Handover Challenges for Cellular-Connected Drones

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ABSTRACT

We report and discuss cell selection and handover measurements for an aerial drone connected to an LTE-A network in a suburban environment. Our experiments show how the handover frequency increases with increasing flight altitude: A drone flying at a typical height of 150 meters is expected to experience five cell changes per minute compared to only one change for ground users moving at the same speed. This behavior can be explained by the differences between ground and aerial devices in terms of cell selection. It is concluded that revised handover techniques and the consideration of drones in the planning and operation of 4G and 5G radio access networks are required.

CCS CONCEPTS

• **Networks** → **Network experimentation**; **Network performance analysis**; **Network measurement**; **Mobile networks**.

KEYWORDS

Wireless communications; LTE-A; drones; UAV; handover.

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1 INTRODUCTION

The deployment of unmanned aerial vehicles (UAVs) — commonly known as *drones* — has generated a wide range of applications. These include surveillance, monitoring, disaster relief, and delivery in various branches, such as commerce, industry, transport, defense, and agriculture. The UAV market is expected to grow from US $11 billion in 2016 to US $52 billion by 2025 [16], which promises an intensified proliferation with further applications in the years to come. This development calls for new solutions in terms of technology, regulation, and ethics.

One important technical challenge is drones' wireless connectivity for the transfer of sensor data and control commands. Such connectivity must be reliable and secure, and needs to support high data volume and short latency in some applications.

Most commercial drone systems employ the IEEE 802.11 WLAN (Wireless Local Area Network) technology for sensor data and proprietary radio technologies for command and control. Given UAVs' three-dimensional mobility, high relative speeds, and changing altitude, IEEE 802.11 does not always meet the stringent service requirements of drone applications envisioned. For example, operation in the unlicensed spectrum raises issues in terms of reliability and security. This is why cellular networks are considered to be an alternative for drone communications. Drones could benefit from the existing network infrastructure — in terms of coverage, reliability, and security — at data rates that are sufficient for many applications. The issue is that cellular networks were not primarily developed and deployed for the use with flying devices. There are ongoing standardization activities [5], but various problems — including radio coverage and interference [17] — remain and need to be solved in order to make cellular connectivity an attractive solution for drones [19].

In this paper, we would like to contribute to this emerging area by focusing on cell association and handovers using field measurements. Specifically, we present experimental findings on the cell association and handover rates for drones connected to an LTE-A (Long Term Evolution Advanced) network on a university campus. To the best of our knowledge, no such study exists in the scientific literature, to date. It is known that the number of base stations visible to an aerial device rises with increasing flight height [17] but the actual handover rate has not been quantified. We analyze this rate as a function of the height and explain the observed behavior. The insights gained highlight the need for advanced handover techniques and revised radio network planning.

The paper is structured as follows: Section 2 addresses the integration of drones into cellular networks with a focus on cell allocation issues. Section 3 presents the experimental analysis, including the setup, scenarios, and results. Section 4 draws conclusions and proposes research directions. A related paper by the same authors [8] studies the data throughput in the identical setup. The software tool used for the measurements is introduced in [14].

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2 INTEGRATION OF DRONES INTO CELLULAR NETWORKS

2.1 General issues and related work

Drones can take on different roles when integrated into cellular networks [21]. First, they can become part of the network infrastructure by acting as mobile base stations or relays [20]. The goals here are to improve coverage, capacity, and connectivity, or to offer the rapid deployment of a radio access network in areas without a fixed infrastructure. The case of drones carrying small base stations is discussed in [4, 12]; and the potential of drones as relays is studied in [3, 7]. This setup is especially useful for particular use cases, such as disaster relief involving infrastructure damage and the provision of extra coverage and capacity during large, temporary gatherings of people (e.g., sport events, concerts). Second, a drone can be user equipment (UE) and act like a mobile phone in the air. The uplink from a drone to a base station can be used to send data to the ground for processing; and the downlink can be used for steering and controlling during the flight.

Our work focuses on drones as aerial UEs. Several challenges to this case have been studied by the research community, but most of the work has been done with simulations rather than experiments (see surveys [6, 9, 11] and [10]). A few papers on cellular-connected drones draw their conclusions from experimental work. Examples include the following: Van der Bergh *et al.* [17] analyze the impact of flight height on the LTE signal level and the number of base stations visible to a drone; Amorim *et al.* [2] and Al-Hourani and Gomez [1] perform LTE experiments to characterize the propagation environment for drones; and Nguyen *et al.* [13] demonstrate the impact of downlink and uplink interference on the traffic in LTE networks. We strongly believe that such experimental assessments and a consideration of practical aspects will shed more light on the associated challenges. Experimental research is demanding and time consuming but will help academic and industrial players gain more insight into the integration of drones into both cellular networks and airspace.

2.2 Antenna tilting and cell association

To serve ground users optimally, the antennas of cellular base stations are tilted downwards. Aerial coverage has only recently gained substantial interest, mainly to provide connectivity for airline passengers on continental flights [15]. In this situation, only a few base stations, with up-tilted antennas, are needed to achieve wide coverage because seamless connectivity is only ensured during the cruise altitude phase of the flight. These solutions cannot be used for commercial drones, since they typically fly at a much lower height (say 50 to 300 m), due to construction and regulatory constraints (Fig. 1). Specific antennas or antenna configurations are therefore needed for drones (cf. [18]).

A drone, as a UE, is inherently different to a terrestrial UE because the assumptions made for terrestrial UEs do not hold true for aerial UEs [17]. To explain this, let us consider a simple example, shown in Figure 2, with two base stations: BS_A and BS_B. The antennas are tilted downwards, such that the main lobes (which concentrate most of the power) are directed toward the ground. A ground user is connected to the BS. Unless they are in the area where the powers

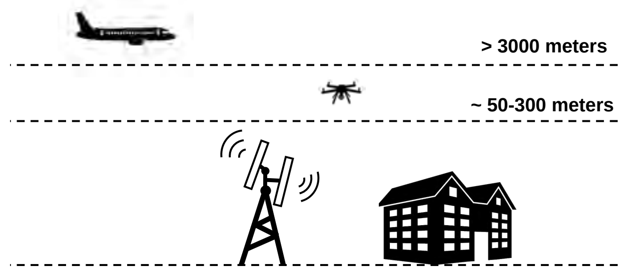


Figure 1: Cellular networks: from the ground to the sky

received from BS_A and BS_B are similar, this ground user remains associated to one of the two cells. Flying drones are served by the antenna's side lobes [10]. A drone located at the position P_1 is served by BS_B although it is in a closer proximity to BS_A, flying a few meters higher to P_2 makes it switch to BS_A and back again to BS_B at P_3. This shows that there is an inherent risk of frequent handovers and ping-pong handovers — even for short flight distances. This reasoning remains valid if the drone flies horizontally from P_2 to P_4. Extending this example to many BSs suggests that the handover rates for drones are high compared to those of regular ground users. We demonstrate and quantify this issue using experiments in the next section.

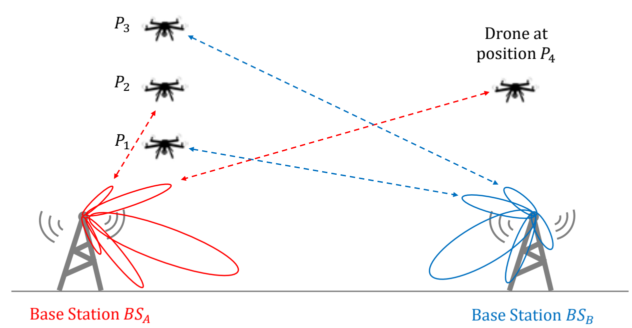


Figure 2: Cell association: Drones connecting to side lobes

3 EXPERIMENTAL ANALYSIS

3.1 Hardware, software, and setup

An AscTec Pelican quadrocopter (Figure 3), carrying a Sony Xperia H8216 smartphone, is flown in a field adjacent to our university campus, which is a suburban-like environment in the city of Klagenfurt. The phone is connected to T-Mobile Austria's LTE-A network, which runs the 3GPP Release 13 in the 800, 1800, 2100, and 2600 MHz bands with carrier aggregation in the downlink. The antennas are mounted at a height of about 30 m with an electric tilt of 5° to 10° and a maximum transmit power of 20 W. The drone's position can be controlled manually or autonomously, thanks to an onboard GPS (Global Positioning System) receiver and inertial measurement unit (IMU) sensors. Data exchange is performed via the Transmission Control Protocol (TCP).

Figure 3: AscTec Pelican quadrocopter

A customized Android application [14] installed on the phone records the radio measurements and sensor data every second. These measurements include the following values: RSRP (Reference Signal Received Power), RSRQ (Reference Signal Received Quality), and Physical Cell ID number (PCI). The PCI identifies the cell sector to which the UE is connected at a specific time stamp. The RSRP, RSRQ, and PCI traces of the serving cell and all neighboring cells are recorded. These measurements enable us to investigate the dynamics of cell association in a real-world deployment.

3.2 Evaluation scenarios

We evaluate four scenarios with the flight paths illustrated in Fig. 4:

- **Scenario #1**: The drone flies at an altitude of 10 m above the ground, in a straight line for 300 m and back. This low-height flight is used as a baseline to highlight the differences between terrestrial and flying UEs. Instead of performing this test with a regular pedestrian user, we choose to fly the drone at low height in order to have exactly the same speed as in the other flights, for a fair comparison of the handover performance. Flying at a height below 10 m is safety critical due to the limitations caused by turbulence and GPS accuracy.
- **Scenarios #2, #3, and #4**: The drone takes off vertically until it reaches a height of 50 m, 100 m, or 150 m, respectively. At the given height and constant speed of 3 m/s, it flies in a straight line for 300 m, returns to its starting point, and performs a steady direct landing. The projection of the straight lines flown in the four different scenarios on the ground, is exactly the same.

The initial take off and final landing phases are not considered in the performance analysis.

3.3 Results and analysis

Figure 5 shows the PCIs of the base stations to which the drone is connected to for every second of the four scenarios. We observe the following: The higher the altitude, the more handovers are performed. This was expected, but still, the extent of the handovers makes us think. On average, a handover occurs every 60 seconds in Scenario #1, every 31 seconds in Scenario #2, every 15 seconds in Scenario #3, and every 12 seconds in Scenario #4. The corresponding handover rates are summarized in Table 1. A drone flying at a typical height of 150 m can be expected to experience five cell changes

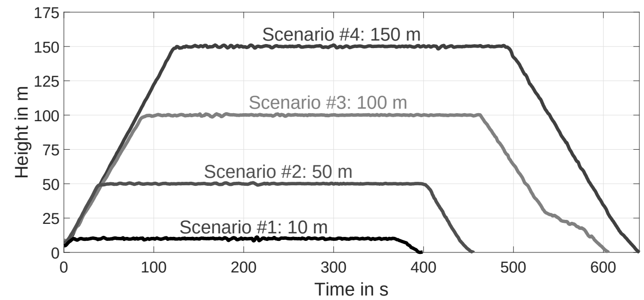


Figure 4: Evaluation scenarios

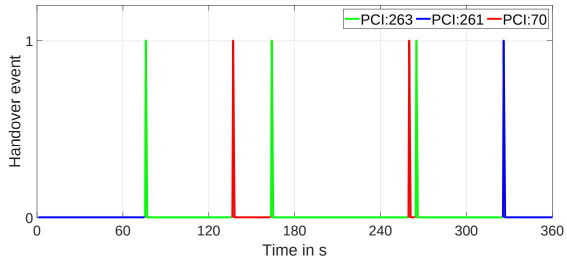
Table 1: Handover rates

Scenario	Height	Handovers
#1	10 m	1.0 min^{-1}
#2	50 m	1.9 min^{-1}
#3	100 m	4.0 min^{-1}
#4	150 m	5.0 min^{-1}

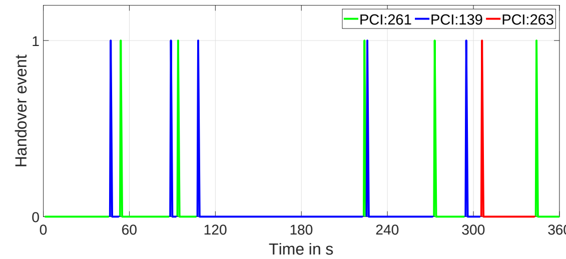
per minute compared to only one change for ground users. Many of these handovers are actually unnecessary. Handovers generate significant signaling traffic, and they may affect advanced network architecture concepts, such as mobile edge computing with respect to the reallocation of computational resources. It is worth noting that the flying UE connects to three, five, or seven different cells (cell sectors, to be more precise) during a six-minute measuring period.

To examine the geographical aspect of the cell association, Figure 6 shows the locations of the base stations to which the drone connects at least once during its flight. The ground projections of the drone positions are represented by blue crosses and the locations of base stations are marked by red triangles. Different PCIs can have the same location if the PCIs correspond to different sectors in the same cell. It can be seen that the drone connects with more distant cells at higher altitudes. At 150 meters, at one point in the experiment, the drone is served by a cell 3.6 km away. During this flight, the drone connects to a greater number of different cells than at lower altitudes.

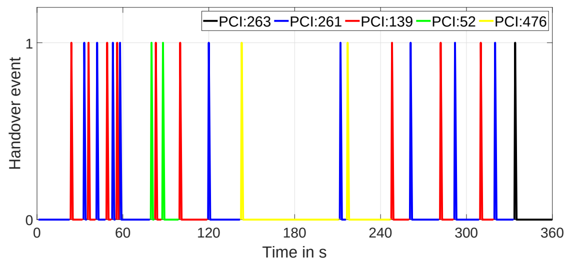
The decisions to execute handovers are based on differences in the RSRP values received from different BS antennas. This makes sense for ground users, since most of the radio power is directed to the ground by the antenna's main lobe. Aerial devices, however, are served by the side lobes. Here, the RSRP values of the different cells are very similar, so minor RSRP changes result in frequent changes in the cell that has the best RSRP value. This situation is illustrated in Figure 7, which shows the RSRP values from different cells for all four scenarios. A visual comparison of Figures 7 (a) and (d) reveals two findings: First, in the baseline ground scenario (#1), the RSRP values from each cell vary moderately without rapid or drastic changes, and the RSRP curves are well separated. Second, for the flight at 150 meters height (#4), all the RSRP values plummet to very low values before soaring again within a very short period of time. Furthermore, given that the drone has line of sight links to



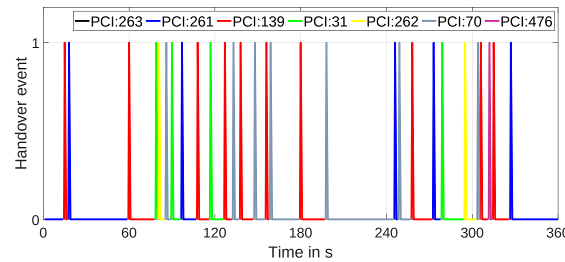
(a) Scenario #1: 10 m



(b) Scenario #2: 50 m



(c) Scenario #3: 100 m

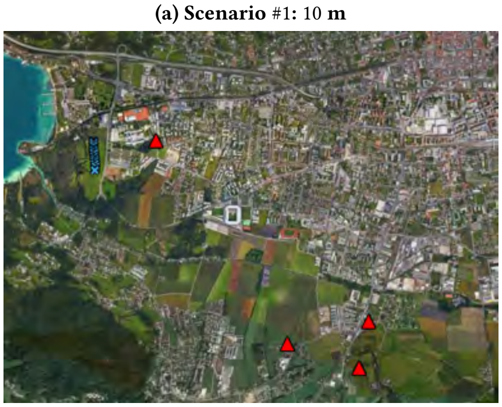


(d) Scenario #4: 150 m

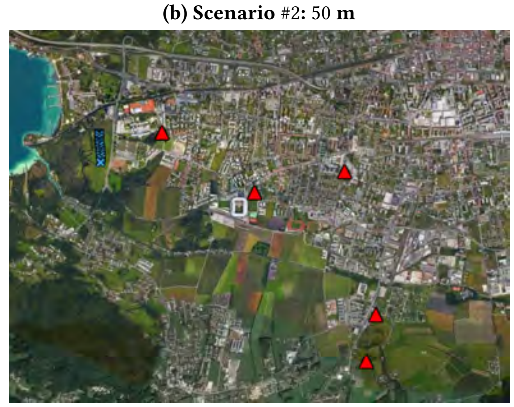
Figure 5: PCIs of the serving cells/sectors over time

(a) Scenario #1: 10 m

(b) Scenario #2: 50 m

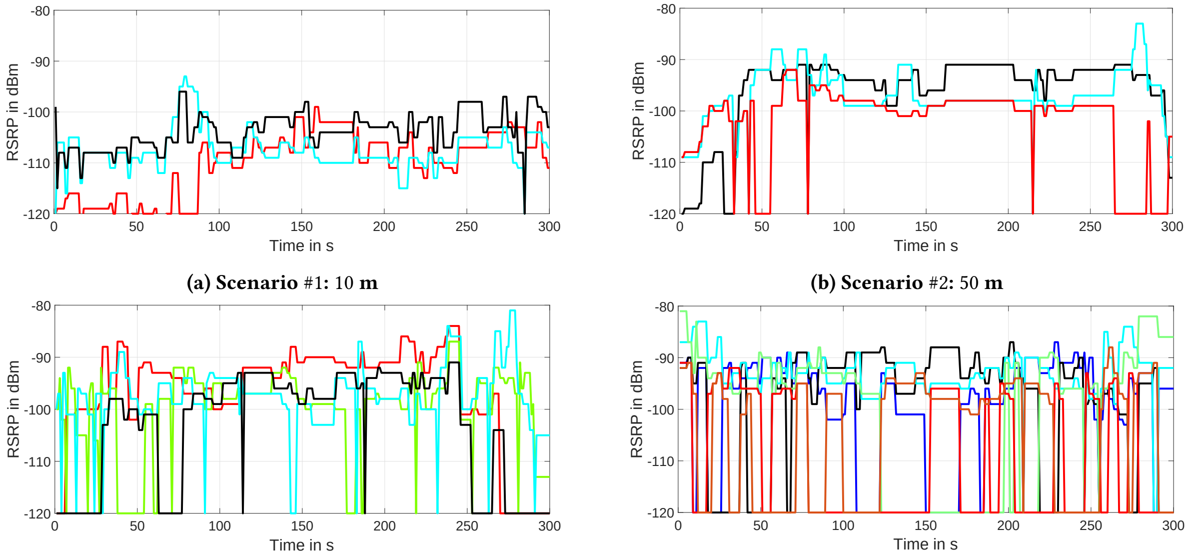


(c) Scenario #3: 100 m



(d) Scenario #4: 150 m

Figure 6: Satellite maps showing drone trajectory (*blue crosses*) and locations of the serving cells (*red triangles*) (Source: Google Maps)



(a) Scenario #1: 10 **m**

(b) Scenario #2: 50 **m**

(c) Scenario #3: 100 **m**

(d) Scenario #4: 150 **m**

Figure 7: RSRP values from cells in communication range with the drone over time for the four different flight heights

many cells at this height, the RSRP curves are quasi-comparable. Thus, the cell providing the highest RSRP changes very rapidly. The same trend can be seen in Scenarios #2 and #3, but to a lesser extent due to the lower altitude.

In conclusion, there is a need for improved handover techniques that address the singularities of drones. These strategies should be resilient with respect to the continual change in the cell providing the highest RSRP. For drones, connecting the UE to the best serving cell by means of RSRP is no longer appropriate.

4 CONCLUSIONS AND OUTLOOK

Outdoor experiments in a suburban-like environment demonstrate that drones connected to today's cellular networks establish links with distant base stations and are subject to frequent handovers once the typical flying altitude has been reached. Enhanced solutions for cell selection and handovers are needed for integrating drones into 4G and 5G networks. These issues need to be addressed by equipment vendors and network operators, who should enhance their radio network planning to take into account the particularities of drones.

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