The New Frontier in RAN Heterogeneity: Multi-tier Drone-Cells

Irem Bor-Yaliniz, Student Member, IEEE, and Halim Yanikomeroglu, Senior Member, IEEE

Abstract—In cellular networks, the locations of the radio access network (RAN) elements are determined mainly based on the long-term traffic behaviour. However, when the random and hard-to-predict spatio-temporal distribution of the traffic (load, demand) does not fully match the fixed locations of the RAN elements (supply), some performance degradation becomes inevitable. The concept of multi-tier cells (heterogeneous networks, HetNets) has been introduced in 4G networks to alleviate this mismatch. However, as the traffic distribution deviates more and more from the long-term average, even the HetNet architecture will have difficulty in coping up with the erratic supply-demand mismatch, unless the RAN is grossly over-engineered (which is a financially non-viable solution). In this article, we study the opportunistic utilization of low-altitude unmanned aerial platforms equipped with base stations (BSs), i.e., drone-BSs, in 5G networks. In particular, we envisage a multi-tier drone-cell network complementing the terrestrial HetNets. The variety of equipment, and non-rigid placement options allow utilizing multi-tier drone-cell networks to serve diversified demands. Hence, drone-cells bring the supply to where the demand is, which sets new frontiers for the heterogeneity in 5G networks. We investigate the advancements promised by drone-cells, and discuss the challenges associated with their operation and management. We propose a drone-cell management framework (DMF) benefiting from the synergy among software defined networking (SDN), network functions virtualization (NFV), and cloud-computing. We demonstrate DMF mechanisms via a case study, and numerically show that it can reduce the cost of utilizing drone-cells in multi-tenancy cellular networks.

Index Terms—Software defined networking, network functions virtualization, drone assisted cellular communications, multi-tier drone-cell networks, cloud computing, next generation cellular networks.

I. INTRODUCTION

Transportation and communication technologies are major contributors to our lifestyles. Combining the state-of-the-art advancements in these two technologies, drone-assisted mobile communications has gained momentum rapidly. Drones equipped with transceivers, i.e., drone-cells, can help satisfy the demands of the fifth generation (5G) networks by acting as base stations (BSs), or relays [1]. Moreover, they can utilize the latest radio access technologies (RATs), such as millimeter wave (mmWave), and free space optical communication (FSO). Miscellaneous assets of drones, and placement options provide the opportunity of creating multi-tier drone-cell networks to enhance connectivity whenever, wherever, and however needed. Therefore, the main advantage of drone-cells is the radical flexibility they create.

The phenomenon of providing ubiquitous connectivity to diversified user and device types is the key challenge for 5G networks. The Achilles heel of the proposed technologies, such as decreasing cell size, cloud radio access networks (C-RAN), distributed antenna systems (DAS), device-to-device communications (D2D), and heterogeneous network deployments (HetNet), is their rigid utilization based on long-term traffic behaviour [2]. In case of unexpected and temporary events creating hard-to-predict inhomogeneous traffic demand [3], such as natural disasters, traffic congestions, or concerts, 5G networks may need additional support to maintain ubiquitous connections. Drone-cells address this need by increasing relevance between the distributions of supply (BSs) and demand (user traffic). They can be used opportunistically to leverage the heterogeneity, i.e., by dynamically deploying base stations with different power levels and RATs.

Although discussions on utilizing drone-cells in cellular networks have flourished recently [1], [4], the readiness of cellular networks to employ such dynamic nodes has not been discussed. For instance, drone-cells require seamless integration to the network during their activity, and seamless disintegration when their service duration is over. This requires the capability of configuring the network efficiently. However, in the 3GPP [5] Long-Term Evolution (LTE) networks, configuration and management are more manual than autonomous. Hence, updating the network, such as adding new applications, tools and technologies, is time and money consuming [5]. Also, massive amounts of granular information about users and network must be continuously collected and analysed by intelligent algorithms to determine the most efficient ways of utilizing drone-cells. Since LTE networks collect and process the data in a distributed fashion, managing and processing big data is not feasible. Hence, the required level of flexibility does not exist in LTE networks [2].

Recent proposals for 5G cellular network architecture aim for creating a flexible network with improved agility and resilience. Cloud computing, software defined networking (SDN), and network functions virtualization (NFV) have been proposed to relax the entrenched structure of the cellular networks, increase openness, ease configuration, and utilize cloud computing for storing and analysing big data. At the same time, these technologies decouple the roles in the business model into infrastructure providers (InP), mobile virtual network operators (MVNO), and service providers (SP) [6], which also changes the owners and sources of information [5].

In order to utilize drone-cells in 5G networks, we propose

1The 3rd Generation Partnership Project.
a drone-cell management framework (DMF), and discuss the related business and information models. The proposed framework relies on creating intelligence from big data in the cloud, and re-configuring the network accordingly by SDN and NFV. In the following section, we describe the drone-cells, the motivations for utilizing them in cellular networks, and the challenges. Then we introduce DMF, and discuss the required information to efficiently manage a drone-cell in various scenarios. Finally, we demonstrate the fundamental principles of DMF via a case study; the Conclusion section closes the paper.

II. DESCRIPTIONS, OPPORTUNITIES AND CHALLENGES

A drone-BS is a low-altitude unmanned aerial vehicle equipped with transceivers to assist the cellular network [1], and drone-cell is the corresponding coverage area. Size of a drone-cell varies based on drone-BS’s altitude, location, transmission power, RATs, antenna directivity, type of drone and the characteristics of the environment. Hence, multi-tier drone-cell networks can be constructed by utilizing several drone types, which is similar to the terrestrial HetNets with macro-, small-, and femto-cells. A multi-tier drone-cell network architecture, assisting the cellular network in several cases, is depicted in Fig. 1.

Drone-cells are useful in scenarios requiring agility and resilience of cellular networks, because they can prevent over-engineering. These type of scenarios can be categorized as temporary, unexpected, and critical, as shown in Table I where relevant test cases of METIS project are listed. Based on the scenario, the benefit of the network from a drone-cell varies. For instance, in the traffic jam, stadium, and dense urban information society scenarios, a drone-cell can help prevent unexpected or temporary congestion in the network. Alternatively, drone-cells can improve resilience of cellular networks by providing additional coverage in case of a natural disaster malfunctioning the BSs, or enabling tele-protection for smart grid.

Critical scenarios have challenging demands, such as very high data rates, or low energy consumption. In case of emergency communications, virtual-reality, and tele-control applications, drone-cells can guarantee very high data rates, and low-latency. Mobility of drone-cells enables them to serve users with high mobility and data rate demand, categorized as a “best experience follows you” scenario by METIS [3]. Alternatively, sensor-type devices requiring low energy consumption can benefit from drone-cells. Instead of forcing low-power devices to transmit to farther BSs, or deploying small cells densely, mobile sinks can be used. A drone-cell can move towards clusters of devices and provide low-power communication due to its proximity and potential line-of-sight (LoS) connectivity. In particular, when unexpected events trigger massive sensor activity, drone-cells can reduce the overall stress on the network, and increase the life-time of sensors.

Although the flexibility of drone-cells allows utilizing them in versatile scenarios, it creates significant design, operation, and management challenges, which are discussed next.

A. Challenges of drone-cells

1) Efficient Design: Drones have been utilized for military, surveillance and reconnaissance applications for long, however, their usage in cellular communications as drone-BSs is a novel concept under investigation. For instance, a preliminary implementation of an LTE eNodeB based operation is presented in [4], where a remote radio head (RRH) is deployed on an off-the-shelf helikite. The helikite is tethered to a truck carrying the baseband unit (BBU), and optical fiber is used for the fronthaul. This tethered helikite design is due to the non-existence of drones that are specifically designed to operate as drone-BSs. Drones are generally designed for their task, which is the reason for their great variety [7, Ch. 5].

Drone-BSs would have unique requirements that can benefit from special-purpose designs, such as long-time hovering, long endurance, robustness against turbulence, minimum wing-span allowing MIMO, and provision of energy for transmission (in addition to flying). For instance, a hybrid-drone can be designed with vertical take-off capability of rotorcrafts, and with collapsible wings (equipped with MIMO antenna elements and solar panels for energy harvesting), which can be unfolded for efficient gliding.

Designing the payload of drone-BSs is as important as determining their mechanics, e.g., size, aerodynamics, and maximum take-off weight [7, Ch. 9]. For efficient usage of the limited volume, weight, and energy of drone-BSs, the payload can vary according to the scenario. Several possible drone-cell configurations are listed below:

- Drone-relay (“Drolay”): Compared to small- or macro-BSs, relays require less processing power, because their RRH may be relatively simple, and they may not require an on-board BBU. Hence, they operate with lighter payloads, and potentially consume less power. The size and weight of RAN nodes may not be critical for terrestrial HetNets, however a lighter payload improves endurance, and decreases CAPEX and OPEX significantly in drone-cell operations.
- Small-drone-BS: They resemble terrestrial small-BSs with wireless backhaul. If a reliable wireless fronthaul can be maintained despite the mobility of drone-BSs, its advantage is twofold: First, it alleviates the weight and processing power required for an on-board BBU. Second, if combined with C-RAN, it can allow cooperation. C-RAN is useful particularly for dense HetNets [9], or when a fleet of drone-BSs are deployed. Scenarios ①, ④, and ⑧ in Fig. 1 exemplify potential usage.
- Macro-drone-BS: They resemble terrestrial macro-BSs with wireless backhaul. They can be deployed for longer endurance, broader coverage, or increased reliability of

2The classification of drones is a rather involved task due to their variety [7, Ch. 5]. However, in this context, the term “low-altitude” is used to differentiate the drone-BSs from the high altitude platforms (HAPs) operating over 20 km.

3Mobile and Wireless Communications Enablers for Twenty-twenty (2020) Information Society.

4Capital expenditure (CAPEX) and operational expenditure (OPEX).
Fig. 1: Multi-tier drone-cell networks can be used for many scenarios: 1) Providing service to rural areas (Macro drone-cell), 2) Deputizing for a malfunctioning BS (Macro drone-cell), 3) Serving users with high mobility (Femto drone-cell), 4) Assisting a macrocell in case of RAN congestion (Pico drone-cell), 5) Assisting a macrocell in case of core network congestion or malfunctioning (Macro drone-cell), 6) Providing additional resources for temporary events, e.g., concerts and sports events, 7) Providing coverage for temporary blind-spots, and 8) Reducing energy dissipation of sensor networks by moving towards them (Femto drone-cell).

TABLE I: Categorization of test cases requiring agility and resilience

| Test Case                              | Temporary | Unexpected | Critical |
|----------------------------------------|-----------|------------|----------|
| Stadium                                | X         |            |          |
| Tele-protection in smart grid          |           | X          |          |
| Traffic Jam                            | X         | X          |          |
| Blind Spots                            | X         | X          |          |
| Open air festival                      | X         |            |          |
| Emergency Communications               |           |            | X        |
| Traffic efficiency and safety          |           |            | X        |
| Dense urban information society        | X         | X          |          |
| Massive deployment of sensor-type devices |          |            |          |

the network, e.g., 1, 5, and 6 (Fig. 1). BBU can be included, if a reliable wireless backhaul exists. Since coverage is strongly related to altitude and power, macro-drone-BSs may have larger size, which allows more payload, e.g. medium-altitude long-endurance drones [7, Ch. 113].

Nevertheless, efficient drone-cell design relies on advancements on low-cost and light-weight energy harvesting, high-efficiency power amplifiers, and alternative fuels, to name a few.

2) Backhaul/fronthaul connection: In terrestrial networks, wireless backhaul/fronthaul is considered when fiber connectivity is unaffordable, e.g., dense HetNets, or rural BSs. However, it is inevitable for multi-tier drone-cell networks. FSO and mmWave are promising for their high-rate, and low spectrum cost. However, their reliability and coverage
are limited, especially for inclement weather conditions [10], [11]. Although mobility of drone-cells help maintain LoS, it necessitates robustness against rapid channel variations.

3) Placement: Terrestrial BSs are deployed based on long-term traffic behaviour and over-engineering when necessary. However, drone-cells require quick and efficient placement. Therefore, it is of critical importance to determine the parameters affecting a drone-cell’s performance, such as its altitude, location, and trajectory based on the network demands [1]. For instance, if a drone-cell is utilized to release congestion in RAN within a congested cell, the target benefit is to offload as many users as needed to the drone-cell [1]. Particularly, if the congestion is at the cell edge, the drone-cell can be placed right on top of the users there. On the other hand, if the congestion is at the backhaul, some of the most popular contents can be cached in a drone-cell for content-centric placement (Sec. IV). Moreover, placement of multi-tier drone-cell networks requires integrated evaluation of many other challenges.

B. Challenges of multi-tier drone-cell networks

There are additional challenges of multi-tier drone-cell networks. Although these challenges are similar to those of terrestrial HetNets, their particulars related to drone-cells are discussed here.

- Physical layer signal processing: The link between the drone-cell and terrestrial nodes, i.e., air-to-ground links, have different characteristics than terrestrial channels [1], [12]. However, the research on air-to-ground links is not mature, and the proposed channel models vary depending on factors, such as temperature, wind, foliage, near-sea environments, urban environments, and the aircraft used for measurement campaigns, to name a few. For instance, higher ground speed causes rapid variation of spatial diversity, and users at different locations with respect to the drone-BS can have different channel characteristics simultaneously [12]. Therefore, designing robust signalling mechanisms with strict energy constraints of drone-BSs is challenging.

- Interference dynamics: Drone-cells in proximity can suffer from co-channel interference for their air-to-ground links, and backhaul/fronthaul. Moreover, drone-cell’s mobility creates Doppler shift, which causes severe inter-carrier interference for RATs at high frequencies (e.g., mmWave). In HetNets, interference of terrestrial and air-to-ground-channels can decrease capacity. Therefore, advanced interference management schemes, which consider the characteristics of air-to-ground links and mobility of drone-cells, are required.

- Cooperation among drone-cells: The dynamic nature of multi-tier drone-cell networks requires cooperation among drone-cells for efficiency in radio resource management. In addition to that, drone-cells can cooperate to adapt to the mobility of the users to decrease handover, optimize power and resource allocations, and avoid collisions.

- Infrastructure decision and planning: The number and assets of drone-cells (e.g., access technology, memory, and speed) to be utilized for a multi-tier drone-cell network depend on circumstances, such as inclement weather conditions, size of the area to be served, type of service (e.g., virtual reality, internet-of-things), target benefit of the network (e.g., congestion release, resilience, low-latency), or service duration. Also, utilizing drone-cells with different access technologies can reduce interference, and increase capacity of multi-tier drone-cell networks, e.g., utilizing a macro-drone-cell with RF, and small-drone-cells with mmWave to prevent frequency reuse. Hence, InPs must have a fleet which can respond to possible scenarios. To optimize the fleet and construct an efficient network, information sharing among all parties of the network, i.e., InPs, MVNOs and SPs, is required.

Cost, lack of regulations, security, and airworthiness are among other challenges of drones. The vital point of matter is considering the effects of utilizing drones in highly sophisticated cellular communication networks, rather than using them for stand-alone applications, e.g., aerial photography or inspection. Therefore, drone-cells require an equivalently sophisticated management system, which is discussed next.

III. THE DRONE-CELL MANAGEMENT FRAMEWORK

A drone-cell is not a one-fits-all solution, instead, it is tailored based on the target benefit. Along with the management of individual drone-cells, multi-tier drone-cell networks require active organization and monitoring, e.g., for nodes changing location, or cells becoming congested. For instance, the mobility of drone-cells introduces a new degree-of-freedom for the mobility management (MM). DMF must collaborate with the MM entities for efficiency, e.g., a drone-cell can follow high-mobility users on a high-way (3) in Fig. 1 to reduce handover. Three capabilities are required to integrate drone-cells with already sophisticated cellular networks:

- Global information: The information gathered by BSs alone cannot be used to provide the required intelligence for managing drone-cells. Global information, including location, type, and habits of the users, functionality of the BSs, and the contents to deliver must be stored and analysed centrally. Big data and cloud computing can be effective solutions for that purpose.

- Control: The cellular networks must be configured efficiently for seamless integration/disintegration of drone-cells, such as changing protocols, and creating new paths. SDN can be useful to update the network automatically via a software-based control plane.

- Programmability: Both drone-cells and network tools need to be programmed based on the network updates. Moreover, sharing the resources made available by a drone-cell can reduce the CAPEX and OPEX. NFV can provide these capabilities to the cellular networks.

The current LTE architecture does not embody all of these abilities, but cloud, SDN and NFV technologies can enable a more capable cellular communication system [2].
A. Enabling Technologies for DMF

In this subsection, we briefly explain the technologies that increase capabilities of cellular networks, and discuss their interactions that is required to efficiently manage drone-cell assisted cellular communications.

1) Software Defined Networking (SDN): In conventional networks, all three planes of networking (control, data/forwarding, and management) are present together in the network devices, such as routers and switches. Therefore, global view of the network is not available, and reconfiguration is costly. SDN has emerged to address these limitations with the following key points:

1) To provide global view of a network, control planes have been taken out of the network elements and centralized. Hence, global network optimization is enabled, and network elements can be as simple as possible, containing the minimum required software.

2) The controller uses software to derive the forwarding information base (FIB), and thus becomes software “defined” networking.

3) The control plane sends the FIB to the forwarding plane via a protocol, e.g., OpenFlow. Thus, the traditional switching and/or routing is now flow-based [5].

Hence, the network can be configured easily to add or remove paths, change the bandwidths of certain links, or update protocols. These flexibilities allow implementing new applications, such as energy-efficient networking, and traffic monitoring in a faster and cost-efficient fashion.

2) Network Functions Virtualization (NFV): NFV allows utilizing general purpose servers, standard storage devices, and switches instead of specific hardware to perform network functions, such as firewalls, deep packet inspection, and packet data network gateways. These commodity hardware can be programmed to perform network functions via software. NFV also enables sharing of available resources, which in turn leads to sharing the cost. Hence, the CAPEX of introducing new applications and the OPEX of responding to various circumstances (either expected or unexpected) can be reduced, and the available resources can be used more efficiently [2].

Although SDN and NFV do not have to exist simultaneously in a network, their efficient interaction creates the most benefit, as shown in a recent proof-of-concept report released by ETSI ISG NFV[6] about SDN usage in NFV architectural framework [13]. Cloud-based solutions can provide comprehensive orchestration of both NFV and SDN layers, as in the case of C-RAN [2], [14].

3) Cloud and Big-Data: A cloud consists of computing power and data storage, which provides efficient and economic use of centralized resources. For example, C-RAN revolutionizes the distributed BS system allowing centralized interference management, and efficient resource allocation [14]. That is due to the intelligence created in the cellular networks by turning local data into global data, and centralizing the distributed processing power [2]. However, since the network is not owned by only one party anymore, information will be flowing to the cloud from various sources. Therefore, potential business and information models for the proposed DMF is discussed next.

B. Business and Information Models of DMF

In traditional cellular networks, a mobile network operator (MNO) owns almost the entire cellular network, such as BSs, and core network, and sharing among MNOs is very limited. However, future cellular networks will be partitioned between InPs, MVNOs and SPs [6].

Fig. 2 represents a DMF with potential business and information models, and shows what is owned by these parties, and what information flows from them to the cloud. According to the model, all physical resources of the cellular network, including drone-cells, BSs, spectrum, and core network, are owned by an InP. The MVNO is responsible for operating the virtual network efficiently such that the services of the SP are delivered to the users successfully. Note that, in this model, perfect isolation and slicing is assumed such that an MVNO has a complete virtual cellular network.

Compared to the traditional cellular networks, more granular data is available, but it is distributed unless collected in a cloud. A brief list of information, which can be critical for the operation of the DMF, is provided in Table II along with its type, source and usage [5]. The results of the processing are then used to orchestrate SDN and NFV for the purpose of integrating drone-cells to the network. This mechanism is demonstrated in Section IV.

C. Challenges for DMF Implementation

Network management required for DMF involves the challenges of NFV and SDN. Slicing of drone-cells, isolation of the traffic of different MVNOs, migration of virtual network functions, virtual resource management, and scheduling can be listed among the major challenges related to NFV [6].

Regarding the SDN in DMF, the main challenges are providing a global view to the SDN controller, i.e., scalability, efficiency in programming new paths, and communicating with different virtual network entities and application interfaces [15]. Especially, latency as a performance indicator is critical for drone-cells [13], [15]. The flow and cloud based networking are promising approaches to overcome these challenges [5], [6], [13], [15].

Flow based networking requires advancements, such as developing new routing protocols, interfaces, and applications. The major difficulties associated with the cloud are centralizing the distributed data, providing security, determining the level of sharing while satisfying the regulations, and providing the power required for processing massive amounts of data [2], [14]. In this sense, real-time collection and processing of the data required to manage a drone’s operation (e.g. tackling with turbulence, avoiding collisions, tracking user mobility) is infeasible. Therefore, DMF is unlikely to alleviate the need for drones with high levels of autonomy [7] Ch. 70], but DMF can provide guidelines, as demonstrated in the following section.

European Telecommunications Standards Institute (ETSI) Industry Specification Group (ISG) for Network Functions Virtualisation (NFV).
Fig. 2: DMF mechanism and potential business and information model: 1) Collect and store global data, 2) Process data for network monitoring and creating intelligence, 3) Provide guidance for drone-cell’s operation (placement, content to be loaded, access technology, service duration, coverage area, moving patterns), 4) Re-configure the virtual network of MVNO for drone-cell integration by SDN and NFV technologies, e.g., introduce another gateway to handle busy traffic and create new paths among the new and existing functions, 5) Drone-cell assists the network, 6) SP can continue delivering services successfully.

| Information                          | Type   | Source | Use                                  |
|--------------------------------------|--------|--------|--------------------------------------|
| International Mobile Subscriber Identity (IMSI) | User   | MNO    | True identity of the user            |
| User profile information             | User   | MVNO   | Subscription type, activities        |
| User’s location                      | Network| MVNO   | Location                             |
| Device type                          | Network| MVNO   | Location, resource allocation provision, etc. |
| Functionality of the nodes           | Network| InP    | Location, coverage extension, energy saving, etc. |
| User’s activity and navigation       | Network| MVNO   | Placement, consumption, lifestyle etc. |
| Content                              | Usage  | SP     | Centers of interest, preferences, pricing, content delivery etc. |
| Long-term historic data              | Usage  | SP     | Content delivery, pricing, etc.      |

IV. A CASE STUDY: 3-D PLACEMENT OF A DRONE-CELL VIA DMF

Efficient placement is a critical and challenging issue for drone-cells. In this section, we propose an objective for DMF, meeting various demands simultaneously. Then, we numerically illustrate the benefit of using DMF by comparing the results with the efficient 3-D placement method proposed in [1], and show that DMF can split costs among MVNOs, without compromising from the network benefit in a multi-tenancy model.

Let us consider a drone-cell, managed via DMF, is used to assist a macro-cell with the following considerations:

- **Congestion release in RAN**: A set of users, $\mathcal{U}$, cannot be served by the BS, because of the congestion. The objective is to serve as many users as possible by the drone-cell. Let $u_i$ denote a binary variable indicating if the $i_{th}$ user in $\mathcal{U}$ is served by the drone-cell. Let that, $\mathcal{U}$ is determined by MVNOs based on connection characteristics of each user [5].

- **Multi-tenancy**: An InP owns the drone-cell and sends it to the congested macrocell according to the intelligence
provided by the cloud, if desired, to maximize the revenue and reduce the OPEX. Assuming all users provide the same revenue (as in [1]), the vector norm operation, respectively, ω, u, and q, based on their importance to the owner of the drone-cells, are interesting problems themselves.

The generic problem in [1] is mathematically formulated in [1] by assuming ωi = 1, and the rest of the weights are 0. We numerically compare the efficiency of DMF in this scenario by assuming multi-tenancy with 1 InP and 2 MVNOs serving the congested macrocell in an urban environment. In order to focus on the effect of multi-tenancy, we assume w1 = w2 = 1, and w3 = w4 = 0. 24 idle users are distributed uniformly, and arbitrarily subscribed to one of the two available MVNOs. All users have 100 dB maximum tolerable pathloss as QoS requirement. Also, MVNOs are identical, e.g. in terms of their agreements with InP, user priorities, and QoS requirements. Therefore, v1 = v2 = 12, which is in favour of providing an equal amount of service to each MVNO. Hence, they can share the cost of the drone-cell equivalently.

Fig. 3 shows how the placement of the drone-cell changes with and without DMF. The circular areas indicate the coverage of the drone-cell, and enclosed users are served by the drone-cell, i.e., their QoS requirements are satisfied. Note that 8 users are enclosed in both placements. In the green circle representing the placement without DMF, 5 users belong to MVNO1 and 3 users belong to MVNO2 out of a total of 8 served users. Hence, the resources of the drone-cell are not distributed as suggested by the cloud. That may reduce the benefit of the network, e.g., MVNO2 may reject the drone-cell’s services. However, when DMF is considered, 4 users of each MVNO are served. At the same time, there is no compromise in network’s benefit, since the total number of served users remains the same.

In order to clarify the advantage of DMF, we consider two network configurations. In the first one, we assume that the drone-cell only serves the users of MVNO1 (e.g., blue dots in Fig. 3). In the second, we assume that both user groups exist. A comparison of the two cases is provided in Fig. 4, where 30 idle users in four different environments are randomly distributed [1], and the results of 100 Monte Carlo simulations are averaged. It shows that MVNO1 shares almost the same number of users (1-2 users less in each case) when it shares the backhaul/fronhaul node. Note that, the weights among the benefits, ωi, can be determined based on their importance to the owner of the drone-cells. Similarly, determining ωi, v, and q, based on their importance to the owner of the drone-cells, are interesting problems themselves.

The generic problem in [1] is mathematically formulated in [1] by assuming ωi = 1, and the rest of the weights are 0. We numerically compare the efficiency of DMF in this scenario by assuming multi-tenancy with 1 InP and 2 MVNOs serving the congested macrocell in an urban environment. In order to focus on the effect of multi-tenancy, we assume w1 = w2 = 1, and w3 = w4 = 0. 24 idle users are distributed uniformly, and arbitrarily subscribed to one of the two available MVNOs. All users have 100 dB maximum tolerable pathloss as QoS requirement. Also, MVNOs are identical, e.g. in terms of their agreements with InP, user priorities, and QoS requirements. Therefore, v1 = v2 = 12, which is in favour of providing an equal amount of service to each MVNO. Hence, they can share the cost of the drone-cell equivalently.

Fig. 3 shows how the placement of the drone-cell changes with and without DMF. The circular areas indicate the coverage of the drone-cell, and enclosed users are served by the drone-cell, i.e., their QoS requirements are satisfied. Note that 8 users are enclosed in both placements. In the green circle representing the placement without DMF, 5 users belong to MVNO1 and 3 users belong to MVNO2 out of a total of 8 served users. Hence, the resources of the drone-cell are not distributed as suggested by the cloud. That may reduce the benefit of the network, e.g., MVNO2 may reject the drone-cell’s services. However, when DMF is considered, 4 users of each MVNO are served. At the same time, there is no compromise in network’s benefit, since the total number of served users remains the same.

In order to clarify the advantage of DMF, we consider two network configurations. In the first one, we assume that the drone-cell only serves the users of MVNO1 (e.g., blue dots in Fig. 3). In the second, we assume that both user groups exist. A comparison of the two cases is provided in Fig. 4, where 30 idle users in four different environments are randomly distributed [1], and the results of 100 Monte Carlo simulations are averaged. It shows that MVNO1 shares almost the same number of users (1-2 users less in each case) when it shares the backhaul/fronhaul node. Note that, the weights among the benefits, ωi, can be determined based on their importance to the owner of the drone-cells. Similarly, determining ωi, v, and q, based on their importance to the owner of the drone-cells, are interesting problems themselves.

The generic problem in [1] is mathematically formulated in [1] by assuming ωi = 1, and the rest of the weights are 0. We numerically compare the efficiency of DMF in this scenario by assuming multi-tenancy with 1 InP and 2 MVNOs serving the congested macrocell in an urban environment. In order to focus on the effect of multi-tenancy, we assume w1 = w2 = 1, and w3 = w4 = 0. 24 idle users are distributed uniformly, and arbitrarily subscribed to one of the two available MVNOs. All users have 100 dB maximum tolerable pathloss as QoS requirement. Also, MVNOs are identical, e.g. in terms of their agreements with InP, user priorities, and QoS requirements. Therefore, v1 = v2 = 12, which is in favour of providing an equal amount of service to each MVNO. Hence, they can share the cost of the drone-cell equivalently.
challenges of utilizing drone-cells in future cellular networks. We also provided DMF for their efficient operation and demonstrated its benefits via a case study.

**REFERENCES**

[1] I. Bor Yaliniz, A. El-Keyi, and H. Yanikomeroglu, “Efficient 3-D placement of an aerial base station in next generation cellular networks,” in *IEEE Int. Conf. on Communications (ICC)*, May 2016, doi: 10.1109/ICC.2016.7525465/2.

[2] P. Demestichas, A. Georgakopoulos, D. Karvounas, K. Tsagkaris, V. Stavroulakis, J. Lu, C. Xiong, and J. Yao, “5G on the horizon: Key challenges for the radio-access network,” *IEEE Veh. Technol. Mag.*, vol. 8, no. 3, pp. 47–53, Sep. 2013.

[3] M. Mirahsan, R. Schoenen, and H. Yanikomeroglu, “HetHetNets: Heterogeneous traffic distribution in heterogeneous wireless cellular networks,” *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 10, pp. 2252–2265, Oct. 2015.

[4] S. Chandrasekharan, K. Gomez, A. Al-Hourani, S. Kandepan, T. Rashheed, L. Goratti, L. Reynaud, D. Grace, I. Bucaille, T. Wirth, and S. Allsopp, “Designing and implementing future aerial communication networks,” *arXiv:1602.05318*, 2016.

[5] A. Brada, K. Singh, T. Ahmed, and T. Rashheed, “Cellular software defined networking: A framework,” *IEEE Commun. Mag.*, vol. 53, no. 6, pp. 36–43, 2015.

[6] C. Liang and F. Yu, “Wireless virtualization for next generation mobile cellular networks,” *IEEE Wireless Commun.*., vol. 22, no. 1, pp. 61–69, Feb. 2015.

[7] K. P. Valavanis and G. J. Vachtsevanos, *Handbook of Unmanned Aerial Vehicles*. Springer Publishing Company Inc., 2015.

[8] ICT-317669 METIS Project, “Scenarios, requirements and KPIs for 5G mobile and wireless system,” Del. D1.1, Tech. Rep., May 2013, [Online]. Available: https://www.metis2020.com/documents/deliverables.

[9] M. Peng, C. Wang, V. Lau, and H. V. Poor, “Fronthaul-constrained cloud radio access networks: Insights and challenges,” *IEEE Wireless Commun.*., vol. 22, no. 2, pp. 152–160, Apr. 2015.

[10] H. Kaushal and G. Kaddoum, “Free space optical communication: Challenges and mitigation techniques,” *arXiv:1506.04836 [cs, math]*, Jun. 2015.

[11] U. Siddique, H. Tabassum, E. Hossain, and D. I. Kim, “Wireless backhauling of 5G small cells: Challenges and solution approaches,” *IEEE Wireless Commun.*., vol. 22, no. 5, pp. 22–31, Oct. 2015.

[12] T. Willink, C. Squires, G. Colman, and M. Muccio, “Measurement and characterization of low altitude air-to-ground MIMO channels,” *IEEE Trans. Veh. Technol.*, vol. PP, no. 99, pp. 1–1, 2015.

[13] DGS/NFV-EVE005, “Network function virtualization (NFV); Ecosystem; Report on SDN usage in NFV architectural framework,” European Telecommunications Standards Institute (ETSI), Tech. Rep., Dec. 2013.

[14] X. Zhou, Z. Zhao, R. Li, Y. Zhou, T. Chen, Z. Niu, and H. Zhang, “Toward 5G: When explosive bursts meet soft cloud,” *IEEE Network*, vol. 28, no. 6, pp. 12–17, Nov. 2014.

[15] S. Sezer, S. Scott-Hayward, P. Chouhan, B. Fraser, D. Lake, J. Finnegan, N. Viljoen, M. Miller, and N. Rao, “Are we ready for SDN? Implementation challenges for software-defined networks,” *IEEE Commun. Mag.*, vol. 51, no. 7, pp. 36–43, 2013.

**V. CONCLUSION**

Recent innovations in cellular communications focused on developing advanced technologies, such as mmWave, to satisfy extreme demands. However, the challenges and costs of over-engineering enclosed these technologies in niche implementations, causing diversion from the aim of providing ubiquitous connectivity for all users. Drone-cells can efficiently tie this gap by introducing a new paradigm in which not only the demand, but also the supply of cellular networks is mobile.

In this article, we discussed the potential advantages and