]. The deployment of drones with UDNs will also raise concerns related to unbalancing load. These problems must be carefully considered in future works.

G. DRONES INTEGRATED IN mcMTC

With the growth of the Internet of Things (IoT) environment, the role of mission-critical Machine-Type Communication (mcMTC) has become essential. However, numerous requirements must be met [53]. Issues such as high mobility and latency are crucial in the integration of mcMTC heterogeneous networks. These connected devices are key devices that require reliable communication. Thus, problems related to connection, HO, and communication reliability must be thoroughly addressed.

H. MM-WAVE AND DRONES

One of the prominent solutions for spectrum resource scarcity is the utilization of mm-wave and terahertz (THz) bands [26-29]. However, if the antennas of the transmitter and receiver are misaligned, disconnections in communication may occur in the mm-wave/THz links with narrow beamwidths. Therefore, the effects of small-scale mobility uncertainties must be examined to allow the mm-waves and UAVs to coexist [54].

I. AIRBONE BASE STATION (ABS)

ABS through UAV cellular networks are commonly used to support wireless coverage. However, when HO is triggered for a device moving to different ABSs, only single device measurements are considered while user relationships are ignored. This leads to communication congestion and inaccurate estimations. This problem requires an intelligent HO method in UAV networks [2]. Unfortunately, most related works are based on simulations rather than real scenarios. Considering real measurement data will significantly help to solve this dilemma.

J. DRONES FOR TELEPRESENCE

Drones can be integrated in several futuristic solutions such as telepresence. However, existing robot technologies are mostly indoors since their mobility is usually challenging and problematic. Therefore, integrating drones can solve the mobility challenge [43]. However, the design is vital and should only be accomplished by considering both the physical and operational properties of drones.

V. RELATED STUDIES

The literature is highly important when it comes to integrating drones in future networks. This section provides a summary of related studies. Several approaches regarding the research problems, findings, and results of these respective works are briefly explained, and future enhancements to be made are provided. Most of these studies propose decision algorithms for the HO of drones and are mainly based on either the mathematical model approach or machine learning methods. New architectures where drones can be integrated as well as novel usage areas are also summarized. The following research works are presented in chronological order. This summary can shed light on the best approaches to be followed for integrating drones, while simultaneously serving as a source of inspiration for future works.

In 2015, Park et al. [55] proposed a coverage decision algorithm for UAV networks. The limitations of UAV networks, such as battery capacity and HO management, have led to broken communication and other problems such as frequent HOs. Traditional HO algorithms cannot work on drones since they are positioned at a different coverage and height between each other. The proposed algorithm is based on RSS and regulates each drone's coverage by adjusting the height and separation distance. A seamless HO success probability and a false HO initiation probability have been derived, and several simulations were performed. Since the coverage algorithm matches all drone heights to a value (the smallest coverage and heights to the lowest possible value), the spacing between the drones can then be modified using *Pf* (false HO initiation probability) and *Ps* (seamless HO success probability). When the overlapped area's vertical distance decreases, *Pf* will increase. As the distance between the drones increases, the overlapped area becomes smaller and so does *Ps*. The probability of success for a seamless HO reduces as the average RSS measurement rises. Conversely, the probability of incorrect HO initiation further decreases as the average RSS measurement time increases. The proposed scheme seems to be a promising candidate for UAV networks, as proven by the simulation results. The algorithm works well when it comes to simulations. However, a more realistic scenario must also be considered by taking into account the drone's payload, radio range of BSs, etc. Moreover, the coverage algorithm makes the RSS of each drone the same, which may not be applicable in reality.

In 2016, Park et al. [56] proposed an efficient HO mechanism for drones network as a continuation of previously mentioned works. UAVs for network services differ from conventional networks because the HO mechanism is conducted in 3D rather than 2D. This algorithm similarly adjusts the height of the drones and the distance between them to optimize network services. It utilizes the seamless HO probability and false HO initiation probability to evaluate the optimal coverage decision algorithm. Moreover, each drone's height must be adjusted by considering physical constraints to create the same coverage for each drone. With these conditions, a seamless HO can be attained. Simulations have been conducted to check how P*s* and P*f* change in various scenarios. Several graphs were obtained for analysis and evaluation. When P*f* increases, the overlapped area's vertical distance decreases. When P*s* decreases, the overlapped area also decreases. Overall, the system can save the battery of drones because frequent HOs are avoided. The proposed algorithm can help optimize the network of drones so that the optimal overlapped area is found. Thus, the interference between drones is minimized by adjusting the same RSS for every drone. The paper proved the proposed idea but some issues must be examined. The most important issue is that it is a challenge to guarantee optimal coverage for drones. For instance, if the drone cannot move to a lower elevation due to an obstacle, its minimum height should be changed. If the drone is affected by climate problems such as wind, the moving drones must increase the RSS level to ensure a smooth HO. Furthermore, the system's reliability and throughput rate must be considered.

In 2016, Mangina et al. [42] proposed a system in which an unmanned semi-autonomous quad rotor is combined with a VR based scheme. Drones are a relatively cheap solution for easy operations. They can be equipped with sensors, which will open doors to different research fields. Drones can also be used for people with special needs to provide visual information. This will allow them to experience what they usually cannot practice, increasing their sense of belonging. By employing this system, the user can move the quad rotor through head movements understood by the VR headset, which is sent to the Augmented Reality Drone (ARD), and then converted into six degrees of freedom. The use case is an alpine expedition in which the user will be virtually part of the team. A test was performed by ten experts and ten beginner users. The experiment included flying the quadrotor in such a way that it follows some pre-specifications. Two parameters have been considered for evaluation: the user's stability and the ease at which the drone is flown. This work involved a Linux system based on ARD. An Arduino Uno board enables the control of the drone's altitude and speed. The measurement results are written in a Python file. Unlike the experienced group of users, the beginners group preferred the controller over the traditional dual-stick controller. This is because the controller is more intuitive, while the traditional one is more accurate. This system's main function is to change the situation of people with limited abilities. Since drone communication is a rich topic with numerous possibilities, the authors encourage new works for further enhancement in this area to help the community with special needs. This work can create real innovation that will empower handicapped individuals. It can serve as an inspiration for future works as well since drone communication offers a very large usage area.

In 2016, Bae [43] proposed a prototype design for a flying robot based on a drone. The possibility of telepresence is something that people can really make use of. However, existing robot technologies are mostly for indoor usage since their mobility is usually challenging and problematic. Integrating drones can solve the mobility problem. The author claimed that telepresence robots should make use of drone technologies. An octocopter was used to keep the entire weight of the robot. The robot is 110 cm tall and weighs 10.47 kg. Through a tablet placed in the head, the Skype application was installed. A test flight was performed, and the drone was seen escalating over the streets and then flying to the target area. Video calls can be made through Skype in the meantime. Skype video calls show that drones can be a promising technology for telepresence in 3D platforms. This platform can be used by governments, police officers, patients in paraplegia, etc. The radius of telepresence can be extended with better wireless coverage and longer-lasting batteries. Producing lightweight and aerodynamically enhanced drones will ultimately improve the overall results of their usage in telepresence. This is a very innovative proposal which can significantly affect the future. It can make countless applications more manageable and improve the quality of life.

In 2017, Orsino et al. [53] proposed a simulation that examines the effects of heterogeneous mobility on Device -to-Device (D2D) and drone-assisted mcMTC in 5G. With the growth of IoT systems, mcMTC's role is now crucial. However, it must meet a wide range of requirements. This paper investigated how diverse mobility patterns affect heterogeneous users. It further proved the increase in availability and connectivity of using alternative connectivity choices. The simulation has been evaluated by utilizing a custom-made simulator named WINTERsim. The overall effect of the heterogeneous device's mobility depends on the contribution of multi-connectivity options that quantify three considered cases: industrial automation, vehicular connectivity, and urban communications. The devices, which are part of the multi-connectivity system, can employ cellular, D2D, and drone-assisted connections. Four mobility models were used to design these environments. For all cases, the devices under consideration receive information through the connection that provides the maximum data rate. It is assumed that cellular connectivity is available only for about 70% of the total area. Several metrics are required for checking the outputs, availability, reliability rate, impact of connectivity, the number of HOs, delay, and the signaling load. The results indicate that the device mobility for low and limited mobility scenarios does not affect the link availability and reliability in a very distinguishable way. For cases where packet sizes were different, utilizing the D2D and drone-assisted communications significantly improved reliability and data rates. On the contrary, deterioration in performance was observed for the events where mobility was intense. The probability of undesired occurrences such as interruption, data losses, remote control faults, device malfunctions, etc., must be considered as well. A detailed and sophisticated modeling of such complex networks is needed and can only be achieved in special cases. This challenging task may enhance the overall results of creating a system as close to the real-time model as possible. The results seem to be aligned with what is expected. However, scenarios are expected to occur in specific locations. In real network environments, variations in both geographical and time aspects are present. Thus, these factors should also be considered in future to obtain more realistic results. The mixed mobility approach may also have a remarkable impact on the field of IoT systems.

In 2017, Lee et al. [46] introduced an intelligent HO scheme for drones using a fuzzy inference system. This system performs the HO decision based on a fuzzy inference procedure. The HO decision depends on parameters that include the radius, coverage, RSS, altitude, and speed. These parameters are fuzzificated by assigning a linguistic variable to their normalized ranges. A set of predefined rules determine the HO decision. Defuzzification occurs afterwards to evaluate the HO decision made. The proposed solution was assessed by utilizing MATLAB fuzzy toolbox to perform the simulation. The scenario consisted of three BSs and one terminal. Random and straight-line movements were conducted to judge the trial times. The results demonstrated that the proposed intelligent HO scheme performed better than the traditional approach. The HO probability was lower for the former simulations. Overall, factors such as speed and altitude affect the number of HOs for drones. The proposed mathematical models for the HO decision in various IoT devices, such as connected cars, are expected to improve by considering the parameters of the environment. The overall result of this proposed model seems to align with the fact that parameters (such as speed and altitude) affect the probability of disconnection, thus influencing the number of HOs. Additionally, the HO decision considers numerous parameters instantly, which is an advantage of fuzzy inference systems. Future works, however, must also consider the fact that multiple users and HetNets positively affect HO.

In 2018, Peng et al. [47] proposed an advanced machine learning solution to approach the problems that come with UAV network requirements. Since it is expected that these networks will be autonomous in predicting node mobility, an advanced machine learning solution is key for more efficient service of UAV networks. A large number of existing solutions are based on predictions made from distance measurements. This paper utilized the classification of movements to different classes based on predicting the nodes near future location, thus solving two problems for optimizing the network. In 3D space, the kinematic equations, where acceleration plays an important role, can characterize the likelihood of the node's movement. The most probable object class is estimated based on the motion trajectory found from solving the state transition equations. After this step, statistical properties are utilized to clarify the mobility parameters. This process is accomplished in three steps. An online class recognition module is applied for the number of classes and parameters that are not predefined but rather learned from the observed trajectories. It is assumed that each drone has a tracking system, like ADS-B technology, which is used to locate through GPS positioning. The motion profiling accuracy results using the Kalman filter are promising with an average success rate of 91%. However, the proposed Joint Mobility Prediction and Profiling (JMPP) is better by a significant margin than all other previously employed methods. The online module generates new object classes over time. This system is very useful since no information is required in the first steps, especially if it is integrated with protocols of communication systems. For the motion trajectory prediction, the result is affected by the tracking system's noise level. A longer trajectory provides more accurate results. When the number of the same type of objects increases, the accuracy can reach 100%. Such results are very significant for the future benefit of information stream in UAV networks. The overall results and findings are incredibly precise, especially when it comes to a system that requires no prior information. This system can be further enhanced because it can learn by itself. If this system is correctly integrated with routing protocols, it can help predict future network topologies. However, the system does not consider the fact that practical UAV networks have minimal tracking resources and limited computational power.

In 2018, Sharma et al. [51] proposed an architecture called Ultra-Dense Cloud-Drone Network (UDCDN). It is known that 5G technology comes with various requirements that must be met due to data transmission density. UDNs are prominent solutions for the demands of the new generation. However, they also possess numerous challenges that must be overcome such as interference problems, energy consumption limitations, front and backhauling issues, etc. Innovative architectures should attempt to mitigate these challenges, and UDCDN is one of them. This architecture's disposition can be dynamically accomplished; that is why it is called the "on-demand" solution. The system consists of HetNets where microcells are low power terrestrial BSs and macrocells are high power BSs. The former assists the density of communication in the user environment level, while the latter covers up the large areas. An air gateway supports the drone network's health surveillance with mobile edge computing for each UDCDN cluster [57]. This architecture requires using unlicensed spectrums to enhance utilization efficiency. Thus, the benefits of UDCDN are numerous, beginning with energy efficiency to lower cost and easy deployment. To maintain this architecture, LTE and mm-wave technologies can be used in UDCDN to control the ABSs and front haul technologies, respectively. Simulations were performed using a commercial software of ray tracing, named Wireless InSite. Three scenarios have been simulated: urban, suburban, and urban high-rises, built upon the design software (3DS Max) and International Telecommunication Union Radio communication (ITU-R) standards have been followed. The cell coverage result was obtained by placing a threshold on the received power parameter. The maximum value of cell coverage increases with lower threshold values. The best altitude for 18 dBm of received power is 300-350 m. As expected, the cell coverage for suburban areas is higher than that of urban areas because in the latter, the scattering effect has high influence. Future research plans integrate UDCDN with terrestrial networks operating at sub-6 GHz and mm-wave bands to optimize the system regarding challenges such as interference, efficiency, and HO performance. Overall, the paper is an extensively detailed study, providing both challenges and benefits. UDCDN is a topic that opens a wide area of research since it can be a very powerful solution for the future of communication. Nevertheless, the authors could have included additional details on how the simulation was conducted and how the overall system is better than other similar studies.

In 2018, Yoo et al. [41] proposed a DDAM concept for delivery services. Currently, people are using E-Commerce for almost everything. The expansion of this industry will lead to more orders that require delivery as well as shorter delivery time. In addition to customer needs, the transportation flux should be decreased. The integration of autonomous mobility and drone-delivery can instantly solve these problems. The drone will serve for picking up the package and travelling connected to the delivery vehicle. Near the end of the route, the drone flies towards the destination and drops the package. Steps of the design science research guidelines are used for evaluating the proposed concept. The authors conducted a SWOT analysis: Strengths, Weaknesses, Opportunities, and Threats. The strengths included using existing resources and eliminating delivery vehicles, while the weaknesses were high cost and uncertainty of routes. The opportunities are numerous since the development of these two technologies will bring about massive changes in future. However, this system also has disadvantages, for example, it can be affected by weather conditions. Therefore, several interviews with experts were held and evaluations from their fields were performed. By shortening the drone's distance, smaller battery, cost, and motors will become of benefit. However, integrating drones with autonomous mobility can be a disadvantage for drones since their speed property is not efficiently used. Moreover, it cannot be the primary delivery method. It is better to only use it during times of high traffic levels. Unless the two technologies are commercialized, the opinions of experts are more of ideas about the future. This study lacks simulation modeling and results, which would help in comparing this idea with other existing solutions.

In 2019, Hu et al. [2] proposed a deep learning-based system for trajectory prediction and an intelligent HO control method used in UAV cellular networks. ABS with assisting UAV cellular networks are broadly applied to support wireless coverage. However, when the HO is triggered for a device moving to different ABSs, only single device measurements are considered. This means that the relationships between users are ignored when HO decisions are taken, leading to communication congestion and imperfect estimations for the HO. This problem prompted the authors to introduce an intelligent HO technique in UAV networks, such as the deep learning-based HO technique. A hidden layer and social pooling are used to capture the interaction between each person's movement patterns. Next, the model is trained by minimizing the loss function. Four key operations (measurement, reporting, judgment, and execution) are implemented to perform the HO decision. Unlike conventional HO, machine learning is used to predict the future trajectory, and a verification function decides whether the user should be switched to another ABS. TensorFlow framework from Google was utilized for the network simulation. A manually built dataset was applied for training and testing data. The model trained to learn the trajectories has 256 hidden layers. The dataset consists of values from real scenarios. Back-Propagation-Through-Time (BPTT) was used to update the parameters in the hidden layers of the deep learning system. Mean Squared Error (MSE) between the predicted value and the ground truth value was applied to calculate this solution's accuracy. It is expected and proven that the accuracy prediction of the model is high since it correctly captured user interactions. The average MSE is lower compared to other similar models. The smaller the Time-to-Trigger (TTT), the better the HO decision's success rate, reaching values up to 84.8%. On average, 8% better accuracy has been reached compared to other systems. Frequent triggering of HO was prevented, and cases where the coverage areas overlap were also considered. Overall, the proposed solution considers different scenarios and reaches an excellent overall result compared to related works. The power of deep learning in prediction proves its potential use in future. However, several issues should be considered such as spectrum, energy, and security management.

In 2019, Nithin et al. [52] developed a location module for enhancing the location services from Over-The-Top (OTT) applications. The coming 5G networks will support a massive number of IoT devices and drones, while the 6G networks will more efficiently support huge number of smart IoT applications and connected drones. Numerous applications supported by these devices will require precise location-based services. However, IoT sensors cannot host GPS servers due to being small in size. Therefore, the 5G and 6G networks must deal with the management of location. This location module is integrated into sensor gateways and the 5G BS, also known as next-generation nodeB (gNB), and collaborates with the direction-finding and beamforming modules. A detailed location map is built and stored in the Service Provider (SP) database, where it is converted to an intelligent map. A use case example was shown to verify the practicability of this module. The drone operators can utilize this location module. The software design of the proposed module was accomplished via Python and consists of four main components: location generator, location data storage, visualization dashboard, and REST (Representational State Transfer) API (Application Programming Interface) services. Drones are more accurately traced and tracked with the information stored in the SP database, while other services can be accomplished by developing mobile applications. The user data is also secured in the SP databases. Additional services can be made possible by implementing advanced machine learning such as address discovery, navigation, product delivery, etc. The location module seems to be a prominent solution for the future of massive connectivity in 5G and 6G networks.

In 2019, Guan et al. [54] investigated the possibility of using mm-waves and THz band communications in drone networks where both the transmitter and receiver are mobile. A prominent solution for spectrum resource scarcity is the utilization of mm-waves and THz bands. However, if the antennas of the transmitter and receiver are misaligned, disconnections in communication may occur in the mm-wave/THz links with narrow beamwidths. Thus, the effects of small-scale mobility uncertainties must be studied. Small- and large-scale mobilities have been analyzed where the former catches the effects of the propeller rotation and engine of drones, while the latter deals with their 3D mobility. Experimental works in the field have been conducted and the effects of micro-, small-, and large-scale mobilities on mm-waves and THz wireless links were analyzed. Three-beam alignment schemes were also investigated: the quasi-optimal, adaptive, and no beam alignments. An Intel Aero Ready-to-Fly (RtF) drone was used for the experimental work. A Nexus 6 smartphone was integrated in the drone where a gyroscope is used to measure the angular velocity. The information is sensed and recorded by the Sensor Kinetics App in the smartphone. During the micro-scale mobility case, the achieved link capacity had frequent fluctuations. However, the performance degradation was only less than 1% compared to the optimal link capacity, thus, it can be neglected. In the small-scale mobility, the performance deteriorated by around 2.5% after 5 seconds without beam alignment. In this case, a constant outage in communication was observed. Overall, small- and large-scale mobilities cause performance deterioration by up to 50%. It is undoubtedly more probable for drones to experience outage when the antennas' beamwidth is narrower. Narrow beamwidth is needed for achieving high Signal to Noise Ratio (SNR) values in mm-wave/THz band communications. Therefore, beamwidth adaption protocols must be investigated so that performance does not degrade. Another future research topic can be beam alignment frequency and directivity angle control in mm-wave/THz bands for observing mobility uncertainties and the effect of weather conditions. Overall, the paper is very well structured and explains a major research problem.

In 2019, Euler et al. [58] investigated the changes in radio environment and analyzed the entanglements that affect UAV performance. Like any other communication system, communication based on UAVs requires significant attention in terms of reliability. A secure and seamless connection is essential. However, as the altitude increases, the challenges become greater because the radio environment is different from the terrestrial case. Therefore, developing solutions that support UAV mobility is very important to avoid communication link failure. To examine network performance, four HO performance metrics were considered: successful HO, HO failure (HOF), RLF, and ping-pong HOs. The rate of RLF was observed through the process of radio link monitoring. Supplementary to the theoretical work, simulations were also accomplished. Two different traffic models have been considered: a full buffer model and a File Transfer Protocol (FTP) traffic model. Different potential solutions were examined. A full system-level simulator was developed where the network is composed of hexagonal cells with several UEs randomly moving in the network. The UEs were placed at the same altitude and initially assigned with the same speed but at random locations. HOF and RLFs were counted in a mutually exclusive way to provide results. Urban-Macro (UMa) and Rural-Macro (RMa) scenarios have been considered for the simulations. Several observations were completed in the UMa scenario with full buffer traffic (100% resource utilization). The HO rate increases with speed, as expected. The experiments indicate that the HO rate and RLF rate are negatively correlated since fewer HOs occur when the altitude increases, but the RLF rate becomes stronger. In addition, frequent RLFs take place when signal strength drops due to the nulls between the antennas' lobes since the HO procedure takes time to occur. For the RMa scenario with FTP traffic, a much better performance was observed. This is due to a less dense network, thus, less interference from neighboring UEs. The HO rate does not reduce with height, and RLFs rarely occur. Finally, a coverage extension feature that allows UEs to operate in worse SNR conditions were simulated. In this case, almost all RLFs and HOFs were eliminated, but a higher ping-pong rate occurred. Future works may include a flight plan that avoids regions with low SNR to improve results. Directional antennas can also be used for the UEs so that the interference level drops. A conditional HO procedure can be considered as a different solution to the problems mentioned above. This work is very well organized and shows results for different parameters.

In 2019, Banagar et al. [59] investigated a stochastic geometry-based drone cellular network model. Of late, significant attention has been placed on Drone Base Stations (DBSs) due to their flexibility and wide usage areas. The spread and trajectories of drones are irregular, so deploying tools from stochastic geometry in their analysis may provide better insight for the network design. In the proposed model, the initial positions of the DBSs were modeled as a Poisson Point Process (PPP), and then each drone moved in a straight line with a constant velocity. Two models regarding the DBSs have been considered for serving the UEs. In the first model, the UE independent model, the serving DBS moves in a random straight line while serving the UE, thus, HO is required. For the UE dependent model, the serving DBS moves towards the UE, so no HO is needed. Further enhancements in performance have been observed since the distance in between became optimal. For the second case, the locations of other DBSs are characterized as an inhomogeneous PPP. Mathematical analysis and proof of theorems were used to obtain the expressions for the coverage and rate. The impact of parameters on density and rate was also observed. Simulations were conducted for both noisy and not noisy environments. The results indicate that the coverage probability saturates very quickly after the DBSs begin to move in the UE-dependent model. This signifies that this model is more advantageous than other models. Moreover, the results from noisy and non-noisy environments demonstrate that the setup is limited due to interference. With the increase of the path loss exponent, the received rate increases due to the decrease in interference power. Lastly, as expected, the received rate decreases with increasing height. This model can be used as a lower bound on the system performance to other similar mobility models. Future work will concentrate on the mathematical analysis for more complex mobility models such as Random Waypoint (RWP) and Random Walk (RW). The overall result of incorporating stochastic geometry in analyzing HO seems to be innovative and promising for the future of drones as BSs. The mathematical approach also seems accurate and helpful for works of a similar nature.

In 2019, Fakhreddine et al. [50] introduced an experimental work in a suburban environment to check how parameters affect the cell selection and HO management process when drones are used as aerial UEs. Deploying UAVs into networks will come with countless benefits due to the wide range of applications that drones can meet but several challenges are introduced as well since service requirements cannot be fulfilled from the standards built for terrestrial networks. Issues of radio coverage, interference, and mobility management must be solved to integrate drones in the network. However, most related efforts for solving these issues are based on simulations rather than real scenarios. In this work, the authors implemented a real-world scenario where drones (AscTec Pelican quadrocopter) have been connected to an LTE-A network at Klagenfurt University. A Sony Xperia H8216 smartphone with T-Mobile LTE-A network was integrated into the drone and flown over a university campus field. The phone application measured several parameters such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Physical Cell ID number (PCI) to trace the serving and neighboring cells. Four scenarios have been considered: drone flying a 300 m distance at 10 m altitude as well as drone taking off vertically and reaching altitudes of 50 m, 100 m, and 150 m. Understandably, as the altitude increases, more HOs will occur. On average, the HO occurred every 60 seconds, every 31 seconds, every 15 seconds, and every 12 seconds with the increase in altitude. Drones will also connect with more distant cells when the altitude increases. Frequent cell change does occur due to minimal changes in RSRP values. Therefore, advanced solutions are required to fully integrate drones in 4G, 5G and 6G networks. As seen from this experimental work, connecting a drone to a cell based on the RSRP value is inefficient.

In 2019, Banagar et al. [48] worked on a stochastic geometry-based mobility model for DBSs networks. The performance of wireless networks is highly dependent on the mobility of wireless nodes. The conventional models are based on static BSs, whereas DBSs are mobile. Various research works have focused on DBS based networks. Some works model the mobility of drones for prominent mobility management solutions. In this study, the BSs are initially located following the PPP distribution. While serving the UEs, they follow a Simplified RWP (SRWP) mobility model. In the beginning, each drone hovers around for a fixed time interval, selects a uniform random direction, and then moves for a fixed distance with a constant velocity. The drone hovers around for the same time interval in the new location until it moves with the same distance but in another random direction. The serving DBS for a UE is selected based on the smallest distance between them. While a drone serves the UE, other DBSs are considered as interference. Two scenarios have been investigated in the analysis: independent UE (UIM) and dependent UE (UDM). During UIM, the DBS moves following the SRWP model, whereas for UDM, the serving DBS approaches the UE. Mathematical analysis and proofs of theorems were used to obtain the expressions for the received rate. Theoretical and simulation results were compared to check the accuracy of this proposed model. The approximations made to reach the mathematical expressions are very accurate based on the results. As expected, when time goes to infinity, the interference becomes more homogeneous. An increase in height brings a decrease in the rate. The UDM also presents more advantages than the UIM model because when the DBS approaches the UE, the distance between them becomes closer to the optimal distance. Proof of the theorems and approximations have been provided in the paper, making this study a complete work and a prominent approach towards the RWP mobility model for drone networks. The overall results of this work seem to be innovative and promising for the future of drones as BSs.

In 2019, Iranmanesh et al. [49] proposed a Delay Tolerant Network (DTN) algorithm that optimizes packets routing in drone communication. Several companies that focus on drone communications have patents that describe how the scanning and collection of data occur while drones drop off the information packets. The conventional transmission protocols such as TCP/IP do not work for drones. Thus, the authors proposed an algorithm called Weighted Flight Path Planning (WFPP). The packets are weighted based on their priority, the time to live, and the power consumption constraint. If the time to live expires, the packet will then be dropped off. Moreover, the algorithm's output is a new path, and if that path is less than the maximum length that the drone can fly, this path will be executed. The path is removed when the contrary holds. The Travelling Salesman Problem (TSP) function selects the shortest possible path. The time complexity of this model depends on the number of TSP calls, which means that there will be a delay if the number of drones increases in the system. Simulation scenarios began with drones randomly placed over an area of 10x10 km^2. Two groups of experiments were conducted: the first with a fixed number of 100 drones and several registered destinations between 20 and 100, and the second with a varied number of drones (between 50 to 250) and a fixed number of registered destinations of 50. Five performance metrics have been evaluated: delivery ratio, average data delivery delay, overhead ratio, energy inefficiency, and average consignment delivery. In the first experiment, WFPP delivers 25% more packets compared to other considered algorithms. When the number of destinations increases, the performance degrades due to the increase in the drones' probability of contacts. The WFPP delivers high priority packets 20% faster, with the delivery delay 66% lower, and the overhead up to 60% less. In the second experiment, increasing the node density did not make WFPP exceptionally better than other algorithms because drones have a higher chance of interfering with each other. However, the WFPP did consequently reach minimum delay when the paths were shorter. This paper proves the point of proposing a new service with better values than existing ones. The overall system demonstrates a much better performance compared to the Encounter Based Routing (EBR) and Opportunistic Network Environment (ONE). In general, the work dealt with various details and challenges faced by UAVs and provided several graphics to support the findings while using a novel approach for the packet-based algorithm. It further proved that visiting corresponding destinations of higher weighted packets result in higher average delivery probability than visiting any other destinations.

In 2019, Bai et al. [60] proposed a new solution (named the route-aware HO algorithm) to achieve reliability in drone communication systems. This solution utilizes flight path information to optimize the network so that unnecessary HOs are minimized, and the false HO probability is reduced. The pre-determined trajectory and the predictability of the aerial channel are employed to achieve mobility management. The proposed algorithm consists of two phases: offline and online. The former is only used when the HO is triggered during SINR calculations. The latter consists of a periodic update of parameters which can improve the performance of dynamic wireless systems and reduce computational complexity. A system-level simulator was developed for the evaluation of HO performance. The scenario was assumed to be an Urban-Macro Aerial Vehicles (UMa-AV) case. The RSRP measurement was continuously updated (every 200 ms) and the update for online thresholds was made every 2 ms. As expected, the HO rate increases with the speed and altitude of drones. However, this rate also decreases from 4 to 32 times depending on the speed and altitude in comparison to other approaches. For 0 m height, the ping pong effect is eliminated and for other height levels, it can reduce by up to 46 times. For aerial UEs at different speeds, the HOF can reduce by 5 to 24 times. Results can be further improved if a better granularity presents the radio link quality and if the estimation accuracy is enhanced.

In 2020, Amer et al. [6] investigated the coverage probability and the effect of different parameters on the proposed system's overall performance. The study related to UAV-UE connectivity requires further investigations on CoMP transmission for providing a smooth connection. Moreover, only scenarios that include static UAV-UEs were highlighted. The simulations assessed the CoMP transmission for cluster scenarios of BSs that serve various UAV-UEs in both static and mobile scenarios. The BSs of a cluster cooperate with each other to serve one UAV-UE that belongs to their cluster. Cauchy's inequality and Gamma approximations were utilized to derive the Upper Bound (UB) and Lower Bound (LB) of the UAV-UE coverage probability for both scenarios. The HO rate and probability were also investigated for the mobile case. These scenarios are incredibly useful when the location of UAV is random and uncertain. Different parameters, such as altitude and speed, were considered so that their effects on HOs and coverage can be examined. It can be seen that as the altitude of UAV-UE decreases, so does the intensity of the coverage probability. As expected, the BSs' intensity improves the coverage probability because more BSs can cooperate to serve the UAV-UEs. When speed increases, the coverage probability decreases because the HO probability increases. The HO rate is linearly affected by the square root of BSs intensity. The inter-CoMP HO rate decreases when the collaboration distance (Rc) increases. The CoMP transmission enhances the attained coverage probability; e.g., from 28% for the baseline scenario to 60% for static UAV UEs. The coverage probability of a UAV-UE was proven to be less than that of a UE on the ground by comparing UAV-UEs' performance with that of ground UEs. This is due to the downward tilted antennas and the interference dominated by LoS for the UAV-UEs. This research can be further enhanced by analyzing various trajectories with different degrees of mobility. The overall results and mathematical approaches are novel and comprehensive. However, this work only considered the feasibility of LoS communication and the antenna configuration with the main and secondary lobes. As known, practical antenna patterns consist of side lobes with nulls between successive lobes. Such a 3D antenna pattern can significantly affect the UAV-UE cell allocation and the HO procedure.

In 2020, Azari et al. [8] recommended a machine learning-based approach for the HO mechanism and resource management for cellular-connected drones. Drones cause severe interference to BSs when aerial and terrestrial users coexist in cellular networks, thus becoming problematic for the uplink communication service of terrestrial users. The above-mentioned challenge was represented using network data for Stockholm city. Several models were built upon the Key Performance Indicator (KPI) (e.g. communication delay and interference) to formulate an optimization problem called HO and H-RRM. The problem used for making HO decisions was approached by machine learning solution techniques that aim to capture the correlations at the temporal and spatial levels. The effects of parameters, such as speed and altitude, were observed to solve this problem. The system model was represented by the air-to-ground channel where the LoS path is dominant. A buffer queue is used to characterize the arrival rate of data as well as the allocated spectrum and the interference from the BSs. Next, the optimization problem is formulated, and the algorithms are utilized to perform the decision-making as well as update the overall process. The Q-learning algorithm was applied, where the Q-function is trained and at each decision epoch, one of the actions is randomly taken. Increasing the delay coefficient (making delay less allowable) leads to more triggered HOs. Increasing the importance of interference in the weighted sum's reward function increases the HO number as well. The contrary has been observed when speed increases. Several similar observations were noticed, but overall, the appropriate delay, interference, and HO coefficients effectively reduced the HO number, total delay, and acquired interference. The proposed solution is very accurate and considers several scenarios which makes it a prominent solution for the HO mechanism of UAVs to coexist in cellular networks with terrestrial users. The uplink scenario can be significantly affected by the usage of drones; therefore, this study proposes a novel algorithm that can help optimize cellular networks. Future works on downlink should be conducted to make this a fully applicable investigation.

The previously mentioned works are only a few selections of the numerous researches in the literature related to the HO of drones and drone integration. Different approaches have been specifically proposed and explained. However, there is room for improvement until the optimization of HetNets is achieved. A summary of these works is presented in Table 1.

VI. PROPOSED SOLUTIONS

The emergence of connected drones and their services has increased the research activities toward mobility and connection problems. Several solutions have been proposed in the literature. The main selected solutions are explained in the following subsections. They are grouped based on the addressed issue and the used approach.

E. ALGORITHM BASED APPROACH

Algorithm-based solutions for HO management include various types, such as RSS, packets, route information, etc. Generally, the algorithms based on RSS are less complicated but also less accurate. An advantage of algorithms is that multiple criteria can be used for the HO decision-making process. This increases the computational complexity but enhances efficiency and precision.

- In [49], the authors proposed a DTN algorithm, called WFPP, which optimizes packets routing in drone communication. The packets are weighted based on their priority, the time to live, and the power consumption constraint. The algorithm produces a new path that can be executed if it is less than the maximum length that the drone can fly. If not, the path is removed.
- In [3], an algorithm based on RSS was proposed. It adjusts the drones' height and the distance between them and utilizes seamless HO probability and false HO initiation probability to evaluate the optimal coverage decision algorithm. Each drone’s height can be adjusted by considering the physical constraints to make the drones’ coverage equal to each other. A similar study was performed in [56]. Likewise, a coverage decision algorithm was proposed in [55]. Again, this algorithm is based on RSS and regulates each drone’s coverage by adjusting the height and separation distance between them. For estimating the proposed solution, seamless HO success probability and false HO initiation probability are derived.
- A solution that utilizes path information, named route-aware HO algorithm, was proposed in [56]. The flight path information is used to optimize the network so that unnecessary HOs are minimized, and false HO probability is reduced. Mobility management is achieved by the pre-determined trajectories and the predictability of the aerial channels. Apart from the offline based algorithm where HO is triggered due to a calculation of SINR, an online-based algorithm was proposed as well. The latter consists of a periodic update of parameters. Thus, it can improve the performance of dynamic wireless systems and reduce computational complexity.

F. DEEP LEARNING / MACHINE LEARNING APPROACHES

The research works accomplished in recent years have focused on machine learning and deep learning-based approaches. With advancements in the artificial intelligence field, these solutions can assure improvements in HO decision-making, save computational costs, and simultaneously deal with security issues. Moreover, the accuracy of predictions and resource usage efficiency can be increased since learning data patterns does not require continuous updates.

- A deep learning-based HO method was proposed in [2]. A hidden layer is utilized to capture the UE’s movement properties, and social pooling is then applied to capture the interaction between UEs. To perform the HO, four key operations are executed: measurement, reporting, judgment, and execution. Unlike the conventional HO, machine learning is used to predict the future trajectory, and a verification function decides if the user should be switched to another ABS.
- A network data for Stockholm was represented in [8]. KPIs, such as communication delay and interference, are used to formulate the optimization problems called HO and H-RRM, which can be approached by machine learning solution techniques that aim to capture the correlations in temporal and spatial levels to make a proper HO decision. The system model is represented through the air-to-ground channel where LoS path is dominant; the buffer queue is used to characterize the arrival rate of data, the allocated spectrum, and the interference from the BSs. Next, the optimization problem is formulated, and the algorithms are utilized to perform the decision-making task and update the HO’s overall process.
- An advanced machine learning solution was used in [47] for the mobility prediction of drones. Kinematic equations in 3D space are employed to characterize the likelihood of the node’s movement. The most likely object class is estimated based on the motion trajectory found from solving the state transition equations. An online class recognition module is applied to learn the number of classes and parameters from the observed trajectories.

G. MULTI-CONNECTIVITY SYSTEM

In [53], the increase in availability and connectivity was proven by using alternative connectivity choices. The devices (which are part of the multi-connectivity system) can employ cellular, D2D, and drone-assisted connections. Three cases have been considered: industrial automation, vehicular connectivity, and urban communications. Moreover, four mobility models were used to design these environments. For all cases, the devices under consideration receive information through the connection that provides the maximum data rate. The performance network depends on the availability and reliability rates, the impact of connectivity, the number of HOs, delay, and signaling load.

On the other hand, the paper also investigated how diverse mobility patterns affect heterogeneous users.

TABLE 1 **SUMMARY OF RELATED WORKS ON DRONE MOBILITY**

Proposed solution	Description
A Coverage Decision Algorithm [55]	The algorithm regulates the coverage of each drone and is based on RSS.
A Coverage Decision Algorithm [56]	This study utilized seamless HO probability and false HO initiation probability for the decision, similar to the previous work.
Drones' Integration in Different Areas [42], [43], [41]	These studies suggested the integration of drones into the lives of people with special needs, telepresence, and delivery systems, respectively.
Multi-Connectivity System [53]	This work examined the effect that different mobility patterns have on heterogeneous users.
Fuzzy Interference System [46]	The recommended algorithm makes decisions based on parameters such as the radius, coverage, RSS, altitude, and speed.
Classification of Movements for Mobility Prediction [47]	This paper proposed a machine-learning based solution which classifies movements based on the prediction of the near future location of nodes.
"On-Demand" Architecture [51]	This paper presented an architecture named UDCDN which can support the demands of the new generation by solving interference problems, energy consumption limitations, front and backhauling issues, etc.
Trajectory Prediction - Deep Learning Based [2]	This paper proposed a deep learning-based HO algorithm which performs trajectory predictions by capturing the interactions between movement patterns.
Location Module for Tracking [52]	To track UAVs and learn of their state while moving, this work suggested a location module that can be integrated in Sensor Gateways and 5G BS.
mm-waves and THz Communications [54]	The authors investigated the utilization of mm-waves and THz band communications in drone networks.
Experimental Work for Understanding the Performance of UAV Networks [58]	To observe the changes and difficulties in the radio environment, this study conducted experimental works based on successful and failed HOs, the RLF number, and the rate of ping-pong HOs.
Stochastic-Geometry Based Models [59], [48]	The authors proposed stochastic geometry-based drone cellular network models.
Experimental Work for HO Management Investigation [50]	This experimental work investigated which and how different parameters affect the cell selection and HO management process of UAV-UEs.
Optimization of Packets Routing [49]	This algorithm optimizes packets routing based on their priority, the time to live, and the power consumption constraint.
Route Aware Algorithm [60]	This algorithm is based on path information in which the flight path data are used to optimize the network.
CoMP Transmission [61]	This work explored the coverage probability and the effect of different parameters on a CoMP transmission system model.
HO Mechanism and Resource Management [8]	This work offered a machine learning-based solution that captures the correlations in temporal and spatial levels to help make HO decisions.

H. MATHEMATICAL APPROXIMATION FOR COVERAGE PROBABILITY

Numerous models have focused on mathematical approximations for the research problem. These models can be used to further enhance systems by understanding the impact of each parameter. A mathematical background is particularly beneficial for research problems that include the likelihood of events to happen. Authors in [6] had investigated the coverage probability and the effect of different parameters on the overall system performance where clusters of BSs serve several UAV-UEs in both static and mobile scenarios. BSs of a cluster cooperate with each other to serve one UAV-UE that belongs to their cluster. Cauchy's inequality and Gamma approximations are utilized to derive the UB and LB on the UAV-UE coverage probability for both scenarios. The HO rate and probability were also investigated for the mobile case. This framework can be useful for scenarios in which the location of UAV is random and uncertain.

I. STOCHASTIC GEOMETRY-BASED MODELS

A stochastic geometry-based drone is one of the solutions proposed to address the issue of connected drones. In [59], a stochastic geometry-based drone cellular network model was investigated. The initial positions of the DBSs are modeled as PPP, then each drone moves in a straight line with a constant velocity. A similar work was accomplished in [48] where a stochastic geometry-based mobility model was proposed for DBS networks. The BSs are initially located following the PPP distribution, while serving UEs follow the SRWP mobility model. In the beginning, each drone hovers around for a fixed time interval, selects a uniformly random direction, and then moves for a fixed distance with a constant velocity. The drone hovers around again for the same time interval in the new location until it moves the same distance but in another random direction. The serving DBS for a UE is selected based on the smallest distance between them. While a drone is serving a UE, other DBSs are considered as interference.

J. FUZZY INFERENCE APPROACH

Fuzzy inference approaches are useful for complicated nonlinear systems, making it possible to handle abstract theories and model relations for input and output parameters, even when their meanings are unclear [62]. Since the moving patterns and characteristics of drones depend on several parameters that can optimize the HO procedure, fuzzy algorithms are a good method. The authors of [46] proposed a new HO decision method for drones based on a fuzzy inference algorithm. The decision depends on parameters that include the radius, coverage, RSS, altitude, and speed. These parameters are fuzzificated, and a set of predefined rules determines the HO decision. Defuzzification occurs afterwards to evaluate the HO decision made. Similarly, a self-optimized advanced solution based on weighted fuzzy logic control was proposed in [16].

K. OPTIMIZATION TECHNIQUE OF PARAMETERS

Optimization technique is another solution used to reduce mobility issues. Several optimization solutions have been developed in the literature. A few are discussed here.

- An experimental work was proposed to check how parameters affect the cell selection and HO management process when drones are used as aerial UEs in a suburban environment [50]. The drones were connected to an LTE-A network at a university campus. Their behavior as a function of height was considered and discussed.
- The paper [58] investigated the radio environment changes and analyzed the entanglements that affect UAVs' performance. The metrics used to examine the network's performance are considered successful, with reduced HOs, RLF number, and rate of ping-pong HOs. RLFs were observed through the process of radio link monitoring. Supplementary to the theoretical work, simulations were also performed. Two different traffic models were considered: a full buffer model and the FTP traffic model. Different potential solutions were examined.

L. LOCATION MODULES OF DRONES

- The authors of [52] proposed a location module for enhancing location services from OTT applications. This location module is integrated into sensor gateways and 5G BS, also known as gNB, and collaborates with the direction-finding and beamforming modules. A detailed location map is built and stored in the SP database where it is converted to an intelligent map. A use case example verified the practicability of this module. It is clear that drone operators can utilize this location module.
- The authors in [54] investigated the possibility of using mm-waves and THz communications in drone networks, especially when both the transmitter and receiver are mobile. Small- and large-scale mobilities were analyzed, where the former catches the effects of the propeller rotation and engine of drones, while the latter deals with their 3D mobility. Experimental works in the field have been conducted and the effects of micro-, small-, and large-scale mobilities on mm-wave and THz wireless links were observed. The three beam alignment schemes were also investigated: the quasi-optimal, adaptive, and no beam alignments.

VII. PERFORMANCE METRICS

The performance metrics for connected drones are mostly related to mobility management. Drones are required to switch their connections several times due to their mobility so as to avoid RLF. Thus, HO performance metrics are crucial to measure the drones' network performance. This section presents five performance metrics, namely HO probability, ping pong HO, HOF, RLF, and throughput. The most significant KPIs and how different works deal with their optimization are also discussed.

A. HANDOVER PROBABILITY

The HO procedure leads to signaling overhead, so it is highly essential to analyze how often HOs will occur and optimize the system accordingly. Several research works have focused on the HO prediction for drone-based networks. For instance, [63] analyzed the HO probability for UAVs to fly at different heights. Consequently, optimal densities are obtained to reduce the rate of HO probability. Another study analyzed the performance of cellular-connected drones under simple and practical antenna configurations [64]. Overall, the drones' altitude, velocity, and density are some of the main factors that influence HO probability.

B. PING-PONG HANDOVER

The ping-pong effect is the frequent connections and disconnections with the BS as the served device changes locations. Signal fluctuation is another issue that leads to the ping-pong effect. The more this phenomenon occurs, the more HOs will be processed, leading to network loading. For this reason, the ping-pong effect for drones should be significantly addressed and minimized. Therefore, the ping-pong effect is considered as a fundamental metric in analyzing the performance of any proposed HO solution [65].

C. HANDOVER FAILURE

HOF is a key parameter in mobility management, especially when the HO procedure is interrupted. Different actions must be taken to resolve it. As a result, HOF should be minimized to reduce resource utilization and latency. In [60], an algorithm based on HO optimization was proposed. It considers HOF to accomplish a reliable and seamless communication.

D. RADIO LINK FAILURE

RLF can occur when the moving equipment experiences poor connection, a high level of interference, or both simultaneously. On such occasions, the communication session is interrupted and consequently, actions for maintaining communication and reliability must be taken. Several studies have considered RLF as a main factor for evaluating HO performance. For instance, the authors in [66] proposed a scheme for RLF recovery during the HO procedure. The authors in [67] provided a survey on HO management which focused on the differences between LTE and 5G New Radio.

E. THROUGHPUT

Unlike bandwidth, based on a theoretical measure of the data that can be transferred, throughput provides a measure of the actual data at the source's destination. Since drones are continuously moving, their throughput performance is crucial for analyzing the performance of the system. In [68], experimental works have been executed to evaluate the throughput performance of a drone connected to the LTE-A network. This study provides an insight into the parameters that affect the throughput of UAV. In [69], the authors proposed an analytical approach for calculating the average throughput reached by a mobile user.

These KPIs are significant metrics that must be considered for evaluating mobility management of connected drones in future HetNets where drones are integrated. The performance of these networks is crucial in the commercialization of drones.

VIII. FUTURE RESEARCH DIRECTIONS

Drones are not yet fully commercialized. It will take some time until they are completely integrated into existing communication networks. Until then, several directions are highlighted for the near future of drone utilization. This section focuses on the significant directions for future research.

A. MOBILITY MANAGEMENT

The mobility management of drones in future HetNets will become an integral factor that must be extensively studied. A higher risk is present for drones due to their movement characterizations since they move fast and in three dimensions. The implementation of mm-wave bands in 5G and 6G networks is also a major issue that further contributes to additional challenges during the mobility of drones. The massive growth of drones and mobile connections will also raise more problems since the load balancing will be a major task that requires an efficient solution. Therefore, mobility management of connected drones must be properly addressed in future networks.

B. MASSIVE MIMO

Massive MIMO is a key technological solution for using drones in communication networks. There are several matters that massive MIMO guarantees, and one of them being the support of high mobility which characterizes drones. Even the most problematic issue of multi-cell massive MIMO, the pilot’s need, is not a limitation for drones, as claimed in [70]. Nevertheless, designing more intelligent massive antennas for drones will be one research target that should be addressed and developed.

C. FANET

Another expected utilization field for drones is the Flying Ad-Hoc Network (FANET). UAV nodes communicate and share data with each-other via cameras and sensors deployed within them. The use of FANETs is very wide, such as in the military, tragedy handling, etc. In [71], the proposed architecture was investigated. In [72], a novel routing protocol for FANETs was proposed. In [73], a clustering algorithm for improving the performance of UAV networks was also recommended.

D. FULL DUPLEX COMMUNICATION

Drones’ increased mobility and low cost offer promising solutions for the high demand and scarcity of the spectrum that identify the 5G and 6G technologies. Integrating full-duplex (bi-directional) communication and drone-mounted BS is a hot topic that can solve issues which require further research. As shown from the results in [74], better throughput performance can be achieved compared to traditional networks.

E. PATH DIVERSITY IN UAV NETWORKS

The Multipath TCP (MPTCP) protocol for adding path diversity in UAV-based networks will be one of the future research directions [75]. System stability can be attained, and an effective bandwidth allocation can be achieved. It is expected that drones will enhance several areas with the commercialization of 5G and further with 6G technology. Although their mobility is quite challenging, using drones in the right direction can be very profitable.

F. MACHINE LEARNING

Machine learning-based solutions that deal with the predictability of drone mobility will be considered as a potential course for enabling drones to be part of future networks. This approach provides continuous learning and optimizations through the training procedure. Understanding drones' environmental impact will improve when more experimental works are accomplished. This will allow further enhancements in UAV systems.

G. IoT

The expansion of IoT usage and the high demand for increased data rates and decreased delays will surely require the use of drones' mobility. IoT integrated with UAVs can provide low-cost architectures and services, therefore, their integration will definitely be part of the future [76]. Several IoT use cases will enable drones to be part of their solutions. Thus, further research investigations and enhancements should be conducted in future networks.

H. FOG RADIO ACCESS NETWORK (FRAN)

FRAN is a prominent model for future networks since it combines fog computing with RAN, enhancing the efficiency of resource usage. The authors in [77] provided a detailed description of FRAN's architecture and discussed its mobility management. Unlike conventional HO schemes, the HO in FRAN is performed in Fog computing Access Points (F-APs), Small Remote Radio Heads, and Macro Remote Radio Heads. According to the simulations, the signaling overhead due to HO in FRAN is lower than that of non-FRAN networks. The data traffic is also lower compared to the traditional RAN. This results in the generation of data traffic and HO procedure, apart from the Baseband Unit pool. The fact is that the data cached in F-AP does not necessarily pass to the core network. Overall, FRAN is a very promising architecture that can improve networking and computing in the near future. The integration of drones and FRAN is a solution that should be considered. However, mobility issues, security, distributions of edge computing, and offloading techniques still require further investigations.

IX. CONCLUSION

UAVs have gained much attention as they are a prominent solution for meeting future network requirements. Several studies in the literature have focused on UAV-based networks. This survey summarizes the existing literature works that are concentrated on the HO of drones and the optimization of UAV-based networks. The general concepts of HO and connected drones have been explained first. Next, several works that deal with the challenges of drones' HO are grouped based on the approaches for solving the research problem, such as algorithm-based, machine/deep learning approaches, experimental works, etc. The novel applications of drones for enhancing daily life activities are summarized as well. The outlines of related literature studies have been provided. The integration of drones into existing HetNets as well as their mobility issues are the current focus in the literature. Moreover, several performance metrics related to mobility management have been discussed. Apart from highlighting existing works, this survey revealed the necessary directions for future research.

APPENDIX

A. Abbreviation List

TABLE 2
LIST OF ABBREVIATIONS IN ALPHABETICAL ORDER

Item	*Description*
1G	1st Generation
3D	Three Dimensional
4G	4th Generation
5G	5th Generation
6G	6th Generation
AP	Access Point
API	Application Programming Interface
ARD	Augmented Reality Drone
BPTT	Back-Propagation-Through-Time
BS	Base Station
CoMP	Coordinated Multi-Point
D2D	Device-to-device
DBS	Drone Base Station
DDAM	Drone Delivery Using Autonomous Mobility
DTN	Delay Tolerant Network
EBR	Encounter Based Routing
eNB	eNodeB
FTP	File Transfer Protocol
GPS	Global Positioning System
HetNets	Heterogeneous Networks
HO	Handover
HOF	Handoff Failure
H-RRM	HO and radio resource management
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU-R	International Telecommunication Union - Radio communication
JMPP	Joint Mobility Prediction and Profiling
KPI	Key Performance Indicators
LoS	Line of Sight
LTE-A	Long Term Evolution – Advanced
mcMTC	Mission-Critical Machine-Type Communication
mm-wave	Millimeter waves
ONE	Opportunistic Network Environment
OTT	Over-The-Top
PCI	Physical Cell ID
PPP	Poisson Point Process
QoS	Quality of Service
REST	Representational State Transfer
RLF	Radio Link Failure
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSS	Received Signal Strength
SINR	Signal to Interference Plus Noise Ratio
SP	Service Provider
TCP/IP	Transmission Control Protocol/Internet Protocol
THz	TeraHertz
TSP	Travelling Salesman Problem

UAV	Unmanned Aerial Vehicle
UE	User Equipment
UDCDN	Ultra-Dense Cloud-Drone Network
UDN	Ultra-Dense Networks
VR	Virtual Reality
WFPP	Weighted Flight Path Planning

B. Methodology

Inspired by the fact that UAVs' integration into current networks faces challenges, especially when it comes to HO, bibliographic research was accomplished on studies that discuss the HO management of drones in heterogeneous networks. The research mostly utilized the IEEE Xplore Library, and focused on works published in the recent years. These works were studied, summarized, and presented in this survey.

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Biography

Joana Angjo was born in Pogradec, Albania in 1998. She completed her B.S. studies in the Electronics and Communication Engineering department at Istanbul Technical University in 2020 and started her graduate studies in Koc University, 2020 in the field of Electrical and Electronics Engineering. Her research interests include NOMA, digital communications, future radio access technologies, drones communications and molecular communications.

Ibraheem Shayea is an Associate Researcher at Istanbul Technical University (ITU), Faculty of Electrical and Electronics Engineering, Department of Electronics & Communications Engineering, Istanbul, Turkey. He is teaching courses for Master and Bachelor students at ITU. The key focuses of his research areas are on mobility management in future Heterogeneous (4G, 5G, and 6G) Networks, Mobile Edge Computing, Machine, and Deep Learning, Internet of things (IoT), Propagation of millimeter-wave, Mobile Broadband Technology and Future Data Traffic Growth and Spectrum Gap Analysis. He has published several scientific research Journals, conference papers, and whitepapers. He worked from the 1st of September 2018 until 31 August 2019 as a Researcher Fellow at Istanbul Technical University (ITU), Istanbul, Turkey. From the 1st of January 2016 until 30 Jun 2018, he worked as a Postdoctoral Fellow at Wireless Communication Center (WCC), University of Technology Malaysia (UTM), Malaysia. From the 1st of January 2011 until 30 December 2015 (during his Ph.D. study), He worked as a Research Assistant and Demonstrator at the Department of Electrical, Electronic Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM), Malaysia. In December 2015, he received his Ph.D. in the field of Electrical & Electronic Engineering, specifically in Wireless Communication Systems, from the Department of Electrical, Electronic Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM), Malaysia. In July 2010, He received his master degree in Communication and Computer Engineering from the Department of Electrical, Electronic Engineering, Faculty of Engineering and Built Environment at the Universiti Kebangsaan Malaysia (UKM), Malaysia. In July 2004 he got his degree, Bachelor in Electronics and Communication Engineering from the Faculty of Engineering, University of Diyala, Iraq.

Mustafa Ergen is professor in Istanbul Technical University. Previously, he was in Turk Telekom as a Chief Technology Advisor. Earlier, Mustafa co-founded Silicon Valley startup WiChorus Inc. focusing 4G technologies and company is acquired by Tellabs [now Coriant]. He was earlier a National Semiconductor Fellow [now TI] at the University of California Berkeley, where he co-founded the Distributed Sensing Lab, focusing on statistical sensor intelligence and vehicular communication. Mustafa completed four programs from UC Berkeley: PhD and MS degrees in electrical engineering, MA degree from International Studies and MOT program from HAAS Business School. His BS is from electrical engineering as valedictorian from ODTU. Prof. Ergen has more than fifthy patent applications, many publications and authored three books: “Mobile Broadband” and “Multi-Carrier Digital Communications” are about wireless communications and published from Springer. Last one is about entrepreneurship, titled “Entrepreneurial Capital: Silicon Valley History and Startup Economy”, published by Alfa in Turkish. He is also founder of venture funded Ambeent Inc. focusing 5G WiFi and AI.

Hafizal Mohamad (SM’10) received the B.Eng. degree (honors) and the Ph.D. degree in electronic engineering from the University of Southampton, UK in 1998 and 2003, respectively. He is currently a Professor at the Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia. His research interests include wireless communication, cognitive radio, mesh networks and Internet of Things. He is the co-inventor of 36 filed patents and 9 granted patents in the field of wireless communication. He has coauthored over 100 research papers. He has served in various leadership roles in the IEEE, including the Vice Chair for IEEE Malaysia Section (2013) and the Chair for IEEE ComSoc/VT Chapter (2009-11). He was the Conference Operation Chair for the IEEE ICC 2016, the Technical Program Chair for the IEEE VTC Spring 2019 and APCC 2011. He is the recipient of several awards, including the ASEAN Outstanding Scientist and Technologist Award (AOSTA) and Top Research Scientist Malaysia (TRSM) by Academy of Sciences Malaysia. He is a registered Professional Engineer with the Board of Engineers Malaysia. He is an enthusiastic supporter of industrial and academic liaison. He is also appointed as an expert panel for various technical committees.

Abdulraqeb Alhammadi received the B.Eng. degree in electronic majoring in telecommunications, the M.S. degree, and the Ph.D. degree in wireless communication from Multimedia University, Malaysia, in 2011, 2015, and 2020, respectively. He also received his second M.S degree from University of Putra Malaysia in 2019. He served as a Research Assistant/Research Scholar with Multimedia University from 2012 to 2019. He was a recipient of several awards, including the Excellent Researcher Award 2019, Multimedia University. He is also the author of more than 30 articles in international journals and conferences. His main research interests include heterogeneous networks, mobility management, D2D communication, cognitive radio networks, localization, and propagation modeling. He is a member of professional institutes and societies, such as IEICE, IACSIT, and IAENG. He is also a member of program committees at international conferences and workshops.

Yousef Ibrahim Daradkeh PhD., P.Eng., Doctor of Engineering Sciences in Computer Engineering and Information Technology (Computer Systems Engineering and Computer Software Engineering), is an Associate Professor at the Department of Computer Engineering and Networks, College of Engineering, Prince Sattam bin Abdulaziz University, KSA. He is a Senior Scientific Researcher and the Assistant Dean for Administrative Affairs. Dr. Daradkeh is a dynamic academician having more than 15 years of experience specializing in teaching and scientific research development and administration experience, He has taught wide spectrum of Computer Science, Computer Engineering and Networks, Computer Software Engineering Courses. Undergraduate and graduate. He has been working as a Post-Doctoral Research Fellow, Department of Electrical and Computer Engineering, University of Calgary, Canada. Dr. Daradkeh is a well-known and respected scientist internationally. He has an excellent experience in designing courses that bridge the gap between academia and industry as well as follow the accreditation requirements. He has published over 90 high quality refereed research papers in the international Journal and Conference, He has also published two books, one Chapter and an Edited Book in the most prestigious publications. He has Membership of The International Academy of Science and Engineering for Development (IASED). The international recognition of his scientific achievements is demonstrated by numerous invitations to participate in the program committees of international conferences and foreign journals, as well as lecturing at renowned scientific centers around the world.