LTE Ground-to-Air Measurements for UAV-assisted cellular networks

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Abstract— **The concept of UAV-assisted cellular networks is quite new and has attracted the interest of researchers, and the telecommunications industry. The UAVs act as flying relays offering telecommunication services to underserved areas as well as providing an alternative data gateway in cases of overloaded base stations due to flash crowd situations. This paper provides representative field trial results from our two year measurement campaign with quadcopters, for different operational scenarios. The measured LTE signal strength and signal-to-interference-plus-noise ratio (SINR) in the air are studied in two different cases: a) an underserved rural area and b) the urban center of a town. In the first scenario high SINR values (>10 dB) are measured at certain altitudes allowing the extension of the network coverage. In the urban area, as the UAV ascends additional cells are detected affecting the SINR values, but also providing the means for macrodiversity.**

***Index Terms*—UAV, LTE, 4G, Flying Relays**

I. Introduction

While the 4G networks are well established and the forthcoming next generation 5G system is being developed, yet there are still cases where the ground network cannot support the required services. Such cases include remote underserved areas, emergency situations (natural disasters, road accidents), but also overloaded base stations due temporarily huge capacity demand from extreme crowdedness or huge number of user devices like in stadiums, conference halls etc. Hence, the use of Unmanned Aerial Vehicles (UAVs) to assist the ground cellular network has recently gained attention from researchers and companies, as it is a potentially low cost, fast and easily deployed solution to failures of the existing network. The idea is that one or more UAVs operate as airborne base stations (BS) or flying relays for cellular telephony, expanding the network to underserved areas and/or enhancing the system capacity (Figure 1).

In this framework, the authors of [1] and [2] propose a network architecture for UAV assisted wireless communications and discuss its characteristics and challenges. In [3] an activity scheduling based on game theory is presented, for UAVs that act as small cells for temporary and emergency coverage. In [4] the authors study the use of mmWaves for achieving high data rates to UAV cellular networks. Furthermore, the performance of aerial LTE BS is investigated in [5], the effect of BS antenna radiation pattern in [6], while the study in [7] shows that the current LTE network needs modifications in order to support the UAVs as flying relays.

Recent studies go deeper into the concept of UAV-assisted cellular networks. The authors of [8] introduce the concept of floating relays with a dynamic coverage in heterogeneous cellular systems, performing analysis on issues like frequency reuse, interference, backhaul resource allocation and dynamic coverage inside a macrocell. In [9] the authors try to investigate if flying BSs can substitute ultra-dense small cells in mobile networks. Finally, [10] presents an algorithm for finding the optimum UAV position for flying relays.

The private sector also seems to welcome the idea of the flying nodes; Everything Everywhere (EE), a major British telecommunications company, has already announced its plans to expand its 4G coverage using UAVs and recently has cooperated with Nokia, using the new Nokia Flexi Zone Pico cells, to perform field trials in Scotland [11]. Google is testing new technologies on UAVs for 5G networks, while Facebook has also announced its plans to test a solar UAV to provide internet to rural areas, anywhere in the world.

In order the UAV to relay services to users, must achieve a reliable connection with the ground network. But as the existing cellular networks are optimized for ground users, a number of critical issues arise, such as the level and the behavior of the cellular signal in the air, the interference levels from neighboring BSs, the impact of the landscape on the system performance and the quality of services that can be expected.

Thus, it is essential to monitor real signals from ground base stations in the sky and analyze their behavior at different altitudes. In this framework, this paper provides LTE signal measurements in the air, from a ground 4G network, using specialized equipment embedded on a small UAV. For this study two areas of interest were selected: i/ a remote area with no access to 4G services and ii/ an urban environment (in the center of a mid-size town) with 4G service. In the first case the UAV could act as a flying relay and offer LTE connectivity to the remote area, while in the second case the UAV could contribute to the increase of the overall capacity of the 4G network e.g. during sports events, road traffic, disasters etc.

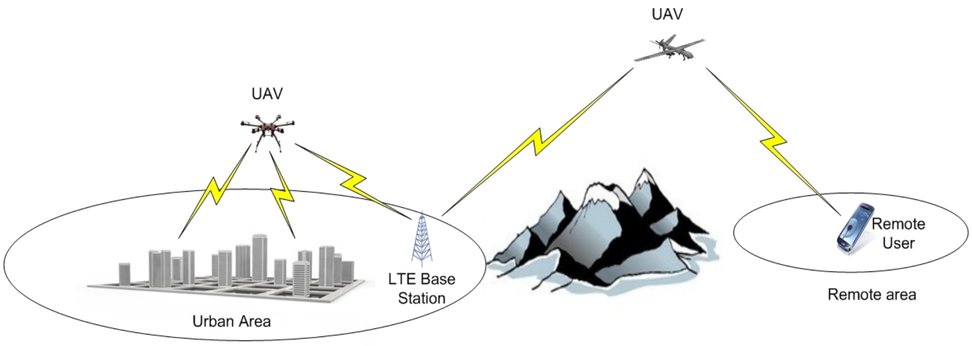

Figure 1: Flying Relays/Base Stations.

II. Measurement Setup and Equipment

The employed UAV is an IRIS+ Quadcopter from 3Drobotics. It uses an autopilot that autonomously flies the vehicle to predetermined waypoints and utilizes a telemetry system, where flight data (e.g. altitude, speed etc.) are transmitted and stored real time to the ground station. The ground station consists of a laptop with the Mission Planner software installed and an individual transmitter (Figure 2). The laptop is connected to the UAV throughout the flight via a 433 MHz link, and stores all the flight data.

The LTE measurement equipment consists of the “Nemo” software by Keysight, installed in a Samsung Galaxy SIII LTE handset (test mobile), which is capable of LTE signal measurements (e.g. Reference Signal Received Power - RSRP and Signal-to-Interference plus noise ratio - SINR). The data post-processing is performed using the “Nemo Analyze Pro” software by Keysight, which is capable of extracting, presenting and analyzing all the measurement data in a variety of formats.

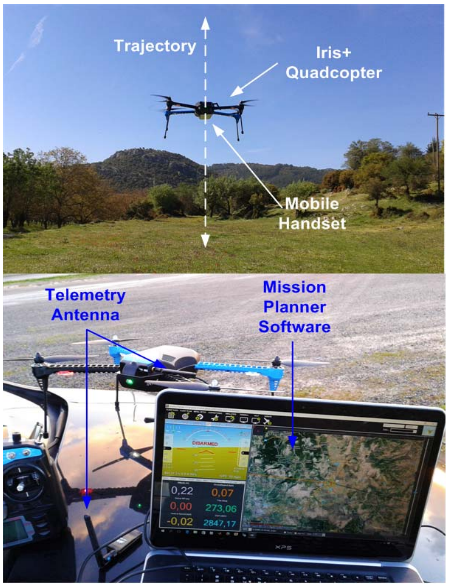

Figure 2: Measurement setup.

In order to monitor the LTE signal behavior in the air, the test mobile is attached on the UAV. At the selected measurement sites, the multicopter smoothly ascends to a specific altitude and then descends back to the ground level, while the test mobile, acting as User Equipment (UE), records the parameters of the received LTE signal during the flight. The levels of the LTE signal from each BS are studied measuring the RSRP. In an LTE system, the UE measures the RSRP of all the cells in its range and sorts the candidate cells for selecting the serving one. Meanwhile, the SINR, which is also measured by the UE, is a significant indicator for the Quality of Service (QoS) that the system provides.

III. Field Measurements

This section presents the measurements in the two aforementioned scenarios and analyzes the LTE signal behavior.

A. 1st Measurement scenario: Remote Area

The chosen area (point A in Figure 3) is just outside a small village, surrounded by mountains, with no line-of-sight (LoS) access to 4G BSs, and almost 2.5km in a straight line from the edge of the town. There are 10 4G BSs in the nearby area, 6 of them are located inside and 4 outside the town. The mast of every BS hosts more than one antenna, while each cell has a unique Physical Cell Identity (PCI).

Figure 4 shows the RSRP of the detected cells (PCIs) as the UAV vertically ascends to 335m and then returns to the ground. The horizontal axis shows the flight time, and the vertical axis shows the measured RSRP, while different colors are used to illustrate the signal from the different cells. In the first 195m of its ascending, the UAV cannot detect any of the aforementioned BSs, hence it has no 4G service. Only when it reaches the altitude of 195 m it starts detecting LTE cells and from this altitude and up to the maximum one (335m) the UE detects 15 different cells (their location can be found in Figure 3). The RSRP of each cell changes during the UAV vertical flight, depending on the position of the BS (i.e. distance and altitude), its 3D antenna radiation pattern and the area landscape.

An important observation for the dominant cells is the sudden increase of their RSRP a few meters after their detection point, due to the first Fresnel zone clearance. After this point, the RSRP presents only some minor fluctuations, due to multipath and the antenna side-lobes of the ground BS (they appear almost symmetrical during the ascending and descending of the UAV). These fluctuations are however not severe, since due to the relatively long distance between the BS and the UAV, the angle of the direct line between them barely changes. Thus, the most critical factor for achieving a good signal strength in the sky is the clearance of the first Fresnel zone and flying at higher altitudes does not significantly improve the received RSRP.

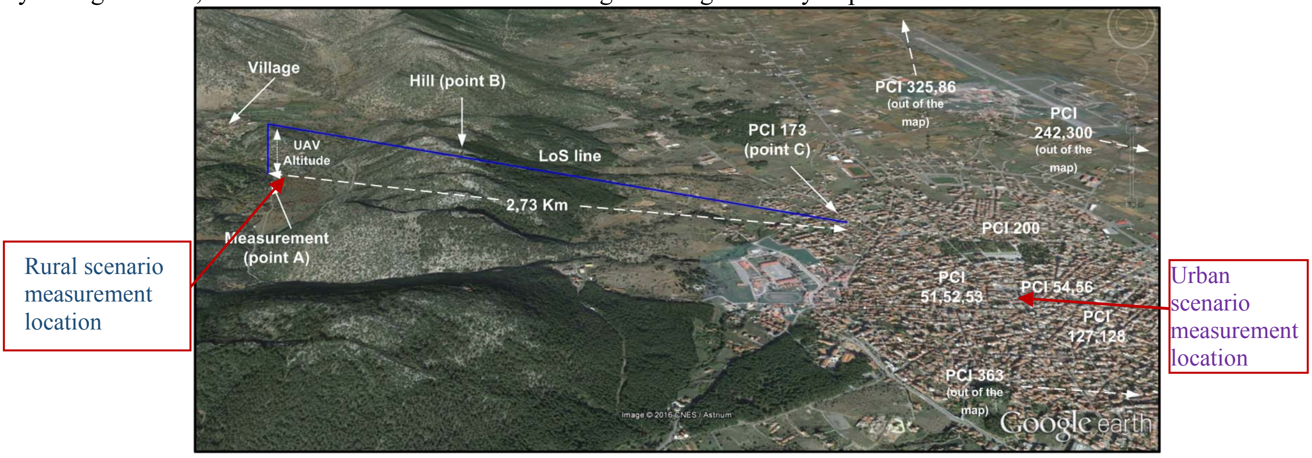

Figure 3: Landscape of the remote area.

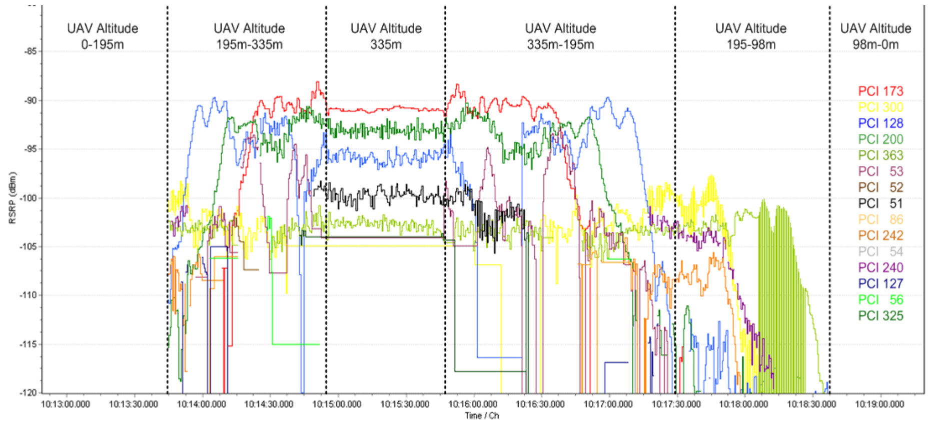

Figure 4: RSRP of the detected cells during the UAV flight

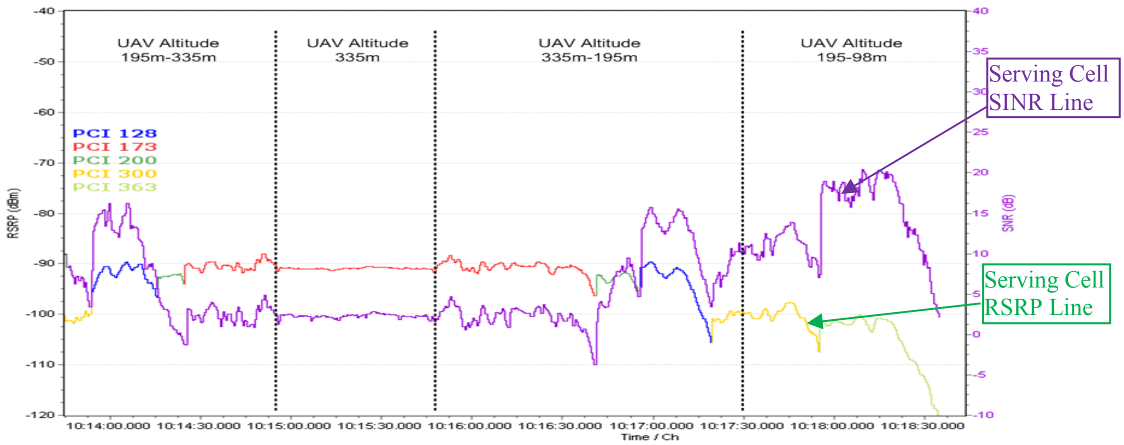

Figure 5: SINR and RSRP of the serving cell.

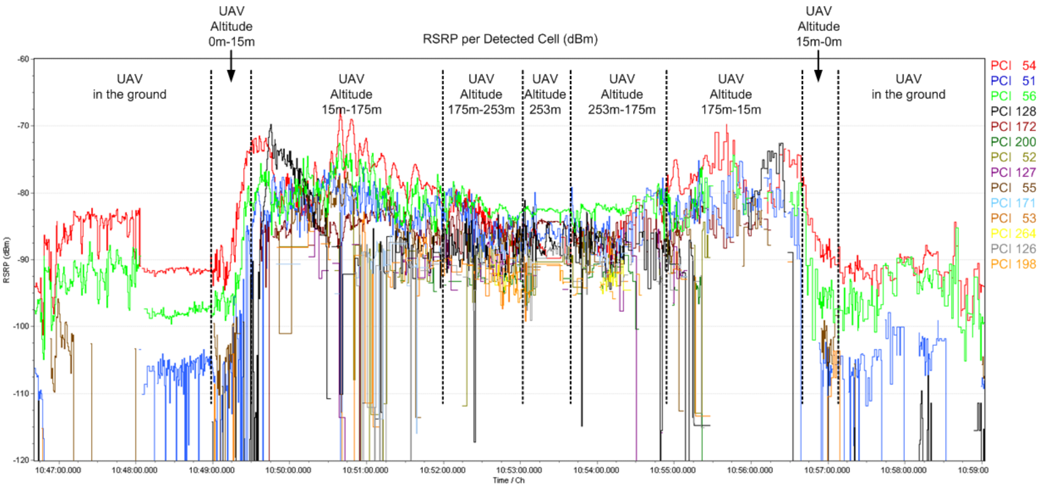

Figure 6: RSRP of the detected cells during the flight

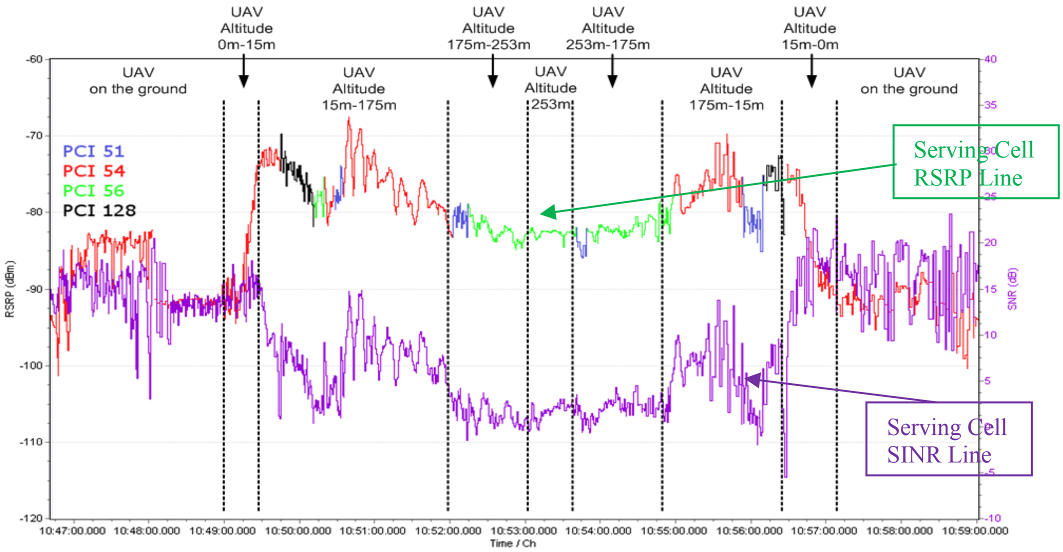

Figure 7: SINR and RSRP of the serving cell.

However, the power of the detected cell is not always the appropriate criterion for service quality. Figure 5 shows the measured SINR and the RSRP of the serving cell during the flight. The UAV makes 7 handovers to different cells, as the signal strength changes. The RSRP line is colored according to the cell that serves the UAV. It is obvious that although the RSRP increases (or stays stable), above the 195m height the SINR decreases. This is mainly due to the stronger interference level that the ascending UAV experiences from the neighboring cells. As the UAV ascends, the difference in the received power between the server and strongest interferer decreases (Figure 4) causing the SINR to drop. When the UAV descends the same behavior is observed until the height of 195m. Below this point, the RSRP drops since the distance from the serving BSs (PCI 300 and 363) increases; those PCIs are outside the town area (see Figure 3). However, the SINR experiences a significant increase around the height of 150m and till the 120m, since the total interference reduces drastically (Figure 4).

It is obvious that in this scenario, flying to higher altitudes is not an optimal solution for achieving high SINR and good QoS. High SINR values (above 15 dB) are observed only at certain altitudes (around 135 m and 220 m), while SINR drops below 5 dB at altitudes more than 220 m. So, not only the received cell power, but also the interference levels must be considered for deriving the optimum location for flying relay services.

B. 2^{nd} *Measurement: Urban Area*

This measurement took place at an open spot, surrounded by tall buildings, almost in the center of the town. The location can be seen on the right side of the map in Figure 3. For this measurement the quadcopter climbed vertically to a maximum height of 253m.

Figure 6 shows the RSRP of the detected cells during the flight. During the first meters of the UAV ascending, the RSRP of the detected cells increases dramatically and new cells are detected, mainly after 15m of altitude. This is due to the UAV flying over the top of the buildings that have an average height of 15m, achieving LoS connection with more BSs.

During the UAV flight from 15m to 120m height, the RSRP of the detected cells fluctuates severely. The elevation angle between the UAV and the ground BSs changes fast during these first meters, hence the multipath as well as the rapidly changing BS antenna gain towards the UAV affects the measured RSRP. Note that at these heights the signal at the UAV is from the side lobes of the BS antenna.

Figure 7 shows the SINR and the RSRP of the serving cell. The RSRP line is colored according to the serving cell ID. In the first 15m of the UAV flight, although the RSRP increases significantly, the SINR changes only slightly. Above the 15m height, the SINR decreases up to 12 dB due to a combination of the serving cell strength fluctuation and the increase of the interference from the extra cells that the mobile can detect above the surrounding buildings.

It is clear that flying above buildings in an urban scenario does not necessarily improve the signal quality, which is clearly optimized for ground users. However, at higher altitudes the UAV can detect more cells. Figure 8 shows the number of detected cells as the UAV changes altitude, as well as the number of cells with RSRP above and below a threshold of 5dB from the serving cell. It shows that flying at higher altitudes (e.g. 75m, 175m or 225m) the UAV detects more strong cells, thus having additional handover options leading to macrodiversity gain.

IV. CONCLUSIONS AND CHALLENGES

Flying relays open the way for ubiquitous wireless coverage, especially to remote underserved or urban busy areas for emergency and/or on demand services. In this context, measurements for two real world operational scenarios were presented and analyzed here.

The *remote area* scenario revealed that a UAV achieves connectivity with ground LTE BSs when it flies above the height that clears the first Fresnel zone of the direct link. At this altitude the UAV could act as a relay enabling network connectivity to ground users. Additionally, the measurements showed that the received RSRP does not significantly improve after the first Fresnel zone clearance, and so the UAV does not need to fly very high. However, the SINR is maximized at certain altitudes, depending on the neighboring interference and the BS distance, so the optimum position of the UAV must be derived for improving the SINR.

The measurements in the *urban area* showed that the RSRP of the serving and detected cells increases when the UAV flies above town buildings, however multipath and the proximity to the BSs antenna causes severe signal strength fluctuations . The SINR suffers an important degradation (up to 12 dB) when the UAV ascends to higher altitudes, because of strong interference from other BSs. On the other hand, more strong cells are detected, enabling the UAV to connect with them acting as an alternative gateway in an overloaded network.

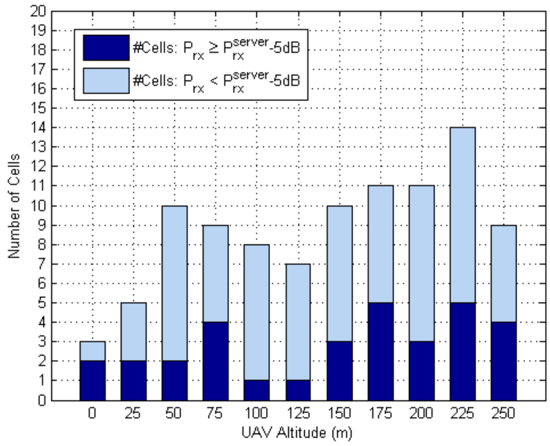

Figure 8: Number of detected cells vs UAV altitude.

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