Enhanced Unmanned Aerial Vehicle Communication Support in LTE-Advanced

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Abstract — **The Long-Term Evolution (LTE) support for Unmanned Aerial Vehicles (UAV) is among vertical services which have been recently addressed in 3GPP standardization activities. Meticulous channel modelling and verification of the legacy network performance when new aerial users are introduced have preceded the actual solution defining phase. This paper briefly describes what challenges have been identified in the study and depicts how those have been tackled. We outline the solutions for enhanced mobility and interference management. In addition, we present simulation results showing how those recently defined LTE mechanisms perform. Finally, we elaborate on what gaps are still to be bridged for optimal performance of UAVs connected to LTE networks.**

Keywords — **UAV, drone, aerial, LTE, 3GPP, Release-15**

I. Introduction

In the recent years the Unmanned Aerial Vehicles (UAVs) have gained the attention of both private and industry users. UAVs (also known as drones) are gradually conquering subsequent areas – with the use cases stretching from more civil-related, such as hobby, taking pictures from above the ground, to more serious military or safety-critical purposes. Their immensely growing presence have struck the attention of various technical fora, including companies subscribed under 3rd Generation Partnership Project (3GPP), global organization standardizing cellular technologies, such as Long-Term Evolution (LTE) or New Radio (5G). That engagement was also partly due to ongoing trend: so-called "vertical markets" and services other than targeting the typical mobile network subscribers, are gaining momentum.

In the first quarter of 2017, 3GPP has approved a study on "Enhanced support for Aerial Vehicles" [1], aimed at verifying to what extent legacy LTE networks are prepared to serve a new type of users - UAVs equipped with LTE modem.

TABLE I: REQUIREMENTS FOR LTE-BASED UAV COMMUNICATIONS (3GPP REL-15)

Parameter	***Value***
Latency of C2 traffic	50 ms
Reliability of C2 traffic	10^{-3} Packet Error Rate
UL/DL* C2 data rate	100 kbps
Application data rate (UL)	up to 50 Mbps
UAV UE height	up to 300 m
UAV UE velocity	up to 160 km/h
UAV UE density (urban)	5 per cell (70 per km^2)

* DL (downlink) denotes the Network-to-UAV radio link; UL (uplink) denotes the UAV-to-Network radio link.

Table I contains a set of requirements and parameters for Aerial Vehicles communications, which was used as a guideline during the LTE Release 15 analysis. The outcome of the aforementioned study has been captured in the 3GPP Technical Report [2]. Various metrics have been evaluated, including downlink (DL) and uplink (UL) interference, radio link/handover failures (RLF/HOF, respectively) and achievable throughput. The overall conclusions have shown that LTE networks can accommodate the UAV UEs, but the performance is not entirely satisfying and not always reliable [3], especially when the density of the Aerial UEs is high. The latter shortcoming could be of utmost importance, if LTE networks are meant to provide the Command and Control (C2) link, inherent to remotely steer the drones and enable Beyond Visual Line of Sight (B-VLOS) flights. B-VLOS support is the key ingredient to serving long-distance UAV routes. Such remote control can be achieved thanks to widely deployed LTE/LTE-Advanced networks.

In consequence, 3GPP decided to undertake the effort and specify a set of enhancements to streamline the overall quality of service (QoS) Aerial UEs experience in LTE networks, while at the same time maintaining the QoS for the legacy, ground-level users. The detailed objectives are listed in the Work Item Description [4] and include the following:

- Enhancements to existing measurement reporting mechanisms, e.g. to enable more reliable interference detection
- Enhancements aimed at improving Aerial UE's network mobility performance based on location information or flight path plan reporting
- UL power control enhancements for interference mitigation

The paper is organized as follows. Section II describes certain challenges identified during the study phase. In Section III the LTE Release 15 enhancements to support Aerial Vehicles are presented and evaluated. Potential future development directions are outlined in Section IV. Finally, Section V echoes the main findings.

II. Mobile Radio Challenges for Connected UAVs

During the study phase, the main goal was to verify how the advent of UAV UEs will impact LTE's key

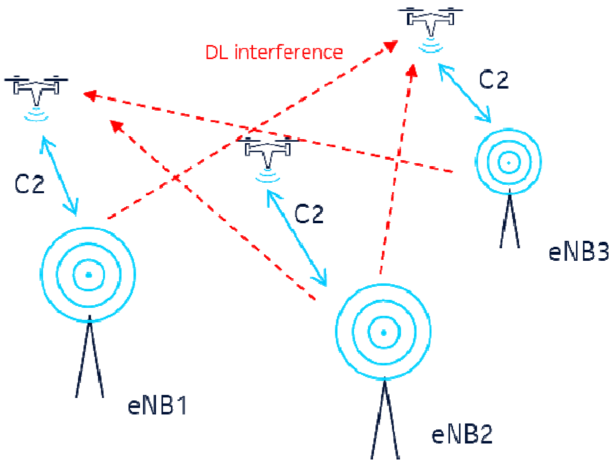

Fig. 1. Command and Control support in large scale and interference limited scenarios

performance indicators, such as achievable throughput, the ratio of radio link failures or the percentage of successful handovers. Aerial UEs operate above the ground level (AGL). Thus, during their flight they will often be located above the base station's antennas and possibly will be receiving signals through one or more of vertical side lobes from the distant cells, resulting in the increased level of DL interference. In a simplified manner, such scenario is depicted in Fig. 1, wherein eNB1 and eNB2 may be interfering even a far-away UAV UE, which exchanges C2 traffic with eNB3.

For the sake of simplicity, Fig. 1 has shown the case where just three eNBs were involved. Nevertheless, in practical LTE deployments, the number of detectable cells can be substantially larger. It may be in particular visible in Urban environments, where smaller inter-site distance (ISD) between adjacent cells is typical. Fig. 2 presents the observed trend how the number of detected cells changes with the increasing height AGL in a rural scenario. It can be noticed that ground users (at 1.5 m AGL) on average detect 5 cells, while UAVs at the height of 120 meters would be already receiving a sufficiently strong signal from more than 16 cells. Fig. 2 allows also to notice how the range of cells rises with the increasing height.

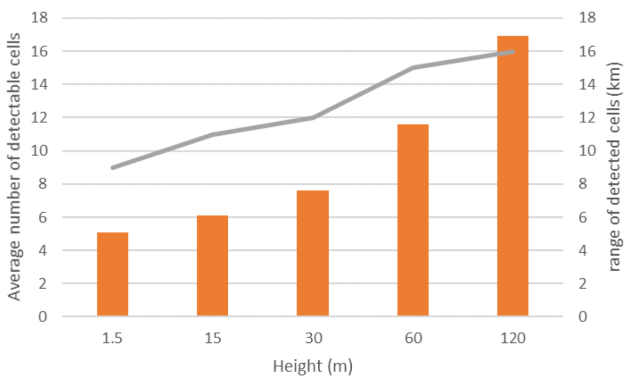

Fig. 2. Example of average number of detectable cells (represented by orange bars) and range of detected cells (represented by grey line) per height, based on experimental investigations in a rural environment [2].

As can be observed, the range nearly doubles when the two extreme values for UE's height are compared, i.e. 1.5 m and 120 m.

III. Enhanced 3GPP Rel-15 LTE Support for Aerial Vehicles

A. Height dependent reporting

In LTE's Radio Resource Control (RRC) protocol [5], measurement events specify criteria which trigger a measurement report to be sent by the UE to its serving eNB. Those reports are typically used to manage UE's mobility, e.g. to initiate a handover to a cell with better radio conditions than the one currently serving the UE. For Aerial UEs, two new events were introduced:

- Event H1: Aerial UE height becomes higher than an absolute threshold;
- Event H2: Aerial UE height becomes lower than an absolute threshold

The moment the conditions for event H1 or H2 are fulfilled, the UE triggers the procedure to send a measurement report. It is a simple indication that a configured height threshold has been crossed, but it may additionally contain current UE's 3D location and its speed in both vertical and horizontal planes. The height threshold is defined as an offset from the sea level altitude. Fig. 3 shows an Aerial UE's trajectory and the points in time when events H1 and H2 are fulfilled or no longer fulfilled.

The purpose of H1 and H2 is somewhat different from LTE's A1 - A6 measurement events [5], although they will be also used as an input to the Radio Resource Management (RRM) algorithm. As proven via simulations presented in [3] or the ones performed during the study in 3GPP [2], the mobility performance of Aerial UE's is highly dependent on their height and speed and there are such combinations thereof, which lead to much higher Radio Link Failure (RLF) and Handover Failure (HOF) rates as compared to ground UEs. By recognizing the height threshold values and obtaining UE's speed information at the same time, the network can adjust UE's mobility related parameters - such as Time-To-Trigger (TTT) - to maximize the chance of the successful handover. Furthermore, the serving cell can use the height information to adjust the DL and UL power setting for the Aerial UE to minimize the overall interference level in the nearby cells.

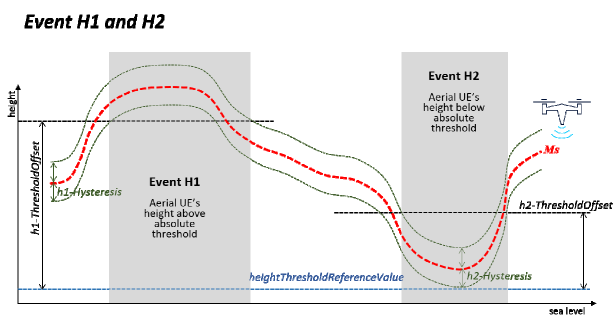

Fig. 3. Example of triggering of H1 and H2 events

B. Downlink and uplink interference detection

As described in the introduction, Aerial UEs typically receive more interference than terrestrial UEs, as the UE in the sky will be 'hearing' numerous cells and is more likely to experience LOS radio conditions. If we use similar measurement report triggers for the purpose of interference detection as commonly used for terrestrial users, the amount of measurement reports is likely to increase significantly. Taking this into account, 3GPP added a possibility to configure the RRM events A3, A4 or A5 [5] such that a measurement is only triggered when a minimum number of cells simultaneously fulfill the configured event, i.e. if the number of cells which fulfill event A3 (or event A4 or A5) is larger or equal to *numberOfTriggeringCells*. If *numberOfTriggeringCells* is not configured, then the measurement report is triggered when one cell fulfills the event. No additional measurement reports are sent when the number of cells fulfilling the event further increases, but when any cell stops fulfilling the event (for A4 or A5), a report is sent (so called 'report on leave', which can be optionally configured by the network).

To illustrate how this works, a simulation example is given in Fig. 4. The figure shows the downlink interference traces for a UAV and a terrestrial user from a simulation, which follows the setup presented in [6]. Several key parameters are captured in Table II.

TABLE II: KEY SIMULATION PARAMETERS

Parameter	***Value***
System bandwidth	20 MHz
Carrier frequency	800 MHz
Simulation area	70 x 70 km
Minimum SINR requirement	- 6dB
Event A4 threshold	-55 dBm
Number of triggering cells	4

The resource load was approximately 35%. On top of this, the estimated interference based on measurements is depicted at the times of the measurements. The estimate is based on the Reference Signal Received Power (RSRP) values in the measurement report and knowledge of the current load in the reported cells, while measurements are triggered when at least 4 cells (i.e. *numberOfTriggeringCells* = 4) fulfill the A4 threshold of -55 dBm. From Fig. 4 we can see that the interference level is very different for the terrestrial user and the aerial user, confirming the findings from earlier publications [3]. The number of measurement reports triggered over the 200 seconds was 121. Of those 121 reports only 1 was related to 4 cells fulfilling the conditions, while 119 were related to leave events. This stems from the way the measurement report triggering condition was designed by 3GPP, as described above.

The alternative would be to send a report each time a new cell is triggering the condition as long as the total number of triggered cells is at least 4. The decision not to go this way was made to limit the signaling overhead caused by a high number of transmitted reports.

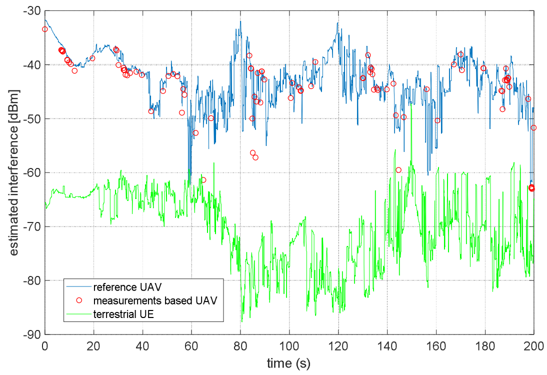

Fig. 4. Example of estimated interference based on measurement reports for an UAV and reference interference levels for the UAV and a terrestrial user

However, this comes at the expense of network not having knowledge exactly which cells fulfill the event at certain point in time. This results in not identifying the ones, which may cause severe DL interference to the UAV or which are subject to UL interference generated by the UAV. Thanks to configuring reporting on leave, network will get the updated set of cells, which are above the configured threshold, each time one of the cells currently on the list fulfills the event leave condition. This is less straightforward than receiving the updated report when new cells are added and moreover, the update is not available to the network in case new cells are added while no cells are removed from the list. It can at least alleviate the issue, but the problem of excessive measurement reporting still exists. In the simulated scenario a report was sent approximately every 2 seconds and while it contained useful information, interference mitigation techniques, most likely, cannot be applied that fast anyway. Originally, 3GPP planned to address the issue of RRM related signaling overhead, but that objective was deprioritized eventually. This is definitely a good candidate for future enhancements in the area of connected aerial vehicles, while in the meantime some workarounds can be applied by the network. One potential solution for the network is to configure A4 event with a *numberOfTriggeringCells* parameter and following the first report being triggered by the UE, configure it with an additional, periodical reporting with a periodicity adjusted to what is truly beneficial to the network to apply interference management techniques properly. As with each workaround, there are some disadvantages and, in that case, this would be the fact that the periodical report, due to its nature, is sent in specified points in time, regardless of whether there is any real update of the measurements or the list of triggered cells.

C. Flight path information

For many commercial UAV applications, such as remote power lines maintenance or pest monitoring in the forests, the UAVs are typically out-of-sight of their operator. Furthermore, their planned flight route is often known and programmed in a UAV in advance. 3GPP decided to take advantage of this trait and specified flight path information reporting from an Aerial UE to Radio Access Network (RAN). An Aerial UE's planned flight route report can be requested by the UE's serving cell with LTE specific *UE*

Information procedure. Network may send a *UEInformationRequest* message including parameter *flightPathInformationReq* and the UE should reply with a flight path information included in *UEInformationResponse* message consisting of up to 20 waypoints. Each waypoint is composed of a 3D location information (information structures from LTE Positioning Protocol (LPP) as defined in [7] are reused), optionally combined with a time stamp to provide the anticipated time of arrival of the UE at the corresponding location with a maximum of one second granularity.

The reporting procedure is presented in Fig. 5. The knowledge of UE's planned flight itinerary by an LTE network can, for instance, provide early resource reservation in cells suitable for a handover and by doing so, ensure a higher QoS. By making the potential target cell pre-prepared for a handover of an Aerial UE, the likelihood of an RLF or HOF can be minimized and hence one of the main issues identified during the 3GPP study item phase may be addressed. Moreover, if flight routes are collected frequently, LTE network can even utilize machine learning to optimize its services for specific Aerial UEs or to use this information together with historical RSRP/RSRQ measurement data collected through, e.g. Minimization of Drive Tests (MDT) feature, to predict the expected QoS level and react accordingly by applying load balancing techniques, directing either Aerial or ground UEs to other frequency layers.

One already identified imperfection of the Rel-15 solution is that the content of the flight plan is largely left to the UE implementation. The standard does not, for example, specify the distance between the waypoints reported by the UE or the accuracy of the provided information. However, it could be in fact impractical to have such requirements imposed due to the diversity of applications, which would have to be supported. Instead, the decision was made to rely on the smart UE implementation to provide the information in the form usable by the networks. Additionally, since UAVs should have a special subscription authorizing them to operate in the mobile network while in flying mode, network operators can have mutual agreements with enterprise customers, who would rely on LTE networks to provide UAV based services. Those service requirements would refine the form of information that should be provided. Eventually, it has to be noted that Unmanned Aircraft System (UAS) Traffic Management (UTM) is believed to be a requirement to make B-VLOS UAS operations - both for commercial applications as well as for hobbyists - a reality [8]. Once deployed, UTM systems, would be a much more reliable source of UAV's flight path plan information and integrating (or interfacing) such system with a 3GPP Core Network would allow operators to provide enhanced services, taking advantage of the UAV's planned itinerary, based on the information obtained directly from UTM system and without having to depend on reporting over the air interface. UTM could, for example, be provided with a network load situation on the planned route and adapt it to ensure the service requirement can be met with the highest possible reliability while minimizing the potential interference to other network users. The Core Network support for UAV services, including utilization of flight path plan information, is undoubtedly a topic worth exploring in the future 3GPP releases.

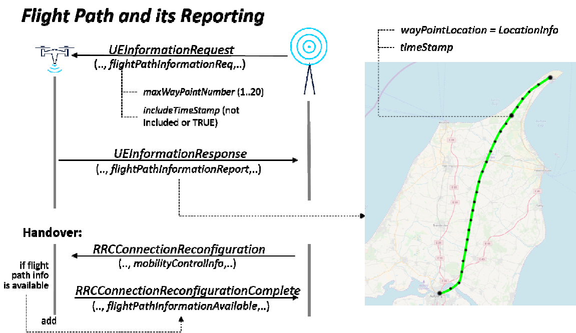

Fig. 5. Flight path plan information reporting by an Aerial UE

D. Power Control

Aerial UEs often have a direct LOS to their serving cells, which is not the typical situation for most of the UEs operating at ground level, especially in urban areas. Thus, Aerial UEs may often require an uplink transmit power significantly lower when compared to the one used for ground UEs, to ensure successful data reception on the network side and to avoid negative impact to terrestrial users (in terms of the interference). On the other hand, and as explained in Section II, an Aerial UE may be connected to a physically distant cell, whose receive antennas will unlikely be tilted to optimally receive the uplink signals of a UE located high above the ground level. In this case, a relatively high uplink power is required. To allow for a wide range of UL transmit power, the UE specific power offset of Aerial UEs can be set to a wider range (from -16 dB to 15 dB) in comparison to legacy LTE UEs (-8 dB and 7 dB).

IV. Further Improvements

Connected UAVs have gained such interest that continuous progress in this area appears to be inevitable. Furthermore, not all of the identified issues were addressed by 3GPP in Release 15, due to time constraints and the need to prioritize major functionalities. The list of potential future enhancements, some of which were already mentioned in the previous sections of the paper, include:

- RRC IDLE mode mobility improvements
- Measurement reporting overhead reduction
- Flight path plan reporting through network interfaces and UTM system
- Vertical movement handover
- Positioning enhancements

The following subsections provide concise description for each of these areas of future research and potential standardization work.

A. RRC IDLE mode mobility enhancements

In case a C2 link is established for a UAV through LTE network, such Aerial UE will spend most of its flying time in RRC CONNECTED mode. However, there are scenarios in which RRC IDLE mode mobility improvements are beneficial. This includes applications, which rely on UAV autonomous operation with link being established only occasionally to exchange certain amount of user data. In such situations it would be important to ensure that from the moment UAV connects to the network, it is under the coverage of the best possible cell and that the network has immediate information about UAV's speed and height, so that power control, interference mitigation and mobility management techniques can be customized accordingly, right after Aerial UE transitions to RRC CONNECTED mode. The potential improvements may include cell reselection parameters scaling based on the Aerial UE's height and speed or location reporting during connection establishment.

B. Measurement reporting overhead reduction

In Section III an interference detection mechanism based on the number of cells triggering the measurement event was presented. An issue related to signaling overhead was mentioned, together with an indication some workarounds exist, but they all have certain flaws. Moreover, it is important to note that the newly introduced events can be used successfully for interference detection, but in addition to those, Aerial UE must be configured with 'traditional' (i.e. single cell based) mobility events. Otherwise, the handover performance could possibly be deteriorated due to delayed measurement reporting. As proven by simulations and trials [9], the number of strong cells seen by the UAV is much higher than for ground UEs. This means that after a first cell triggers a measurement event, there is a high likelihood, subsequent reports will be sent shortly afterwards to inform about additional cells triggering the same event. However, the RSRP levels of the reported cells would not change significantly and they will unlikely affect the handover's target cell choice made by the serving eNB. One possible way to address this issue is to specify a prohibit timer, controlling the period during which a UE would refrain from sending consecutive reports after the first report for the specific event was transmitted to the network. Some further details on this mechanism can be found in [10].

C. Flight path plan reporting enhancements

The potential enhancements for flight path reporting were already mentioned in Section III and are shortly recapped here. The main advantage and disadvantage at the same time of the reporting functionality is its flexibility, i.e. lack of required minimum distance between consecutive waypoints, their accuracy, etc. As pointed out, with the large enterprise customers, network operators may mutually agree on the form of the information reported by the UEs. However, the same Aerial UEs may also be utilized by numerous individual customers and it might not always be possible to tailor their implementation to each specific need. Influencing and modifying UE implementation is also much more troublesome, as compared to agreeing on the information, which could be exchanged between operator's core network entities and customer's IT systems (e.g. UTM) where Application Programming Interfaces (APIs) may be utilized. Thus, the solutions where flight path plan information is provided from the UTM system through the operator's core network during connection establishment or while UE moves inside the network already upon the connection establishment, would be beneficial. Additionally, the geolocation information normally available and utilized by UTM system could be combined by operator's network or IT systems with the network infrastructure and topology information to deduce which are the nodes likely to be on the UE's flying path and adjust mobility or interference management algorithms accordingly. Moreover, network load information could be made available to the UAV application's user or the network could suggest alternative paths ensuring best performance for both UAV and ground users.

D. Vertical movement handover

A lot of attention during the work in 3GPP was given to the fact that handover procedures and corresponding parameters should be different for Aerial UEs compared to terrestrial users, depending on their height and horizontal speed. However, Aerial UEs have the possibility not only to move in horizontal direction, but also in vertical direction. From a flight safety point of view - especially the take-off and landing are critical procedures, as the large percentage of accidents occur during these phases [11]. At the same time the radio propagation is changing rapidly in the vertical dimension and is fundamentally different from horizontal movement, as antenna patterns are narrower in the vertical compared to the horizontal direction and radio conditions change more rapidly when the UE moves in vertical domain. An evocative example is the clearance of the roof tops in an urban area. Fig. 6 shows the results from measurements in an urban area where a network scanner was moved from ground level to 40 meters in steps of 10 meters. The network scanner measured continuously the cells it could detect with an average measurement report rate of 7 Hz and one measurement report included all detectable cells at that point in time.

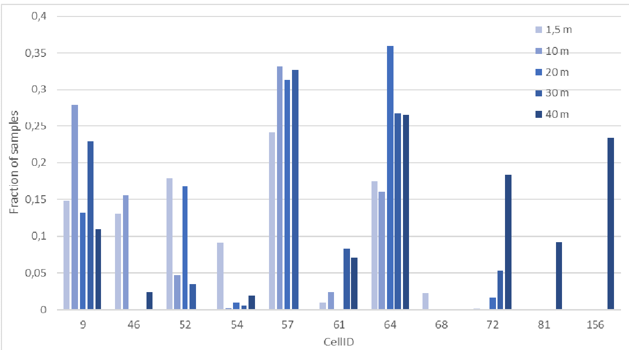

Fig. 6. Distribution of cells with strongest measured RSRP value for different heights in urban environment based on measurements

Fig. 6 shows the distribution of the cells with the strongest RSRP level per height. It can be easily noticed that the distribution changes a lot with height. While cell 9 always appears at some point at different heights, cell 81 only shows up when the height is 40 m and the radio path is free of obstructions. The vertical speed of a drone is typically in the order of 6 m/s, but can be also considerably larger and is likely to further increase in the future, along with the continuous progress in UAV technology. It means the radio conditions are likely to be changing faster and independently in the vertical and horizontal directions.

To ensure the required high reliability during the take-off and landing as well as to tackle various radio conditions, independent handover settings for UEs moving in vertical plane would be beneficial.

E. Positioning enhancements

Positioning enhancements were also initially included in the scope of the study made by 3GPP, but they were eventually deprioritized. Although the existing positioning techniques are already an intrinsic part of most UAV applications and drones are usually equipped with a set of positioning sensors, there are certain applications, which could take advantage of very high precision and/or indoor positioning techniques. Such applications include, e.g. building maintenance or drones utilized in factories or warehouses (industrial use-cases).

V. CONCLUSION

The goal of this paper was to underline how thriving and up-to-date research and standardization topic is to ensure Aerial UEs can be provided with an efficient and reliable communications via cellular networks. We have highlighted the difficulties that have been analyzed and resolved throughout the 3GPP Release 15 work item, such as deteriorated mobility success ratio or increased interference level. In addition to describing what kind of enhancements have been defined, we have also evaluated the performance of interference detection scheme, relying on the number of cells simultaneously triggering the measurement event. It has been shown the vast majority of reports is actually sent when the interference level decreases, not when additional cells start to negatively contribute to the overall DL interference level. Eventually, we have discussed what kind of improvements can be foreseen – not only to those already specified techniques, but also in other areas related to connected Aerial UEs. The first 3GPP release supporting the UAVs is already approved, but the rapid pace of Aerial vehicles' expansion implies there would be new use cases, requiring enhanced standardization support – in both LTE and 5G (New Radio).

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