Drone Interference Mitigation Trial Report

Final 1.0

19 November 2018

Group Technology Networks CoE

Eric Murray

Contents

1 Introduction

Drones are beginning to be used by enterprises to support their operations. For example, drones are used for tower inspection, surveillance and, to a limited extent, deliveries (e.g. medical supplies [7] and pizzas [8]). Such enterprise use cases can be enhanced if the drone is connected to the cellular network, allowing Beyond Visual Line of Sight (BVLOS) flying – essential for use cases such as linear asset inspection (pipelines, power lines, etc.) and long-distance logistics – uploading of payload data (video, etc.) to cloud servers, and general drone condition monitoring.

Hence it can be expected that many enterprise drones will be equipped with cellular modems and be cellular connected. In addition, regulators are currently discussing and, to a limited extent, trialling the concept of UAS Traffic Management (UTM) (e.g. U-Space in Europe [4] and NASA UTM in the United States [5]), which is essentially air traffic control for drones. Drones would be required to identify themselves to the UTM and have a flight plan approved before they would be allowed to fly. Such proposals are only likely to be feasible if drones are connected to the UTM system by cellular, which would imply a large percentage of drones being equipped with cellular modems. Although the traffic volumes required by the UTM system itself will be small, the drone operator is likely to use the modem for other higher-bandwidth services if the drone anyway needs to be equipped with one.

Whilst the absolute number of cellular connected drones will always be only a tiny percentage of the total number of cellular-connected devices, drones have the potential to create significantly more interference into neighbouring cell sites than a typical device (see Section 2.1 below for an explanation of this). Consequently, cellular operators, network equipment vendors and 3GPP themselves [6] have been investigating how such excess interference can be mitigated.

Many of the approaches being discussed require modifications to the UE itself, either in the standard to which it complies or the way in which it is implemented and integrated into the drone. However, one approach being proposed is compatible with existing LTE modems, and that is to modify the way in which the uplink power control operates within the serving eNB itself. If the eNB can identify that the connected UE is mounted on a drone, then it can make proprietary modifications to the operation of uplink power control that nevertheless remain compatible with existing signalling.

Ericsson have implemented such a mechanism as part of their Advanced Subscriber Group Handling (ASGH) feature. The fact that the UE is mounted on a drone is identified to the eNB by assigning a specific Subscriber Profile ID (SPID) to SIMs intended for use in drones. To avoid a complex SIM management issue, this implies that the SIMs are either embedded in the drones (i.e. eSIM), or are issued to the drone operator as part of an enterprise contract. However, in the absence of alternative mitigations, use of this feature may have some value for connected drones using current LTE modem designs.

This document describes a trial undertaken by Vodafone Group, Vodafone Ireland and Ericsson Ireland to demonstrate operation of the feature for a drone use case. As part of the trial, the uplink interference at neighbouring cell sites was monitored to observe any reduction that could be attributed to use of the ASGH feature.

2 Background and Proposed Mitigations

2.1 The Drone Interference Issue

Whilst in flight, drones can typically be expected to fly up to 120 metres above ground level, and at a reasonable height above buildings and other obstacles on the ground. One consequence of this is that the propagation path to surrounding cell sites that would be experienced by a UE mounted on the drone would typically improve compared to a UE on the ground as there is no clutter in the way. Whilst antenna gains may reduce, given that cellular base-station antennas are typically down-tilted, the net effect is usually an increase in received signal level. This has been demonstrated in several trials (see, for example, [1] & [2]).

Whilst the signal level to the serving cell may improve, the interference levels to neighbouring sites will also increase, as the propagation path to these also improves. In fact, given that the antenna incidence angle of the propagation path at neighbouring sites will be shallower than the angle at the serving site (assuming this is closer to the drone), then propagation to neighbouring sites can be expected to improve at a faster rate than for the serving cell as the drone gains height.

This improved propagation to neighbouring cells sites results in increased interference; on the downlink affecting the drone UE itself but, on the uplink, affecting all users connected to the neighbouring cells. Again, this effect has been demonstrated in trials (e.g. [1] and [3]). As the dominant link for drone traffic is expected to be the uplink (e.g. video streaming or other sensor data upload), drone-based UEs have the potential to degrade uplink QoS for other users in the area where the drone is operating.

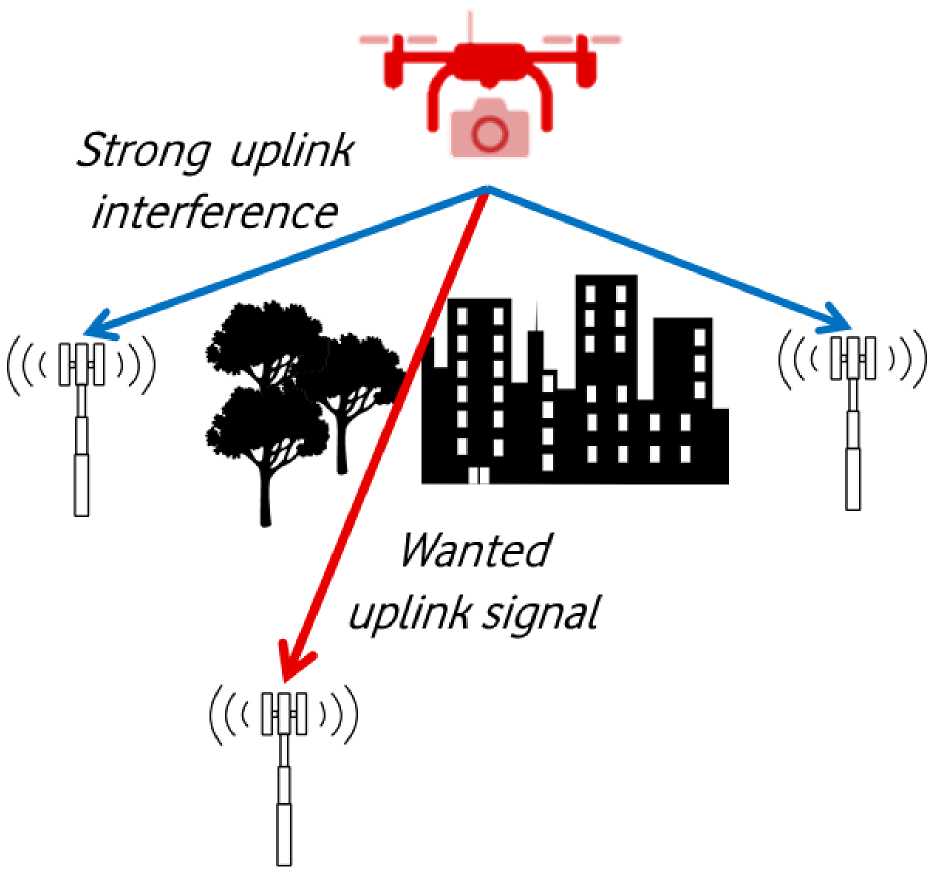

Figure 1: The Drone Uplink Interference Problem

2.2 Proposed Mitigations

A number of techniques have been proposed to mitigate this additional uplink interference.

2.2.1 Ericsson Advanced Subscriber Group Handling (ASGH) Feature

The ASGH feature from Ericsson allows an eNB supporting the feature to modify its Radio Resource Management (RRM) functions for subscribers (i.e. UEs) identified as belonging to a defined subscriber group. It has feature number FAJ 121 4767 and is supported from L18Q2 onwards.

Subscriber groups are defined by specified combination of the following subscription and bearer parameters:

SIM (Subscription) Parameters

- SPID (Subscriber Profile ID)

Bearer Parameters

- QCI (QoS Class Identifier)
- ARP (Allocation and Retention Priority)

Wild cards are allowed and, for this trial, the subscriber group was defined solely by a specific SPID value (in this case, 100) valid for all bearers irrespective of QCI and ARP. Only the default bearer was tested. The SPID is defined in the HSS, and signalled to the eNB by the MME within the INITIAL CONTEXT SETUP REQUEST message. During handover, it can also be signalled to the target eNB via the X2 interface.

Once a member of a defined subscriber group is connected and has been identified, the eNB then modifies the specified RRM parameters only for that UE. The modified parameter set can be eNB specific, with different eNBs treating the subscriber group differently. As currently defined, the ASGH feature allows the following parameters to be modified:

Attribute name	Description	Default value and range
pZeroNominalPuschOffset	Defines an offset in units of 1dB to pZeroNominalPusch as defined in EUtranCellFDD/TDD.	Default: 0 Range: {-10..20}
pZeroNominalPucchOffset	Defines an offset in units of 1dB to pZeroNominalPucch as defined in EUtranCellFDD/TDD.	Default: 0 Range: {-10..20}
qciOffsetForQCI6	Defines QCI6 bearer offset, allowing the QCI to be mapped to an operator defined QCI.	Default: 0 Range: {0, 4..250}
qciOffsetForQCI7	Defines QCI6 bearer offset, allowing the QCI to be mapped to an operator defined QCI.	Default: 0 Range: {0, 3..249}
qciOffsetForQCI8	Defines QCI6 bearer offset, allowing the QCI to be mapped to an operator defined QCI.	Default: 0 Range: {0, 2..248}
qciOffsetForQCI9	Defines QCI6 bearer offset, allowing the QCI to be mapped to an operator defined QCI.	Default: 0 Range: {0..247}

Table 1 : RRM Parameters Modifiable by ASGH

It can be seen that ASGH can modify both the priority and uplink transmit power for a defined subscriber class. As the trial was looking to use the ASGH feature to reduce uplink interference, only the pZeroNominalPuschOffset and pZeroNominalPucchOffset parameters were modified, with other parameters being left at their default values.

The idea is that, because the propagation from the drone UE to the serving eNB is likely to be better than that expected from a normal UE (at ground level), the default value for these parameters will result in the drone using too much interference power. Hence negative offsets can be applied to reduce the drone transmit power. This may, of course, reduce the QoS experienced by the drone, and hence there is a balance to be struck between drone QoS and uplink interference to other users.

For reasons that must be considered proprietary to Ericsson, the modifications are applied by the eNB indirectly via the TPC bits, and not via the dedicated p0-NominalPUSCH and p0-NominalPUCSCH values signalled directly to the UE via RRC signalling. Hence operation of the feature can only be verified by actually measuring the uplink transmit power.

2.2.2 Other Mitigations

Other uplink interference mitigation techniques have been considered for drones, but were not tested as part of this trial. They are mentioned here for completeness and to emphasise that other solutions are being considered but have not yet been tested.

Other mitigation being considered include:

- Directional beam-steering or switched-beam antennas on the drone
- Interference cancellation (at the eNB for uplink interference mitigation; at the drone for downlink interference mitigation)
- MaMIMO, benefiting from the vertical separation between drones and other users, and the ability of MaMIMO antennas use beamforming
- A separate frequency layer for drones
- Intercell Interference Coordination (ICIC) between cells supporting drones and neighbouring cells

Many of these proposals benefit from mitigating both uplink and downlink interference, but have their own advantages and disadvantages. Key advantages of the ASGH feature are that:

- It works for 4G and is compliant with 3GPP standards for 4G
- It does not require any modification at all to existing 4G UE designs
- It only requires software modifications to the eNB

3 Trial Description

3.1 Location

The trial was conducted in Ireland with the support of both Vodafone Ireland and Ericsson Ireland. The brief was to find a cluster of L800 cells with an intersite spacing around 5 to 10 km within which a location could be found from which to fly the drone. A cluster of 6 sites (18 cells) to the north-west of Dublin was identified.

Figure 2: Map of Trial Area

For reasons that will become clear, a tethered drone was used for the testing requiring use of a petrol generator and tethering unit on the ground. Given the requirements for vehicle access (to carry the equipment) and possible negative impact of the testing on the local population due to noise and possible privacy concerns, it was decided to fly the drone close to site MH013 where the access conditions were known, the landlord agreeable and the local population limited.

The following cells were thus involved in the trial. The cells from each site pointing most directly to the test location are highlighted in yellow in Table 2 above.

Site ID	Site Name	Longitude	Latitude	Cell	Azimuth	Distance to Test Location (m)	Relative Sector Angle to Test Location (°)
MH013	Loughanstown	-7.02713	53.62911	MH013L1	120	50	12
				MH013L2	223		-91
				MH013L3	360		132

Site ID	Site Name	Longitude	Latitude	Cell	Azimuth	Distance to Test Location (m)	Relative Sector Angle to Test Location (°)
MH033	Athboy	-6.91578	53.63639	MH033L1	90	7350	173
				MH033L2	180		83
				MH033L3	300		-37
MH055	Moymet Trim	-6.83873	53.58655	MH055L1	35	13260	76
				MH055L2	150		141
				MH055L3	295		-4
MH094	Ballivor	-6.99943	53.54244	MH094L1	15	9750	-25
				MH094L2	115		-125
				MH094L3	245		105
MHCSK	Crossakeel	-7.01509	53.71608	MHCSKL1	60	9770	124
				MHCSKL2	160		24
				MHCSKL3	270		-86
WH011	Delvin	-7.09735	53.6177	WH011L1	95	4890	-20
				WH011L2	190		-115
				WH011L3	310		125

Table 2 : Cells Involved in the Trial

3.2 Trial Architecture

The live L800 (LTE on Band 20) network was used for the trial, with the following pre-requisites:

- The RAN had to be upgraded to L18Q2 (which was anyway planned)
- Feature FAJ 121 4767 (ASGH) had to be enabled for site MH013
- Feature FAJ 121 4157 (Uplink Interference Reporting) had to be enabled for all sites in the above cluster
- A SPID value of 100 had to be associated with the test SIM be capable of being signalled to the serving eNB via the MME

The ASGH feature was dynamically configured via O&M as each test case was executed. No additional modifications were required to the network.

3.3 Test Devices

The following test devices were used for the trial.

3.3.1 Drone

Vodafone Group Technology provided a DJI S900 drone and Elistair tethering system for the trial, capable of extended flying times at heights between around 45 metres and 75 metres AGL. Power for the drone is provided from a petrol generator via a tethering link.

Picture of the set-up is shown below

Figure 3: DJI S900 and Elistair Tethering System

Figure 4: DJI S900 and Elistair Tethering System

The test UE was carried in a plastic pouch zip-tied to the underside of the drone.

3.3.2 Test UE

A Sony Xperia smartphone equipped with XCAL software was used for the trial. XCAL was configured to collect data continuously during the flight, resulting in very large data files (up to 10 GBytes per test case). Consequently, these files had to be sent and analysed after the test cases had been completed, and could not be uploaded in real-time. Use of XCAL was essential to allow measurement of the uplink transmit power of the test UE, along with other relevant radio parameters.

3.3.3 Test iPerf Server

A test sever in the UK was configured to act as an iPerf server and monitor uplink data throughput. This was used to confirm that the data throughput logged by the UE matched that actually uploaded to the server, verifying that data was really being transmitted.

3.4 Test Procedure

The test procedure involved configuring the ASGH feature for the defined test case and then flying the drone at the maximum possible height whilst carrying the test UE. A drone height of 75 metres was specified for the trial (the maximum that can be achieved by the tethering system) but weather conditions and power limitations reduced this to around 60 – 65 metres.

The uplink interference generated by the test UE was monitored at each cell in the cluster using the Ericsson Uplink Interference Reporting feature mentioned above. This feature accumulates the interference information for reporting via OSS counters with a resolution of 15 minutes. It was desired to generate interference over a minimum of two consecutive counter periods which means that, to avoid the need to time synchronise the drone tests with the counter periods, a minimum of 45 minutes flying time was therefore required per test case (ensuring that at least 30 minutes' test time would coincide with 2 complete counter reporting intervals).

Consequently, a flying time of 60 minutes was specified for each test, requiring the use of a tethered drone (as drones flying on batteries alone do not have this endurance). The uplink interference reporting feature was enabled before the trial began to allow the "background" level of interference to be established.

The test UE was configured to send data to the iPerf server at the maximum rate that could be supported by the bearer. Tests in the UK had shown that UDP traffic resulted in an increase in data throughput of approximately 15% compared to TCP, and hence this was originally specified as the test service to maximise data throughput. However, it was found that UDP traffic could not reach the iPerf server from the Vodafone Ireland network (possibly an MTU or port blocking issue) and the test UE XCAL log files could not be read by Accuver's XCAP analysis software (since resolved). Consequently, the test service was modified to TCP and the initial test case re-run.

The following test cases were defined. Only the test cases highlighted in yellow were fully executed and reported in this document.

Test Case	ASGH Parameter Values		Mobility	Comments
	pZeroNominalPuschOffset	pZeroNominalPucchOffset		
1 (Baseline)	0 dB	0 dB	No	Equivalent to using the default SPID
2	– 1 dB	– 1 dB	No	
3	– 2 dB	– 2 dB	No	
4	– 3 dB	– 3 dB	No	
5	– 5 dB	– 5 dB	No	
6	Any	Any	Yes (between site sectors)	To test SPID signalling during handover

Table 3 : Test Cases Defined for the Trial

Test case 6 was scrapped as it was impractical to reliably trigger a handover given the relative sector orientations relative to the tethering unit, and there was anyway no way to confirm from the test UE logs whether the ASGH feature would have been successfully triggered in the target cell following handover.

Test cases 2 and 3 were partially executed but needed to be re-run (due to corruption of the log files and the low height of the drone due to high winds during the initial test days), and it was also decided to abandon these given the results obtained for test cases 4 and 5.

3.5 Out of Scope

The following features were out of scope of the trial:

- Downlink performance and interference mitigation
- Interference mitigation techniques other than ASGH
- Drone heights above the maximum that could be achieved by the tethering system (in practice, around 65 metres)
- Drone locations far from the serving cell (e.g. at cell boundaries)

4 Trial Results

The following results were obtained during the trial.

4.1 Impact of ASGH on Drone QoS

The test service for the drone was continuous TCP data upload (using iPerf) at the maximum data rate that could be supported by the bearer. This was not known in advance, but turned out to be around 9,000 kb/s, which was unexpectedly low due to the low resource allocation (around 40% of the available resources). It is not clear whether this low resource allocation was a result of policy, or an indirect consequence of using an acknowledged transmission protocol. Such upload speeds would support HD video streaming (1080p, but not 4K video, which requires around 12,500 kb/s when compressed) or large file uploads. A number of other UE metrics were collected via XCAL.

The following parameters were measured for each test case:

Test Case	PUSCH / PUCCH p0 Offset (dB)	Average PUSCH Power (dBm)	Average PUCCH Power (dBm)	Average PUSCH MCS (max 28)	Average PUSCH PRB Number (out of 50)	Average Uplink Throughput (kb/s) (% of baseline)
1 (Baseline)	0	5.0	-24.4	23.8	19.8	9273.6
4	-3	-3.6	-34.4	23.7	18.9	9027.7 97.3 %
5	-5	-5.0	-35.7	23.7	19.1	9023.9 97.3 %

Table 4 : Test UE QoS Results

It can be seen that reducing the p0 offset does indeed reduce the average power used for the PUSCH and PUCCH with no corresponding decrease in achieved MCS (Modulation and Coding Scheme). The achieved throughput reduces slightly, but only because fewer PRBs (Physical Resource Blocks) were allocated for Test Cases 4 & 5, which is unlikely to have been a side effect of the ASGH feature. The total number of PRBs available for a 10 MHz bandwidth cell is 50, hence the UE was typically allocated only 40% of the available cell resources. This is likely the result of an allocation policy limiting the number of resources that can be given to any one UE.

These results show that a UE in good propagation conditions is transmitting more uplink power than required when using the default 3GPP parameters, and the ASGH feature can reduce this excess transmit power. The results do not tell us how much further the uplink transmit power could be reduced before the average MCS would start to reduce.

But if the drone was to move into worse propagation conditions (relative to the serving cell), then the power reduction would have an impact on the achievable MCS. So the conclusion is not that the ASGH feature can be used to reduce uplink transmit power with no consequence for the drone UE QoS, but rather that it can be used to balance the reduction in QoS with the reduction in interference. Ericsson simulations suggest the optimum p0 offset is around – 3 dB, but more extensive trials would be required to verify this.

4.2 Impact of ASGH on Uplink Interference

The primary objective of using the ASGH feature is to reduce the interference created by the drone UE into neighbouring cell sites. To verify this, it was necessary to monitor the uplink interference at the cells identified in Table 2. This was done by enabling Ericsson's Uplink Interference Reporting feature in each cell. This was enabled before the trial began, so that the "background" level of interference in the absence of any drone traffic could be measured.

The measured interference levels for each cell are shown in Table 5 below, where the cells pointing most directly towards the test location being highlighted in yellow, with cell MH013L1 being the dominant serving cell for the drone. The background levels were averaged over a 24-hour period one week before the trial date. The interference levels measured whilst each test case was executed are clearly only averaged over the one-hour duration of each test.

	Background Reference	Test Case 1 Baseline		Test Case 4 - 3dB Offset		Test Case 5 - 5dB Offset	
Site	Interference (dBm)	Interference (dBm)	Delta over Background (dB)	Interference (dBm)	Delta over Test Case 1 (dB)	Interference (dBm)	Delta over Test Case 4 (dB)
MH013L1	-119.1	-115.7	3.4	-119.2	-3.5	-116.8	2.5
MH013L2	-119.3	-109.7	9.6	-115.8	-6.1	-116.2	-0.4
MH013L3	-119.4	-107.1	12.4	-115.8	-8.7	-116.0	-0.2
MH033L1	-119.4	-119.2	0.2	-119.4	-0.2	-118.4	1.0
MH033L2	-119.1	-117.9	1.2	-117.3	0.7	-117.9	-0.6
MH033L3	-118.9	-117.3	1.6	-117.9	-0.6	-118.5	-0.7
MH055L1	-118.7	-119.3	-0.6	-119.1	0.2	-118.9	0.2
MH055L2	-117.8	-117.8	0.0	-118.4	-0.6	-117.9	0.5
MH055L3	-117.7	-117.2	0.5	-118.5	-1.3	-119.1	-0.6
MH094L1	-118.5	-115.8	2.7	-118.5	-2.7	-118.9	-0.4
MH094L2	-118.4	-118.5	-0.1	-117.8	0.7	-118.1	-0.3
MH094L3	-118.2	-118.0	0.2	-117.6	0.4	-117.9	-0.3
MHCSKL1	-118.6	-118.1	0.5	-118.4	-0.3	-117.9	0.4
MHCSKL2	-107.8	-113.4	-5.7	-116.4	-2.9	-113.2	3.2
MHCSKL3	-118.4	-119.1	-0.7	-119.4	-0.4	-119.0	0.4
WH011L1	-118.8	-118.9	-0.1	-119.1	-0.2	-119.2	-0.1
WH011L2	-119.0	-118.8	0.3	-119.2	-0.4	-119.1	0.0
WH011L3	-119.1	-119.7	-0.6	-119.7	0.0	-119.6	0.1

Table 5 : Measured Interference Levels

For those that prefer data to be charted, the reported interference levels are shown graphically below in Figure 5 below.

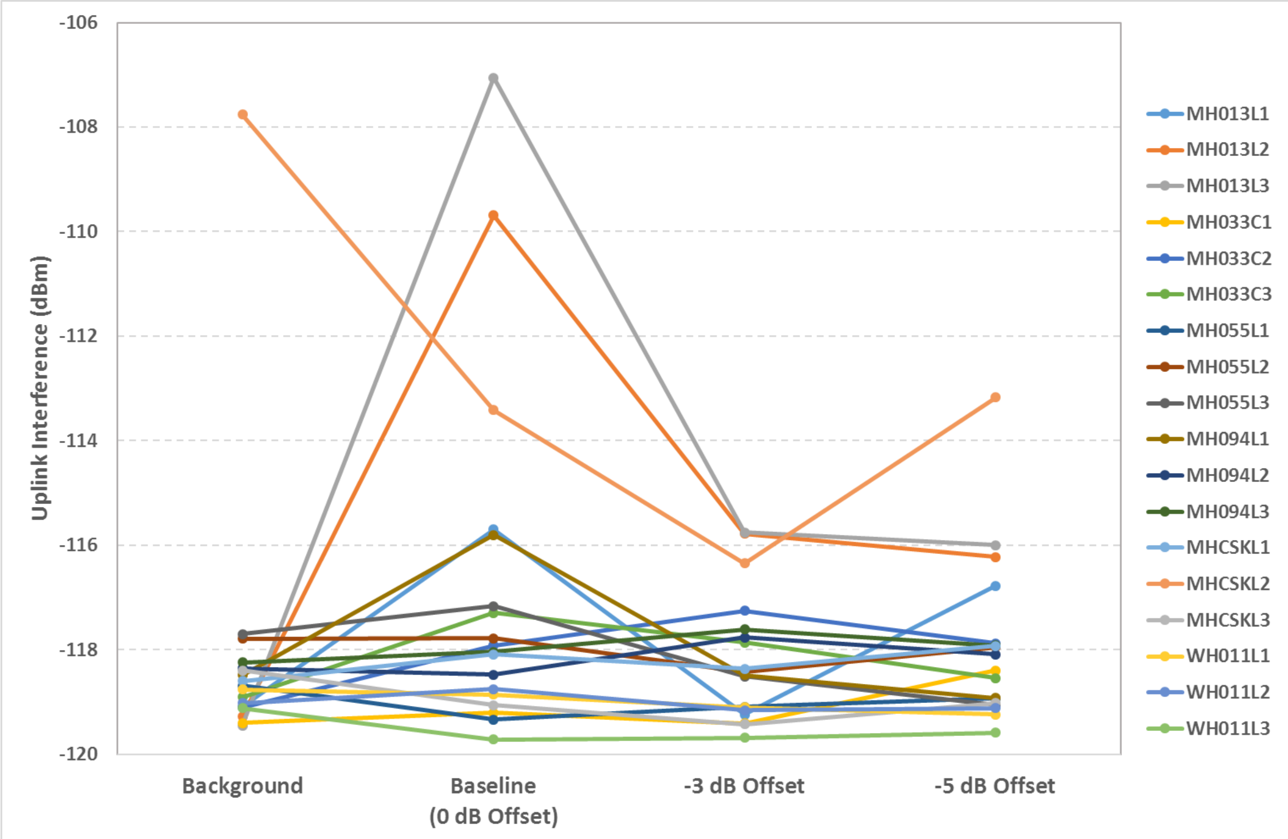

Figure 5: Measured Uplink Interference Levels

The first point to note is that the background interference cell MHCSKL2 was clearly subject to a high interference source on the reference day chosen for the background interference measurements, with an interference level more than 10 dB higher than the other cells. In fact, this interference source was generally but intermittently present throughout the trial period, including the trial date itself, making that cell unusable for drone interference measurements. This was unfortunate, as this was the cell at that site pointing most directly towards the test location.

The interference measured for each cell for each test case is also shown in this table, along with the delta increase (in red) or decrease (in green) of the interference relative to the previous test case (or, for test case 1, relative to the background reference). It can be seen that the interference changes relative to the previous test case were typically very low (< 1 dB), with the notable exception of the adjacent cells to the serving cell (i.e. MH013L2 and MH013L3) where, as would be expected, the interference changes were much higher.

However, test case 1 (baseline) does generally lead to higher interference levels (highlighted in red) at the neighbouring cells compared to the reference background, with the cell pointing most directly to the test location usually experiencing a higher interference rise than its neighbours (note that MH013L1, being the dominant serving cell, does not regard the drone transmissions as interference). The highest interference rise away from the serving site is only 2.7 dB, however, which is not that much. Curiously, the closest neighbouring site to the serving site (WH011) showed virtually no change in interference levels due to the drone. This appears to be due to a relatively high antenna tilt used on that sector.

Comparing test case 4 (- 3dB offset) to the baseline, it can be seen that measured interference levels generally tend to be lower, particularly at the serving site and cells pointing most directly towards the test location. Where the interference level does rise (at four cells), the measured rise is small (< 0.7 dB) and not necessarily due to the drone at all. For test case 5 (- 5dB offset), the picture is more mixed, with almost as many cells experiencing an interference rise (compared to test case 4) as experience a fall. Almost all the changes when the p0 offset is increased from – 3 to – 5 dB are small.

5 Conclusions and Future Work

The trial demonstrated that:

- The ASGH feature can be used to reduce the uplink transmit power used by a UE relative to the default parameters. If the UE is in good radio conditions, then the effect on the MCS and hence QoS is negligible, but some degradation can be expected in poorer radio conditions.
- The reduced uplink transmit power does lead to a reduction in uplink intercell interference. However, the reduction was typically small, as the interference rise due to the drone UE was itself typically small. This suggests that excess interference due to drone-based UEs is not necessarily a significant issue in rural areas with high intersite cell separations such as the trial area.

There were a number of factors in the trial design that would have contributed to the relatively low uplink intercell interference, particularly the relatively low drone height that could be achieved using the tethered drone (65 metres compared with a maximum allowable of 120 metres), the closeness of the drone to the serving cell, and the 40% limit on PRBs that could be allocated to the test UE.

Typical drone operations can therefore be expected to have a higher uplink interference than was observed in this trial, particularly in urban areas. But although the ASGH feature can reduce the uplink interference impact, it is somewhat a blunt instrument, as it would be enabled irrespective of the radio conditions being experienced by the drone UE or the interference it was actually generating. Tuning this feature on a per drone or even per cell basis would appear to be impractical.

Recommendations

Consequently, it is recommended that:

- Research and trials of other interference mitigation mechanisms continue, particularly antenna design
- The trade-off between UE QoS and uplink transmit power achieved by the ASGH feature be examined further for a wider range of radio conditions. Note that this does not need to be drone-based testing, but could be done in a lab (using channel emulation) or with a ground-based UE.
- Use of ASGH for drone interference mitigation only be considered for use tactically in locations where it is an already available RAN feature, interference is a demonstrable problem, and no other solutions are feasible. It should not be deployed solely for the purpose of drone interference mitigation, and should not be enabled by default for all cells serving drone UEs
- Consideration should be given to extending the ASGH feature as applicable for drone UEs to include dynamic enabling and disabling of the feature (or, alternatively, dynamic parameter modification) depending on the radio conditions experienced by the drone UE and the predicted excess interference being generated, so that an optimum balance between the drone QoS and the uplink interference generated can be maintained in all radio conditions experienced by the drone.

6 References

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