Public LTE Network Measurements with Drones in Rural Environment

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***Abstract*—This paper presents long term evolution (LTE) uplink measurements taken with two drones operating in a public cellular network in rural environment. Three similar measurement scenarios with drone flight altitudes of 50 m and 100 m above ground level are studied with different measurement software and equipment. Four different key performance indicators (KPIs) are presented in the paper: Physical Resource Block (PRB) usage, Modulation and Coding Scheme (MCS) class, throughput and transmission power. These together help to analyse the overall interference behaviour, which is an essential part of the paper. The results show that aerial UEs add minor interference to the network, which decrease the MCS class of the ground level UEs and slightly increase their transmission power. The resulting data rates are roughly the same as them operating in the same cell because of increased PRB amount per user equipment (UE). This effect is similar to that of a ground level UE switching cell in the cell edge area to another cell. In addition, ground level cell edge area UE performs slightly poorer in comparison with a UE near the serving cell antenna when drones are utilized. Nevertheless, two drones operating in the air with smart phones connected to them do not have a critical effect on the performance of the normal ground level UEs from the throughput point of view, but slightly increase the resource utilization.**

***Index Terms*—Drone, UAV, KPI, LTE, Interference, Cellular Network, Measurements**

I. Introduction

Drones, or unmanned aerial vehicles (UAVs), are quickly becoming a new business area with current forecasts indicating a market potential worth $100 billion in the following few years [1]. The use cases for drones are vast and new ones are emerging constantly. Currently, drones are utilized at least in the following categories: inspection and surveys, transport and logistics, surveillance and monitoring, communications and media [2] without forgetting development and research utilization. Furthermore, one of the most important use cases for drones is related to a disaster response, enabling fast relaying of real-time information from the disaster area [3]. The conventional scheme for utilizing the drones has been mostly by having local, line-of-sight (LOS) connection between the drone and the drone operator. This also means that the communication link utilized for the drone control is local, usually Wi-Fi based technology utilizing unlicensed frequency bands. This limits the operation of drones to those areas, where the drone can be operated locally.

The current trend is to move towards from manually controlled local visual line-of-sight (VLOS) missions to automatic beyond visual line-of-site (BVLOS) and extended visual line-of-sight (EVLOS) missions. Either manually controlled or fully automatically operating drone, these operations require good communications capabilities and more specifically wide-area network coverage instead of local connections in the vicinity of the drone pilot, which are not sufficient. A good option for this purpose is the utilization of cellular networks.

Existing cellular networks can offer this connectivity as discussed in a 3rd generation partnership project (3GPP) work item for aerial vehicles operating on long-term evolution (LTE) networks as a part of LTE Release 15 [4] and [5]. A closer look of this study was presented in [6] and [7], where the challenges regarding co-channel interference detection and mitigation were discussed. When a drone takes off the ground, the signal characteristics change and it may potentially cause more interference than a terrestrial UE as the signal is reaching also more easily the neighbouring cells [8] and [9].

One of the reasons for this behaviour is the difference in the characteristics of radio channels between the terrestrial and aerial use cases. In the aerial radio channel, the likelihood of having a line-of-sight (LOS) propagation for the radio signals is higher than those of terrestrial radio channels [10]. When the likelihood of LOS propagation increases with the height of the drone, the propagation losses for aerial UEs are closer to that of the free space loss. In addition, flying UEs outside of the nearby antenna main lobe attach to cells further way and increase uplink (UL) interference in the nearby cells when UEs are not connected to the closest antennas. Some studies exist on trying to model the propagation for aerial UEs [11] taking also into account the height [12] or the angle [13] of the UE with respect to ground level or base station antenna, but these are out of the scope of this paper.

This paper presents measurements performed with airborne UEs (smart phones attached to drones) and their impact on the ground level UEs through increased interference in the UL channels. Therefore, a special attention is given towards interference related parameters, where the focus is in the changes in modulation and coding scheme (MCS) as well as in the change of the number of physical resource blocks (PRBs) the UEs have been scheduled. These parameters define the available data rate in the uplink in the end, which is also studied together with the uplink transmission power. The results are compared with that of a normal ground level utilization of the network under normal public cellular network traffic conditions.

II. Drones and Cellular Radio Connectivity

A fundamental difference with utilizing cellular networks for drone operations is that they are designed for ground level usage. Therefore, it is expected that the UEs utilize the network on the ground level, not 50–150 m above it in the air. This particular problem has aroused a lot of interest in the field, for example trying to find out how well these cellular networks could support UAV communications [14]. There are some studies about the mobility issues related to utilizing mobile networks with drones and some concerned with the change in the propagation characteristics addressing connections in the air, and even some suggestions to enhance the UAV connectivity. Furthermore, the coexistence of terrestrial and aerial UEs operating in the same cellular network has been studied in [15] with simulations. However, the impact of airborne UEs, that is phones attached to drones, to ground level UEs has not been studied enough in the research field in terms of practical measurements.

The mobility issues related to the airborne utilization of cellular networks have been studied in [16]. According to this study, the current existing terrestrial LTE networks are able to offer good mobility support for UAVs, at least for a small number of them. The paper highlights two challenges when concerning larger densities of drones. The first one relates to handover procedures when flying through base station antenna sidelobe nulls. It is shown that the current procedure might be too slow for this fast change and radio link failure can happen before the actual handover process can be finalized. The second problem relates to the huge amount of cells available at higher altitude above ground level, which can result in difficulties establishing and maintaining a connection to the network. This will also cause new requirements for radio network optimization and dimensioning.

Propagation characteristics of connections from base stations to aerial UEs have been studied in [17]. The study concludes that current LTE networks might not be used effectively with airborne UEs and does require modifications to the system to enable a smooth integration of LTE-enabled UAVs. This is based on the potential interference problems with strong LOS components between the flying UEs and ground level UEs through UL channel interference.

The authors in [10] suggest several enhancements to the current UAV connectivity. These are the mitigation of interference, aerial UE identification, and mobility enhancements. The interference mitigation could be addressed with multipoint coordination, new (uplink) power control schemes, dedicated cells or partitioning radio resources separately for aerial and terrestrial usage. By identifying aerial UEs from the ground level UEs, they can be separated from the normal network functionality and more optimized network parameters can be addressed to them. This can help in reducing the interference those UEs are causing to the ground level UEs as well as help with the mobility issues. It is pointed out in [10] that mobility enhancement requires more studies on cell selection, handover efficiency and robustness. Finally, the identification of aerial UE is suggested as a means to improve the current situation.

From the drone operations point of view the most essential part to study is the interference the flying UEs are causing to the ground level UEs through increased UL channel interference. This paper focuses on analyzing the following KPIs in LTE network: the utilization of UL PRBs, the selection of UL MCS and the combination of these with UL throughput. Some attention is also given to the UL transmission (TX) power.

The amount of PRBs affects the achieved throughput, as it translates to more bandwidth for the transmission. The amount of PRBs scheduled for UE depends on scheduling algorithms as well as traffic load the network has at the cell the UE is utilizing. When more UEs are in the same cell, the average amount one UE can utilize decreases. However, in order to analyze the change in achievable data rates, one has to also take into account the utilized MCS class. When the channel conditions are good, high MCS class can be utilized and if the channel has poor conditions a lower MCS class is required.

III. Studied Scenarios

All the measurements in this study were performed in a normally operating Band 20 (800 MHz) public LTE cellular network to study the results in a public network. The studied scenarios include three similar automated flights performed in Jorvas, Finland, in a rural environment. Each measurement scenario had two commercial drones in the sky, at 50 m and 100 m altitude above ground level flying back and forth with a constant speed of 18 km/h, with phones (UE1 and UE2) attached to them. The drones were programmed to fly the same predetermined flight route automatically (with two different heights) in order to have repeatable scenarios. In addition to the aerial UEs, two phones (UE3 and UE4) were stationed on the ground level for the entire measurement (UE3 is located near the serving cell antenna and UE4 further away from it, closer to cell edge area). Figure 1 shows the aerial view of the measurement routes and Table I the essential information from the measurement scenarios. All four UEs were programmed to transfer as much data as possible in the uplink direction with file transfer protocol (FTP) (no limitations or restrictions for the data rate). This represents sending in example UL video stream with the highest possible quality the network is able to provide.

The measurements have been performed with several different equipment and software as listed in Table II. Both drones utilized in the measurements were commercial drones manufactured by DJI, with two models: Inspire2 and Phantom 4 Pro, which are shown in Figure 2. The phone equipment consisted of the following smart phones: two Samsung Galaxy S8, one Samsung Galaxy S5 and one Sony Xperia X Performance. Three different measurement software were utilized: Keysight Nemo Outdoor, Rohde & Schwarz QualiPoc and

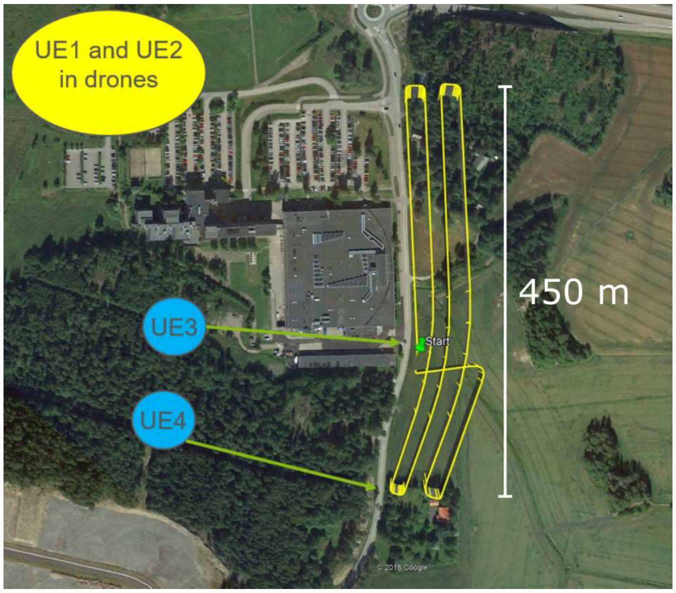


Fig. 1: Measurement route. Drones with UE1 and UE2 are following the yellow route with 50 m and 100m flying altitude above ground. UE3 and UE4 (filled blue circles) are fixed to two different locations. Map: Google Earth, Landsat / Copernicus.

TABLE I: The essential measurement parameters.

Parameter	Value
Environment	Rural
Number of drones	2
Drone flying speed	18 km/h
Flying altitudes	50 m and 100 m
Flight duration	9–10 min
Test UEs in the air	2
Test UEs on the ground	2
Network technology	LTE
Frequency band	Band 20 (800 MHz)
Bandwidth (maximum PRBs)	10 MHz (50 PRBs)
Operations mode	Full FTP transfer in UL (All UEs) (similar to full video stream)

InfoVista TEMS. Although different measurement software were utilized, it does not affect the reliability of the results as each software and equipment is measuring the same KPIs which are based on 3GPP specifications. Therefore, only the representation of the results differs a bit from one software to another. The combinations of different configurations per each test (scenario) is presented in Table III.

A comparison with only ground level UEs was also studied with a ground scenario. This involved two ground level UEs (UE3 and UE4) positioned such that UE3 was fixed near the serving cell antenna and UE4 was taken closer to the cell edge area. Then it was studied how the performance of UE3 and UE4 changes when UE4 switched to another cell and back to the same cell as UE3 in order to analyze the reference case when no aerial UE was in the air. This was performed with

Fig. 2: Measurement drones. Inspire2 on the left and Phantom 4 Pro on the right.

TABLE II: Measurement equipment and software.

Drones	DJI Inspire 2 (Insp2) DJI Phantom 4 Pro (P4P)
Phones	1 × Samsung Galaxy S5 (S5) 2 × Samsung Galaxy S8 (S8) 1 × Sony Xperia X Performance (Sony)
Measurement software	Keysight Nemo Outdoor (NEMO) Rohde & Schwarz QualiPoc (QPOC) InfoVista TEMS (TEMS)

TABLE III: Different configurations for each measurement.

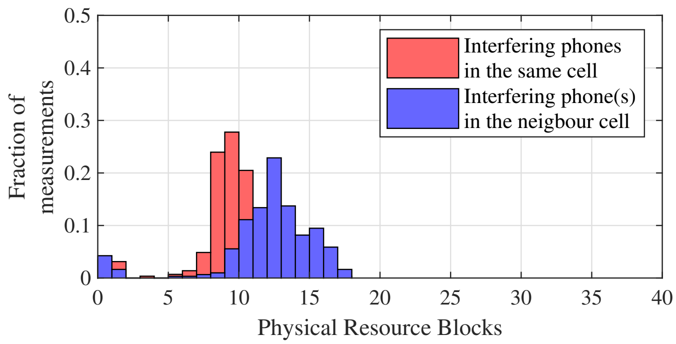
	scenario 1	**scenario 2**	**scenario 3**
UE1 (50 m)	Sony (TEMS)	S8 (QPOC)	Sony (TEMS)
UE2 (100 m)	S8 (QPOC)	Sony (TEMS)	S8 (NEMO)
UE3	S5 (NEMO)	S5 (NEMO)	S5 (NEMO)
UE4	S8 (NEMO)	S8 (NEMO)	S8 (QPOC)
Drone1 (50 m)	P4P	Insp2	P4P
Drone2 (100 m)	Insp2	P4P	Insp2

only two phones (in addition to UEs not part of the test setup).

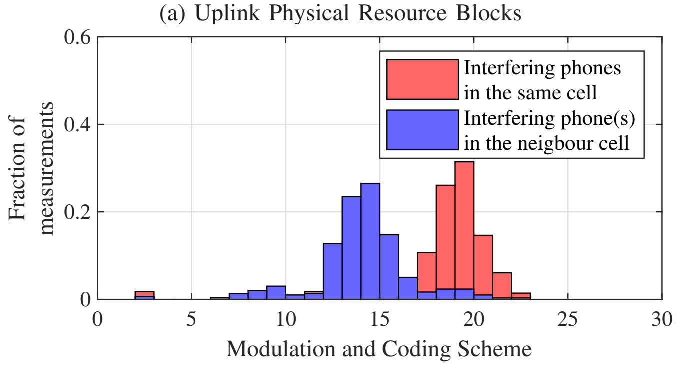
IV. Measurement Results and Analysis

The measurement results are representing the collected KPI values selected from the time window starting from the point when the first drone lifts to the air and ending to the moment when the last drone lands. The results are grouped into two categories: those times when all (all UEs part of the test setup, both terrestrial and aerial UEs) are in the same cell, and those times when at least the other aerial UE is at another cell (referred as the interference case). Visualization of the differences of having the aerial UEs in the same cell or in the neighbouring cell can be seen from Fig. 3. It shows scenario 1 UE3 measurement data, that is the ground level UE near the antenna. It can be noted that the resulting data rates are roughly the same in both cases. However, this comes with a cost at the PRB utilization rate. The similar data rate is achieved in the interference case with a higher amount of PRBs to compensate the lower UL MCS class values.

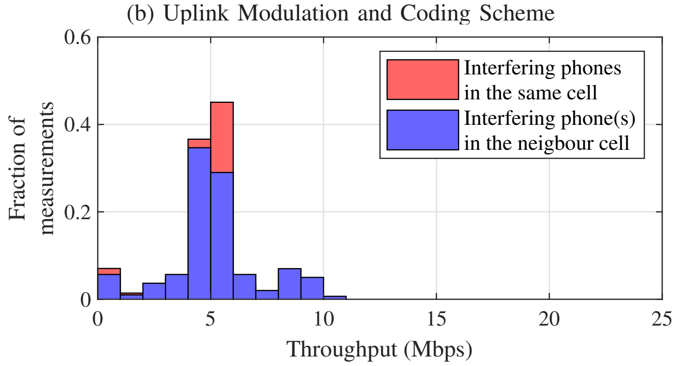
A summary of the KPIs of interest is presented in Table IV for UE3 (near the serving cell antenna) and Table V for



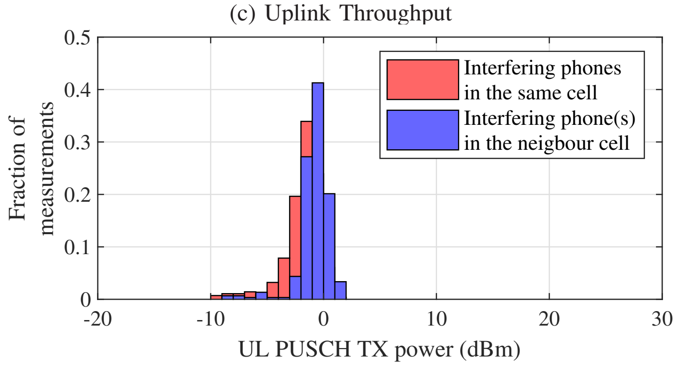
(a) Uplink Physical Resource Blocks



(b) Uplink Modulation and Coding Scheme



(c) Uplink Throughput



(d) Uplink TX power

Fig. 3: Example from scenario 1 UE3 data. Histograms of the normalized fractions of measurement data are shown for UL PRBs, UL MCS, UL throughput and UL TX power in a) to d).

UE4 (further away from the serving antenna). The values for UE4 scenario 3 were not available for UL PRBs and UL MCS, because the measurement software (QPOC) was missing that information, however the values for UL data rate were available.

Table IV and Table V show that the amount of physical resource blocks increases on average between 30% to 52% when the aerial UEs move from the same cell to the neighbouring cell. At the same time, the MCS class decreases on average between 3.7 to 5.0 classes. The transmission power shows an increase of 1.0 dB to 3.4 dB between cases where the flying UEs are in the same cell as the ground level UEs and where they are connected to the neighbour cell. Furthermore, the UE closer to the cell edge area (UE4) is affected more than the UE closer to the antenna (UE3). This can be seem most clearly from the UL TX power behaviour as the UE closer to the antenna needed 1.0 dB to 1.1 dB higher TX power in the interference case, where as UE closer to the cell edge needed already 1.7 dB to 3.4 dB higher transmission power.

The reference case results (ground scenario), where only ground level UEs (UE3 and UE4) were utilized, are shown in Table VI. It shows how the ground level network utilization look like when a cell switch occurs under normal network traffic conditions. This shows that as the other UE switches

TABLE IV: Average values of the UE3 results for different scenarios. (S) indicates that aerial UEs are in the same cell and (I) that at least the other aerial UE is in a neighbour cell.

KPIs of interest	**scenario 1**		**scenario 2**		**scenario 3**	
UE3	(S)	(I)	(S)	(I)	(S)	(I)
UL PRBs	9.1	12.0	8.9	11.6	10.2	13.6
UL MCS class	18.5	14.1	18.0	14.3	18.4	14.0
UL data rate (Mbps)	4.6	5.1	4.1	4.4	5.0	6.1
UL TX power (dBm)	-1.9	-0.9	-2.1	-1.0	-2.4	-1.3

TABLE V: Average values of the UE4 results for different scenarios. (S) indicates that aerial UEs are in the same cell and (I) that at least the other aerial UE is in a neighbour cell.

KPIs of interest	**scenario 1**		**scenario 2**		**scenario 3**	
UE4	(S)	(I)	(S)	(I)	(S)	(I)
UL PRBs	8.1	12.3	7.7	11.5	-	-
UL MCS class	19.1	14.6	18.9	13.9	-	-
UL data rate (Mbps)	3.6	3.6	3.5	2.7	3.2	3.8
UL TX power (dBm)	6.7	8.7	5.3	7.0	7.9	11.3

TABLE VI: Average values of the ground level reference case (ground scenario) results for UE3 and UE4. (A) indicates that the phones are in the same cell and (B) that UE4 is in a neighbour cell.

KPIs of interest	**UE3**		**UE4**	
	(A)	(B)	(A)	(B)
UL PRBs	15.9	23.1	20.4	38.5
UL MCS class	20.4	14.9	20.2	18.0
UL data rate (Mbps)	9.1	9.4	8.7	16.7
UL TX power (dBm)	0.1	3.1	8.7	20.3

cell, the amount of PRBs increases for both phones and at the same time the MCS class decreases for them and the data rates in the uplink direction increases. The UL TX power difference is notably higher for UE4 in the ground level case (from 8.7 dBm to 20.3 dBm) when it switches the cell indicating that the other cell is located further away than the previous cell. The ground scenario utilizes two UEs instead of four UEs in the drone scenarios and therefore the values are notably higher in that case. It should be remembered that all of these results have been achieved in a normal public LTE network where also other commercial UEs utilize the network simultaneously with an unknown number of UEs.

V. Conclusion

The measurements performed in this paper include two aerial UEs and two ground level UEs operating in a public cellular network in a rural area. A measurement campaign was performed to study the impact of aerial UEs interference with the ground level UEs. The interfering aerial UEs reduced the MCS class of the ground level UEs, but the resulting uplink data rate was roughly the same. This is seen from having more physical resource blocks allocated to the UE and increasing the output power when aerial UEs move from the same cell as the ground level UEs to the neighbouring cells. Therefore, from purely UL throughput point-of-view, having two drones operate in the air with smart phones connected to them do not have critical effect in the performance of the normal ground level UEs. However, this come with the cost of increased resource utilization and output power. Moreover, it was observed that the UE closer to the cell edge area is affected more by the interference from the drones than the UE closer to the serving cell antenna. It should be noted that all of the measurements were performed in a public LTE network that can affect the achieved results and analysis as other UEs could also use the same network without restrictions. This, on the other hand, provides more insight how in practise these drones are affecting the normal network utilization.

VI. Future Work

Multiple drones flying would be good to be conducted in order to see how many simultaneously active flying UEs can be served by the network. Therefore, the next step is to perform measurements with several drones operating in a public cellular network. As the business potential is larger in the urban areas with higher amount of potential customers and shorter distances, the next phase is targeting urban environment. Another part to consider in the future studies is the inclusion of network side data, that is the data collected from the radio network elements, in order to study these aspects from that side as well.

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