On-Demand Ultra-Dense Cloud Drone Networks: Opportunities, Challenges and Benefits

Navuday Sharma, Maurizio Magarini, Dushantha Nalin K. Jayakody, Vishal Sharma, and Jun Li

Abstract

The paradigm of previous 4G cellular technology has led to an increase in requirements for high data rate demands of mobile users in 5G. In order to meet this demand, constant densification of communication networks was required. Ultra Dense Networks (UDNs) have been proposed as a promising 5G technology to fulfill these requirements by the efficient and dynamic distribution of the radio resources. However, for implementation of UDN, mobile operators have to face many challenges such as severe interference resulting in a limited capacity due to the dense deployment of small cells, site location and acquisition for the deployment of base stations, backhauling issues, energy consumption, etc. In this article, in order to alleviate these limitations, we propose a novel idea of Ultra Dense Cloud-Drone Network (UDCDN) architecture. This scheme is featured with "on-demand" quality and substantial flexibility in terms of deployment. This anchors the challenges of traditional UDN settings and offers numerous benefits. Through simulation results of cell coverage, we verify the genuineness of implementing the proposed scheme and offer a new paradigm shift for UDN.

Introduction

The rapid growth in communication traffic has evolved the current macrocell network to become more tight and compact, eventually leading to small cell architecture or Ultra Dense Networks (UDNs). However, not only the growing traffic drives the future network demands, but also the request for higher data rates by the subscribers. According to a recent survey in [1], data rates are expected to increase up to 10 Mb/s in 2020 and 100 Mb/s in 2030, from 1 Mb/s in 2010, with monthly consumption rising from 1 GB/month to 30 GB/month.

To meet these requirements, current macrocells are evolving toward multi-carrier aggregation, use of mmWave spectrum, and increased spectral efficiency, through advanced antenna solutions such as multiple-input multiple-output (MIMO) and distributed antenna systems.

However, the high maintenance cost and renting of a macrocell base station (BS) lead mobile operators to prefer the deployment of a UDN due to low power transmission and increase in capacity by efficient spatial reuse of the spectrum. There are several challenges to be met for successful implementation of UDN. Major limitations of UDN are high signal to noise plus interference ratio, due to the compact cell architecture and high overlapping of the coverage areas, high mobility scenarios with a large number of handovers occurring simultaneously, management of mobile-Xhaul, operator and vendor management, conflict resolutions between the service providers, etc. [1, 2].

In this article, we propose the novel idea of an Ultra Dense Cloud-Drone Network (UDCDN). Drones, earlier developed for military applications such as surveillance and reconnaissance, are now being actively implemented for many civil applications and recently in 5G [3]. We argue that this is a timely and an efficient replacement for UDN in terms of on-demand deployment, energy efficiency, cost reduction and simpler network architecture with cloud-based and edge-based processing. However, some issues need to be addressed in UDCDN, starting with system design and technical aspects of administrative and legal grounds for implementation. A fog-cloud based Radio Access Network (FC-RAN) architecture, which combines centralized (C-RAN), heterogeneous (H-RAN) and fog (F-RAN) radio access networks [4], was preferred to meet the Long Term Evolution (LTE) architecture requirements of low latency, high traffic volumes, and data rate. The motivation of this idea is to reduce the mobile operator's cost and radio resource continuous utilization by the real-time deployment of UDN using the drone-assisted network, while still meeting the cellular traffic requirements of 5G. Also, due to a multitude of use cases of 5G, network slicing is a fundamental key aspect to be inherited with UDCDN. With powerful Network Function Virtualization (NFV) technology, quick deployment of network slices is possible with better management and utilization of resources to fulfill a one-type-fits-all philosophy [5]. For employing UDCDN on a certain slice, network operators should decide slice functionality and resources, for example, processing, storage, bandwidth resources, etc. Then, the

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This architecture is on-demand with the deployment of a dense network in real time only when it is needed, depending on the feedback obtained from the cloud-stored database. Therefore, it provides several benefits over the proposed terrestrial UDNs due to several challenges that need to be taken care off.

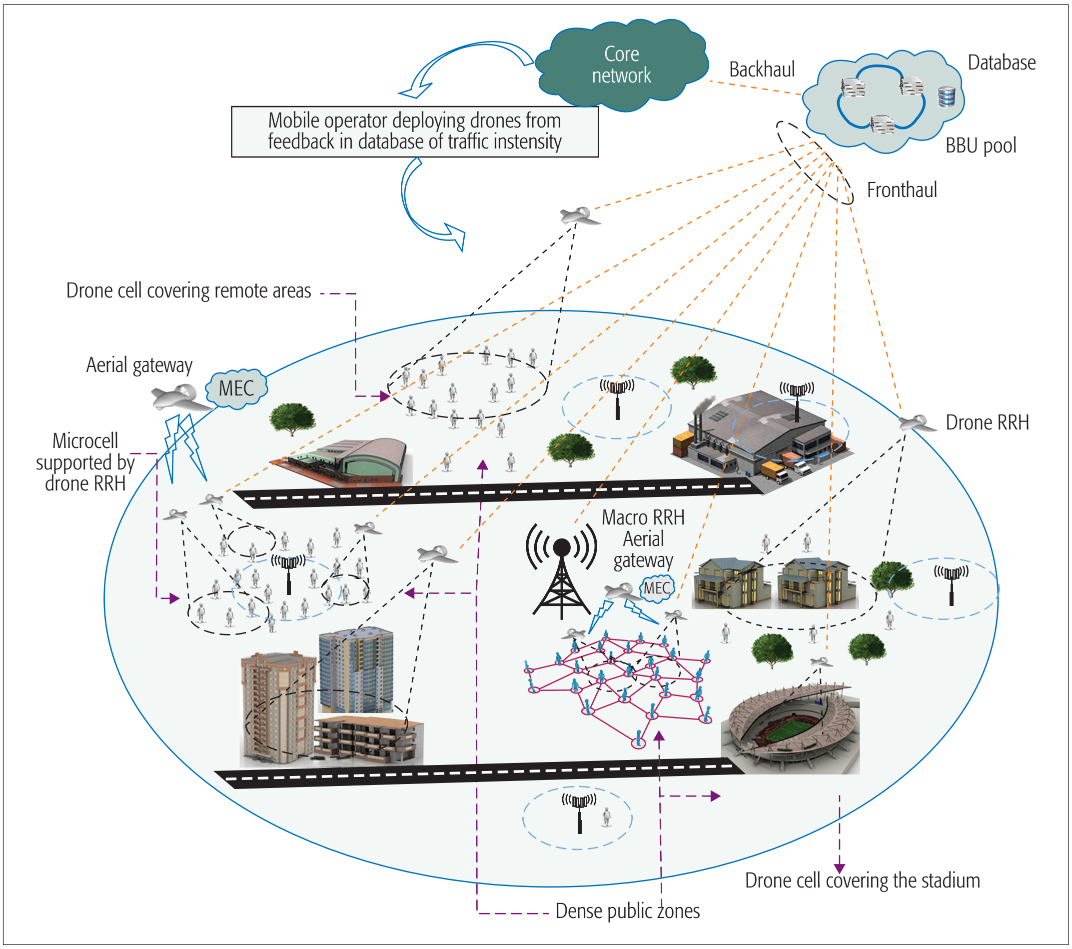

Figure 1. UDCDN system architecture.

slice request is notified through a specific interface, and therefore embedding a virtual network into the physical network in an efficient way. On this aspect, several algorithmic considerations are given in [5].

To the extent of authors' knowledge, this is the first article proposing such a system architecture for UDN. However, in [6] the authors envision a multi-tier drone cell network with terrestrial Heterogenous Networks (HetNets), where they focus on a drone management framework with technologies and possible challenges. This is different from our vision for UDN since we do not consider a multi-tier network and also we emphasize on *on-demand* UDN formation. Also, we address aspects such as health monitoring and autonomous control of UDCDN.

The rest of the article is organized as follows. First, we present the major challenges and benefits for deploying UDCDN, followed by a description of its system architecture. Then, we briefly discuss drone control by means of LTE and its Wireless Sensor Network (WSN) based health-monitoring. Then a discussion on the appropriate fronthauling and backhauling technologies is given. Finally, simulation results are used to illustrate the coverage analysis for the drone-mounted base stations, and then we present our final concluding remarks.

Proposed System Architecture

We propose heterogeneous networks (HetNets) based on drone cells, constituting the UDN, where microcells are formed by low power terrestrial BSs and macrocells are formed by high power terrestrial BS, for providing cellular coverage to the mobile users as shown in Fig. 1. The drone radio remote head (RRH), or aerial base station (ABS), connects various parts of the city, where high traffic intensity is observed. The macro RRH covers a large part of the city with the macrocell overlap with the drone cell. The microcells are also integrated to support the density of the user environment, as in the present cellular architecture. The size of the drone cell can be in the range from a femtocell to picocell as shown by simulation results. This distribution in a HetNet with overlap in microcell and macrocell leads to unequal distribution of radio resources among the users. However, this issue for a terrestrial UDN can be solved with the use of UDCDN, as explained in upcoming sections. Each UDCDN cluster is supported by an aerial gateway for health monitoring of the drone network using Mobile Edge Computing (MEC). The vast traffic information pattern managed by a cluster of ABS, micro BS, and macro BS, are processed and stored partly in the local databases of their edge cloud servers and partly by a virtualized base band unit (BBU) pool hosted in the central offices (CO) in metro segments. The information from these databases is one of the driving conditions in the ABS trajectory planning and autonomous deployment of higher numbers toward the city area to manage high traffic overload. Moreover, two interfaces are needed to connect drones with operator orchestrators, X2 and S1 [4]. X2 will be present between the drone RRH for handover and coordination schemes, while S1 are needed between the BBU and the core network. Using NFV technology, the BBU pool in the CO can also host the virtual network functions (VNF), which can reconfigure the network depending on the users and network operators' requirements. VNF can also run as virtual machines (VMs) deployed on commercial-off-the-shelf servers in data centers, thus enabling better use of network resources and increasing network scalability and flexibility. The VMs can be scaled according to drones added or removed from the network based on the data traffic using different scaling methods, such as dynamic memory and core scaling, virtual memory streaming, cost-aware scaling, etc. This architecture is on-demand with the deployment of a dense network in real time only when it is needed, depending on the feedback obtained from the cloud-stored database. Therefore, it provides several benefits over the proposed terrestrial UDNs due to several challenges that need to be taken care off such as site location and acquisition, energy expenditure, backhauling, etc. [1, 2].

Due to limited availability of spectrum, we propose to use LTE-Unlicensed spectrum at 2.4 GHz and 5 GHz for ABS, as is used by WiFi and Bluetooth devices. Because of the adaptive nature of the architecture, it is not always mandatory to form a dense network, but only when there is a huge traffic demand in certain areas of the city as happens, for example, in concert zones, sports stadiums, public rallies etc.

Challenges and Benefits

The introduction of UDCDN to HetNets has certain limitations and advantages as discussed below.

Benefits Of UDCDNs

Dynamic Cell Coverage Area: An ABS is capable of dynamically changing the area of coverage depending on its altitude and transmission power as shown in [7]. Due to this possibility, UDCDN cell coverage ranges from 10 m (femtocell) to 300 m (picocell), making UDCDN a suitable substitute for UDN. Therefore, the density of the network can be flexibly changed. In the simulations section, we analyze the dependence of ABS altitude to the cell coverage.

Energy Efficiency: The energy budget of a drone is contributed by the maintenance of the flight status, on-board processing, and the power required by the BS to transmit to users, for downlink, and also for fronthaul and backhaul. The power consumed by the drone for flight and on-board processing is assumed to be constant in this article. However, the power utilized by a drone to fly depends on standard lift, drag, and propulsion models when the assumption of a quasi-static equilibrium flight is done. For our analysis, we keep the dependence of power consumption only on the power transmitted by the ABS. As will be shown in our simulation results, cell coverage depends on the power transmitted by the ABS. Due to the adaptable and flexible behavior of UDCDN, high power consumption is only needed when deploying a dense network. Meanwhile, a lower power is maintained in flying and transmission. In order to meet the demands of power, a continuous renewable source is required, therefore several solar-powered drone flight tests have been conducted by Facebook (Project Aquila), Google (Project Loon), and many others to fulfill the requirements. However, natural resources such as sunlight may be inefficient due to their irregular and unforeseeable nature, therefore a fly-and-recharge strategy can also be implemented for meeting power requirements via RF energy harvesting or another far field energy source. In this domain, simultaneous wireless information and power transfer (SWIPT) is emerging as a promising energy harvesting technology, through which ABS can transfer power and information simultaneously [8], among neighboring ABS and ground users with significant gains in spectral efficiency, time delay and energy consumption. Since wireless power transfer was proposed for near-field regions due to health concerns of the users by electromagnetic (EM) radiation, drones have the leverage to fly near to the EM source.

Easy Deployment: On-demand deployment and flexibility of this system define the real-time formation of UDCDN based on the feedback requirement of data rate obtained from the cloud database, depending on the amount of traffic generated. This on-demand deployment leads to the formation of an adequate number of dense networks, as per the requirement to avoid the use of continuous radio resources and energy of the drone. This reduces the overall cost of the system, as an on-demand use of radio resources is a form of dynamic spectrum management, using the wireless channels only when needed.

Site Location: The deployment of a terrestrial BS has been a topic of discussion for UDNs. Macrocell BS deployment is based on maximizing the cell coverage area and obtaining a higher throughput [1]. For small cell networks, instead of higher site availability due to low antenna heights, still is a challenging task because of the geolocation of network traffic and types of devices used [1]. This can be overcome by UDCDN due to its on-demand deployment and flying potential.

Cost: The cost of on-demand UDCDN is much lower than terrestrial UDN. This is because of the lower cost of solar cells, UAV and sensors, which collectively reduce the cost of the ABS as compared to the terrestrial base stations. Also, due to the use of solar-powered drones, power costs will be reduced drastically. This is beneficial for mobile operators because it reduces the total cost of ownership (TCO) of the cells [1].

Data Offloading: To manage a large amount of data traffic, data offloading to the WiFi band [9] or device-to-device (D2D) radio links [10] are required to improve the performance of the system. These data offloading techniques reduce the traffic load on the network without any additional cost on the infrastructure. Also, since drone cells operate in the low-frequency bands, as proposed here, they might interfere with the unlicensed WiFi band. Therefore, in order to avoid this interference, we need to employ a mitigation technique. Delay in data traffic takes place during offloading, which enforces the requirement of dynamic data offloading techniques with delay-tolerant data to offload over WiFi or D2D and delay-intolerant remaining on the cellular network.

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For the development of this system, ensuring the safety of the people is of primary importance. Therefore, continuous operation and position monitoring of the drone is needed. This can be accomplished by placing wireless sensors on the drone for its structural and operational component monitoring.

Payload Considerations: Several sensors, circuit boards and batteries are required to operate the drone. Apart from these, the BS and solar cells also add to the payload weight in this system. The requirement is to minimize the payload weight for efficient system design. The payload weight depends on the size of the drone as per the guidelines of the respective aviation authority in each country.

Challenges of UDCDNs

Interference Management: ABS has a small coverage area in the order of femtocell. Due to a limited coverage area, there is a probability of cell overlapping, which causes co-channel interference (CCI) for the air-to-ground links, between the user and the ABS, and wireless backhaul/fronthaul. Also, a high Doppler shift is observed due to the mobility of ABS, which leads to inter-carrier interference (ICI) and therefore decreases the capacity. The problem of CCI can be solved by optimizing the trajectory of the drone to minimize the overlap between cells. However, for ICI, several interference mitigation techniques such as receiver windowing and ICI self-cancellation exist.

Drone Flight Standardization: For the commercial use of drones, standard regulations have been developed by aviation regulatory authorities in each country, with the goal of minimizing the possible risk and damage to other aircrafts, people, and property on the ground. The International Civil Aviation Organization (ICAO), a United Nations agency, is responsible for deploying these standards in 191 member countries worldwide. However, each country sets up its own standard based on these guidelines. For example, the Federal Aviation Administration (FAA) regularizes standards in the U.S. and the European Aviation Safety Agency (EASA) in Europe. Standardization of rules is a stringent and long process, which ensures complete safety for people and public property.

Drone Health Monitoring and Position Monitoring: For the development of this system, ensuring the safety of people is of primary importance. Therefore, continuous operation and position monitoring of the drone is needed. This can be accomplished by placing wireless sensors on the drone for its structural and operational component monitoring such as rotor torque, vibration, crosswind force or gust force, etc., as discussed in a later section. Position monitoring can be done by employing advanced global positioning and navigation systems.

Drone Trajectory Planning with Group Optimization: The trajectory of the drone depends on various factors, with the primary factor being the geographical region of the city, which generates the maximum data traffic. The drone detects this parameter in real-time from the cloud database and establishes its waypoints autonomously. However, there are certain other factors that would affect the drone's trajectory, such as wind and gust force, infrastructure planning, minimizing energy constraint, optimal path with collision avoidance from buildings, and surrounding drones. This trajectory can be modeled using genetic algorithms and swarm optimization techniques.

Handover Management: Handover is one of the crucial concerns with the UDNs. Efficient strategies are required to regulate the handovers without excessive signaling overhead and latency because there are more users near user-site access points (APs). Furthermore, with the advent of UDCDN, a new handover scenario may arise from users to drones and the infrastructure to drones. Since UAVs provides better coverage, it is easier to consider existing LTE handover standards for managing handoffs that arise from the high mobility of users.

Adaptive Distribution of Radio Resources: As mentioned in the previous section, due to cell overlapping in HetNet, radio resources are non-uniformly exploited by users. The reason is when we assume a uniform distribution of users in the entire area of operation, only a few users will lie under the terrestrial UDN. They have access to maximum resources while most of the users do not. This problem is solved in the proposed architecture since the deployment of a number of ABS toward an area depends on traffic intensity obtained from a database in the cloud.

Aerial Base Station Control Over LTE

For maintaining UDCDN, there is the requirement of controlling a swarm of ABS via an LTE network. However, fast maneuvering of the drones is needed to work in highly populated urban environments for quick UDCDN deployment and collision avoidance. To execute this, ultra-low latency in the order of 1 ms or less and ultra-high reliability communications are needed, which can be achieved through recent advances in 5G PHY layer and NET layer design. New 5G waveforms such as Generalized Frequency Division Multiplexing (GFDM), Universal Filtered Multi-Carrier (UFMC) and Filtered Bank, Multi-Carrier (FBMC), along with numerologies and frame structure, are designed in the PHY layer [11]. In the NET layer, the current progress thrives toward the development of FC-RAN [4] for low latency applications where C-RAN consists of global centralized communication and control cloud which facilitates resource pooling, layer inter-working, capacity and scalability by exploiting data-centric processing for both centralized and distributed RAN architectures, while F-RAN consists of distributed communication and storage cloud which comprises devices at the network edge. Also, trajectory planning of ABS in the city has much importance as explained in previous sections. Several field tests have been performed by Qualcomm and China Mobile recently for coverage, signal strength, throughput, and latency. Successful handovers and strong signal strength were observed, making the entire system suitable for deployment in the market.

Aerial Base Station Health Monitoring Via Wireless Sensor Networks

ABS on-board equipment and structure monitoring are extremely important for any mobile operator to avoid ABS accidents and jeopardize human lives. However, to the best of our knowledge, there is no existing literature addressing these aspects. Here, we propose a simple Internet of Things (IoT) based architecture to monitor the health of each ABS in the city. We propose to deploy a UAV as an aerial gateway, with the sole function of collecting the information from the various sensors present on the ABSs, performing the task of data aggregation, and forwarding this data toward the cloud via an LTE network established by other ABS, micro BS or the macro BS, as shown in Fig. 1. However, there is the possibility of processing the data in the cloud using MEC algorithms rather than local processing on-board ABS to conserve power of the drone. It is required to identify the data rate from the sensors in order to prioritize the information to be computed using MEC. For high data rate sensors, MEC is recommended, while for low data rate sensors, on-board processing can be implemented. Here, we mention a similar study present in the literature [12], where UAVs have been used as an IoT platform, creating the Internet of Drones (IoD).

Fronthauling and Backhauling

Fronthauling is one of the major design challenges for this system [13, 14]. Many network functions, such as a cooperative management of CCI and smooth handover, call for the need of efficient fronthauling between the BBU pool and drone RRH, are needed. However, a few challenges that need to be addressed are as follows:

- Adaptive deployment of UDCDN makes fronthauling complex.
- Higher fronthauling capacity is needed when UDCDN is deployed.
- Wired fronthaul solutions based on optical fiber cannot be used for such a system. Therefore, wireless options have to be explored.

For UDCDN, we propose to use millimeter-wave (mm-Wave) and free space optical (FSO) as potential fronthaul technologies. The factors influencing mm-Wave are as follows.

•There is a spectrum scarcity in cellular networks. A common range of frequencies used in LTE goes from 699 MHz to 3800 MHz. They can be used in combination with other telecom generation technologies such as HSPA and GSM. The scarcity of spectrum resources led researchers to move toward mm-Wave spectrum ranging from 30 GHz to 300 GHz. Among these high-frequency bands, 60 GHz is an unlicensed band with 9 GHz bandwidth that has attracted researchers to use this band. Several channel modeling studies have been done by research groups such as the 5G mm-Wave Channel Model Alliance, NYU Wireless, MMmagic, Miweba, etc.

•Due to the extremely low wavelength of mm-Wave frequency bands, there is high attenuation due to atmospheric effects in mm-Wave transmission. Therefore, mm-Wave communication is preferred over short distances and in LOS conditions. As we adopt low altitude ABS for UDN, both of these conditions are met for our proposed architecture while deploying an on-demand UDN.

Similarly, a few factors that influence the use of FSO are as follows:

- Wide bandwidth, which results in higher fronthauling capacity.
- Exploring the frequency band above 300 GHz and high directionality of the laser beam leading to better LOS conditions.

Scenario	α	β	γ	Number of buildings	Buildings width (m)	Street width (m)
Suburban	0.1	750	8	750	11.54	24.97
Urban	0.3	500	15	500	24.49	20.23
Urban high rise	0.5	300	50	300	40.82	16.91

Table 1. City layout parameters [7].

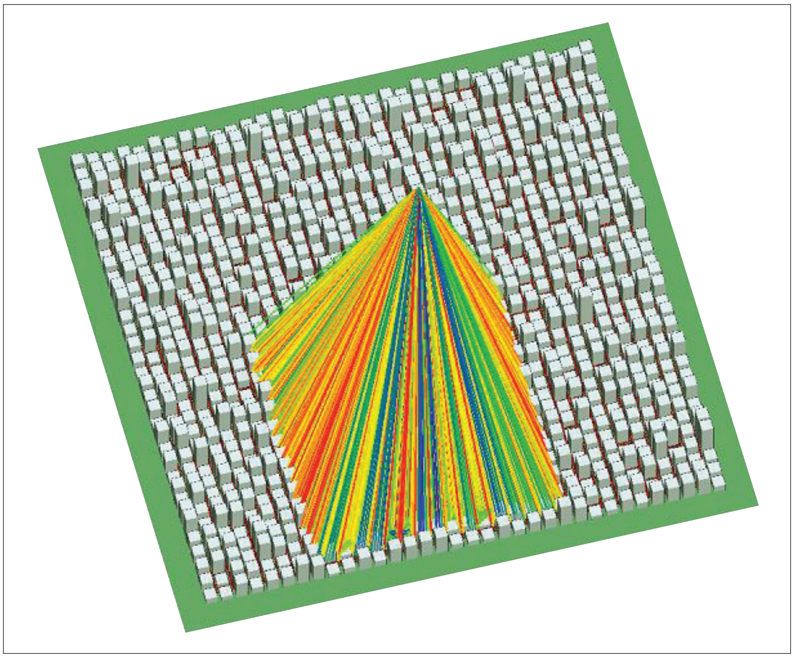

Figure 2. Simulation setup of 2000 × 2000 m^2, with simulated area of 1000 × 1000 m^2 of Urban High Rise Scenario with ABS altitude of 2000m for ray tracing in Wireless InSite.

For backhauling, it is possible to use both wired and wireless solutions for this system, similar to the terrestrial UDN. To reduce the TCO, including capital expenditure (CAPEX) and operational expenditure (OPEX) of network operators, reconfigurable network functions using NFV for S1 and X2 interfaces are needed in the core segments, depending on high traffic periods, delay and capacity constraints, on-demand quick deployment, link failures and dynamic FC-RAN topology reconfiguration. Using UDCDN, such network functions can be avoided through low-complexity management of the drone network. However, still to guarantee above restrictive constraints and service specific parameters in Service Level Agreements such as quality of service and minimum bitrate, Customer Virtual Network reconfiguration [15] can be supported in the core and metro segments of the network.

Simulation Results for Cell Coverage Analysis by Aerial Base Station

Dynamically changing the cell coverage area based on ABS height and transmitting power is one of the major benefits of UDCDN. This allows the mobile operator to control the density of UDCDN by deploying a low number of drones to provide the same throughput to the users and also avoid overlapping of the cells to avoid inter-

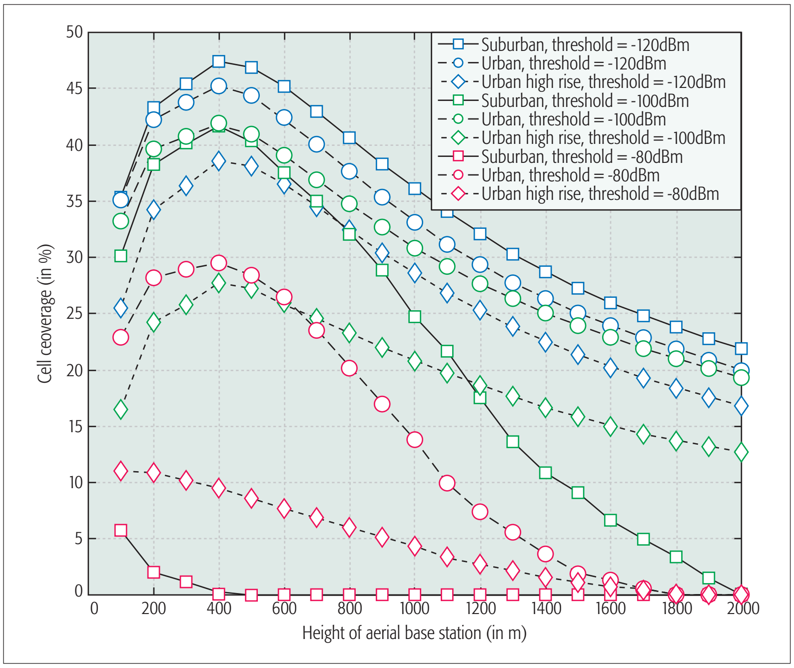

Figure 3. Cell coverage with variation in ABS height.

Scenario	Cell area A_C (m^2)	No. of buildings	Building area (m^2)	Final cell area (m^2)
Suburban	$\simeq$ 104, 000	750	10,379	93,543
Urban	$\simeq$ 104, 000	500	31,189	72,733
Urban high rise	$\simeq$ 104, 000	300	51,961	51,961

Table 2. Cell area for the simulation [7].

ference. Here, we present the simulation results obtained from a commercial software of ray tracing, Wireless InSite. The simulation setup is shown in Fig. 2. We simulated three generalized scenarios: suburban, urban, and urban high rise, developed on a computer-aided design software, 3DS Max, based on the ITU-R parameters for designing the layout of a city as given in Table 1.

- α = Ratio of land area covered by the buildings out of the total area (*dimensionless*).
- β = Mean number of buildings per unit area (building/km^2).
- γ = Variable determining the building height distribution.

The receivers were uniformly distributed over the simulation area of 1000 × 1000m^2, with the ABS present in the center mounted with an omni-directional antenna. The heights of the buildings were Rayleigh distributed. Many simulations were carried out at different ABS height intervals of 100 m, from 100–2000 m, at 2.4 GHz carrier frequency and 20 MHz signal bandwidth, with transmission power of ABS ranging from 18–46 dBm. Although, it is expected to have a high density of users in an urban environment, in order to demonstrate the *on-demand* quality of our system, we also consider a suburban environment where an impulsive demand for a higher data rate and volume is anticipated (via rural events, rallies, and public gatherings). The usefulness of developing a generalized scenario helps us in comparing these results to any real city scenario.

The cell coverage results were obtained by setting a threshold on the received power, found from the ray tracing simulations. Only receivers with received power $P_{rx}(r)$ at distance r from the ABS, above the threshold were included in the cell coverage area. The cell coverage in Fig. 3 and Fig. 4 is plotted as the percentage of assumed normalizing cell area A_C. The simulations were performed at –120 dBm, –100 dBm and –80 dBm of P_{rx}. For 200 m radius of A_C and –120 dBm P_{rx}, the final cell area after removing the building area from A_C is shown in Table 2. It was observed that the maximum cell coverage increases with lesser received power threshold at the edge of the cell. In our simulations, the maximum coverage was obtained by setting the threshold to –120 dBm. We assumed practical received signal strength indicator (RSSI) values in LTE for our simulations as obtained in a practical scenario. As we increased the RSSI to –80 dBm, the cell coverage decreased.

Also, it was found that the optimal altitude of ABS for maximum coverage at 18 dBm was between 300 m and 350 m for all environments. Finally, we also verified that cell coverage is higher for the suburban environment and lower for urban high rise when we set –120 dBm as a threshold. However, this trend changes as the threshold increases, where the suburban environment has the least coverage than the urban and urban high rise environments. This is because in urban conditions, the air-to-ground channel experiences Rician fading due to the presence of an LOS path. In suburban areas, Rayleigh fading is experienced as the presence of reflected signals that are stronger than LOS. Therefore, as the received power threshold is increased, fading changes from Rayleigh to Rician in suburban environments and vice versa in urban environments [7]. Thus, a generalized approach is to use a Rician distribution where both LOS and NLOS paths are considered.

As shown in Fig. 4, the cell coverage increases as the transmitted power of the ABS increases. Also, the cell coverage increases linearly with transmitter power at –80 dBm, but becomes almost constant at –120 dBm. This is because the received power of –120 dBm is already the least value required to maintain the connectivity with the ABS. Therefore, the receivers receiving less than –120 dBm are not present in the coverage area of the cell. Also, as expected, the cell coverage is higher for the suburban environment than urban environments, due to Rayleigh fading where multipath and scattering effects dominate, leading to the constructive and destructive addition of receiving power with their phase and delay and therefore leading to higher received power. For the simulations, a line of sight probabilistic path loss air-to-ground channel model is used [7].

Conclusion

We presented an on-demand and flexible Ultra Dense Cloud-Drone Network (UDCDN), deployed in a real-time based communication traffic feedback from various areas of a city. An architecture is proposed for this system by introducing the challenges and benefits for its implementation followed by a detailed discussion. We then highlighted the operational monitoring of the drone as one of the the key factors for this architecture. Also, control of the drone using an LTE base station is discussed, together with fronthauling and backhauling technologies for this system. Finally, we have shown the simulation results for dynamic cell coverage area variation with height and transmitting power of the aerial base station. This is effective to avoid and manage cell overlapping and mitigate interference. In our future work, we plan to integrate UDCDN with terrestrial networks operating at sub-6 GHz and millimeter-wave bands with a main focus on inter-cell and multi-tier interference, spectral and energy efficiency with drone trajectory optimization and handover performance.

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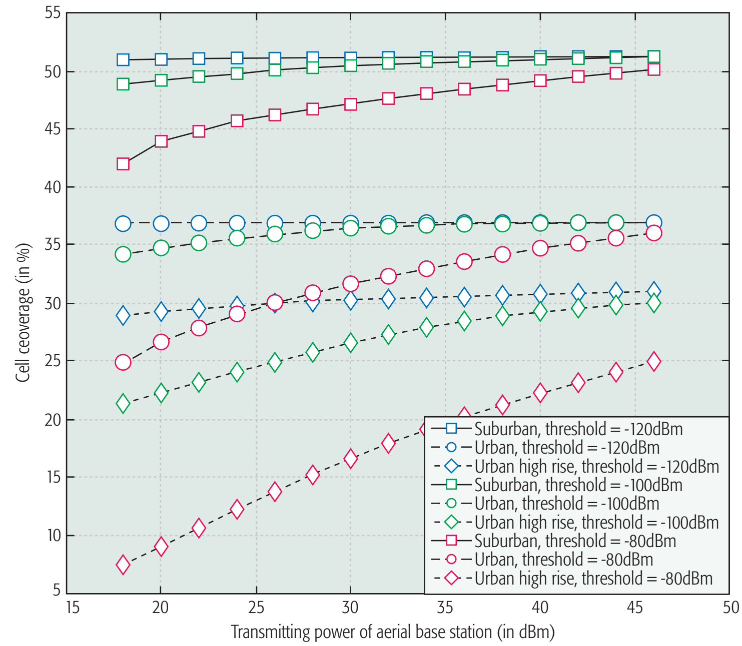

Figure 4. Cell coverage with variation in ABS transmitting power.

Biographies

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