An Overview of 3GPP Release-15 Study on Enhanced LTE Support for Connected Drones

Siva D. Muruganathan†, Xingqin Lin‡, Helka-Liina Määttänen‡, Zhenhua Zou†, Wuri A. Hapsari‡, Shinpei Yasukawa‡

†Ericsson, ‡NTT DOCOMO

Contact: xingqin.lin@ericsson.com

Abstract—Cellular connectivity to low altitude unmanned aerial vehicles (UAVs) has received significant interest recently which has led to a 3GPP study on enhanced LTE support for connected UAVs in Release 15. The objective of the study is to investigate the capability of long-term evolution (LTE) networks for providing connectivity to UAVs. In this article, we provide an overview of the 3GPP study. We first introduce UAV connectivity requirements and performance evaluation scenarios defined in the study. We then discuss radio channel models and the key identified challenges of using LTE networks to provide connectivity to UAVs. Finally, we summarize potential solutions to address the challenges including interference detection and mitigation techniques, mobility enhancements, and UAV identification.

I. INTRODUCTION

Most of the activities in terms of research and development in the area of mobile broadband have been focused on providing wireless broadband communication to outdoor users on the ground or indoor users in buildings. Recently, the area of providing cellular connectivity to low altitude unmanned aerial vehicles (UAVs, a.k.a. drones) has gathered increasing interest from the industry [1]-[4], academia [5]-[6], and public policy makers [7]-[8]. There is a plethora of use cases for supporting aerial vehicles on cellular networks, some of which include search-and-rescue, surveillance, wildlife conservation, package delivery, and monitoring of critical infrastructure [9].

When aerial vehicles are flying well above eNodeB antennas, they may have a high likelihood of line-of-sight (LOS) propagation conditions to multiple neighbouring eNodeBs. In such a scenario, an uplink signal transmitted from an aerial vehicle may become visible and cause interference to multiple neighbouring eNodeBs [10]. If this interference is not controlled or mitigated, it may adversely impact the uplink performance of existing users on the ground. Hence, to protect the existing users in the LTE network, the network may have to perform certain actions such as ensuring that such interference is mitigated or performing admission control of aerial vehicles in the network. As a prerequisite to either of these actions, the network may first need to identify the aerial vehicles. With the abovementioned LOS propagation conditions, downlink signals transmitted from multiple eNodeBs may cause downlink interference to the aerial vehicle. Another open issue is whether the existing mobility mechanism of LTE networks is sufficient or whether it needs enhancements to support cellular connectivity of aerial vehicles.

To better answer these issues and to understand the potential of LTE networks for providing cellular connectivity to aerial vehicles, the 3rd generation partnership project (3GPP) started the Release-15 study on enhanced LTE support for aerial vehicles in March 2017 [11]. This study assessed the performance of LTE networks supporting aerial vehicles with up to Release-14 functionality. The study was completed in December 2017 and the outcomes are documented in the 3GPP technical report TR 36.777 [1] including comprehensive analysis, evaluation, and field measurement results. With the completion of this study item, 3GPP has started a follow-up work item [12] to advance LTE technologies to provide more efficient cellular connectivity to aerial vehicles. The enhancements for enhanced LTE support for connected drones is expected to be specified by 3GPP at the conclusion of the work item which is expected to conclude in June 2018.

In this article, we provide an overview of the 3GPP Release-15 study on enhanced LTE support for aerial vehicles and summarize the key findings. The overview provided by this article is an accessible first reference for researchers interested in learning the 3GPP state-of-the-art findings on cellular connected drones.

II. PERFORMANCE REQUIREMENTS

Although aerial user equipments (UEs) can be deployed for a plethora of use cases, the two main data types with regards to wireless connectivity of aerial UEs are command and control data and application data.

The ability to send command and control traffic to aerial UEs from eNodeBs can significantly improve the safety and operation of aerial UEs. For instance, it is critical that information such as changes in the flight route are conveyed to the aerial UEs in a timely manner with sufficient reliability. In the 3GPP Release-15 study, the performance requirements on command and control to ensure proper operational control of aerial UEs were defined. In addition to defining requirements for command and control, the Release-15 study also defined requirements for application data. A summary of the agreed performance requirements from the Release-15 study is given in Table 1.

III. EVALUATION SCENARIOS AND ASSUMPTIONS

To evaluate the performance of LTE networks in the presence of LTE connected aerial vehicles, the following three scenarios were defined in the Release-15 study [1]:

1. Urban-macro with aerial vehicles (UMa-AV)
2. Urban-micro with aerial vehicles (UMi-AV)
Table 1. Performance Requirements [1]

| Command and Control Data                | Application Data                        |
|-----------------------------------------|-----------------------------------------|
| Data type examples                      |                                          |
| • telemetry                             | • video streaming                       |
| • waypoint update for autonomous aerial vehicle operation | • image transfer                        |
| • real-time piloting                    | • transmission of other sensor data     |
| • flight authorization                  |                                          |
| • navigation database update            |                                          |

Latency
- one-way radio interface latency of 50 ms from eNodeB to aerial UE
- similar to LTE terrestrial UEs

Uplink/downlink data rate
- 60-100 kbps for both uplink and downlink
- up to 50 Mbps for uplink
- N/A

Command and control reliability
- up to $10^{-3}$ packet error loss rate

3. Rural-macro with aerial vehicles (RMa-AV)

UMa-AV represents scenarios where the eNodeB antennas are mounted above the rooftop levels of surrounding buildings in urban environment. Urban scenarios with below rooftop eNodeB antenna mountings are represented by UMi-AV. Larger cells in rural environment with eNodeB antennas mounted on top of towers are represented by RMa-AV. Figure 1 illustrates the evaluation scenarios used in the Release-15 study along with the inter-site distance (ISD), building height, and eNodeB height for each scenario.

In UMa-AV, UMi-AV and RMa-AV, aerial vehicles are modeled as outdoor UEs with heights well above ground level (AGL). In the Release-15 study, a maximum height of 300 m AGL was considered for aerial UEs. For performance evaluations, the height of the aerial UEs was assumed to be uniformly distributed between 1.5 m AGL and 300 m AGL. Fixed aerial UE heights of 50, 100, 200, or 300 m AGL were also considered in the study for system level performance evaluations.

In addition to modelling aerial vehicles, the three scenarios model terrestrial users on the ground and inside buildings. In all three scenarios, the user distribution of both indoor and outdoor terrestrial users is modelled according to the existing 3GPP models defined in [13].

The total number of UEs (including both aerial UEs and terrestrial UEs) per cell is assumed to be 15. To study the impact of supporting aerial UEs with different densities in a cell, aerial UE ratios of 0%, 0.67%, 7.1%, 25%, and 50% were considered. Note that in [1], aerial UE ratio is defined as the ratio between the number of aerial UEs per cell and the number of terrestrial UEs (including both indoor and outdoor) per cell. Further details of evaluation assumptions for system level simulations and mobility simulations can be found in Annexes A.1 and A.2 of [1], respectively.

IV. CHANNEL MODELLING

In UMa-AV, UMi-AV, and RMa-AV, the channel modelling of terrestrial users is according to the channel models defined in [13]. To characterize the channels between aerial UEs and eNodeBs, the Release-15 study defined models for LOS probability, pathloss, shadow-fading, and fast-fading. In this section, we highlight some key aspects of these models.

A. LOS Probability

To define LOS probability, an aerial UE height dependent modelling approach was adopted in the study. For all three scenarios, the LOS probability models defined in [13] are reused for aerial UE heights below a lower height threshold. The height threshold is $22.5\, \text{m}$ for UMa-AV and UMi-AV, while the height threshold is $10\, \text{m}$ for RMa-AV.

Since eNodeB antennas are well above rooftop in UMa-AV and RMa-AV, a 100% LOS probability is assumed above an upper height threshold. The height threshold is $100\, \text{m}$ and $40\, \text{m}$ for UMa-AV and RMa-AV, respectively. As eNodeB antennas are below rooftop in UMi-AV, the probability of non-line-of-sight (NLOS) is generally higher in UMi-AV when compared to UMa-AV and RMa-AV. Hence, the upper height threshold is not applicable in UMi-AV.

In the aerial UE height range between the lower and upper height thresholds, the LOS probability models in [1] were derived via ray tracing simulations for UMa-AV and RMa-AV. For UMi-AV, ray tracing simulations were used to derive a LOS probability model that applies for aerial UE heights above the lower height threshold. The details of the agreed LOS probability models can be found in Table B-1 of [1]. Figure 2 illustrates the LOS probabilities derived in the Release-15 study for the three different scenarios at different aerial UE heights.

B. Pathloss and Shadow-Fading

For all three scenarios, the pathloss and shadow-fading models defined in [13] are reused for aerial UE heights below a lower height threshold. The lower height threshold is $22.5\, \text{m}$ for UMa-AV and UMi-AV, while the lower height threshold is $10\, \text{m}$ for RMa-AV.

In the aerial UE height range above the lower height threshold, pathloss and shadow-fading models for both LOS and NLOS conditions were agreed in the Release-15 study considering field measurements and ray tracing simulation results contributed by multiple sources. The detailed
discussions which led to these agreed pathloss models can be found in [14]. The agreed pathloss and shadow-fading models can be found in Tables B-2 and B-3 of [1], respectively. Figure 3 shows the LOS pathlosses for the three scenarios at different aerial UE heights.

C. Fast-Fading

Three alternative fast-fading models were agreed during the Release-15 study. The three alternatives differ in the angular spreads, delay spreads, and K-factor ranges as well as modelling methodology. The first alternative is based on a clustered delay line model which is derived according to the procedures outlined in Annex B.1.1 of [1]. The second alternative (outlined in Annex B.1.2 of [1]) is based on aerial UE height dependent modelling of angular spreads, delay spreads, and K-factor. The third alternative (outlined in Annex B.1.3 of [1]) is based on the fast-fading model of [13] with the K-factor set to 15dB.

V. PROBLEMS IDENTIFIED DURING THE STUDY

During the Release-15 study, evaluations were performed under the scenarios and channel models described in Sections III and IV, and interference problems were identified in both uplink and downlink for scenarios involving aerial UEs. In this section, we highlight the uplink and downlink interference problems identified during the study.

A. Uplink Interference

In the uplink, the aerial UEs were found to cause interference to more cells than a typical terrestrial UE could. This is because aerial UEs, when they are airborne, experience LOS propagation conditions to more cells with higher probability than terrestrial UEs. This generally translates into higher interference caused by an airborne aerial UE to these cells. The uplink interference over thermal (IoT) ratios for terrestrial UEs is given in Figure 4(a) which shows the effect of increased uplink interference on terrestrial UEs as the aerial UE ratio increases.

Due to the increased uplink interference, the uplink throughput performance of terrestrial UEs degrades when the aerial UE ratio is increased in the network. The degraded uplink throughput of terrestrial UEs in turn increases the uplink resource utilization level in the network. In other words, degraded uplink throughputs imply that the UEs take longer time to transmit their data which will consume more resources and will lead to increased uplink resource utilization. An increased uplink resource utilization level inherently means an increased level of uplink interference in the network, which in turn was observed to degrade the uplink performance of both aerial UEs and terrestrial UEs. The corresponding uplink results demonstrating the degraded uplink performance are given in Annexes D.2.1 and D.2.2 of [1].

B. Downlink Interference

In the downlink, compared to a typical terrestrial UE, the aerial UEs observe interference from more cells due to the LOS propagation conditions experienced by aerial UEs when they are airborne. Figure 4(b) compares the five-percentile downlink geometry experienced by the aerial UEs when compared to that experienced by terrestrial UEs. Here geometry

![Figure 2](image-url)
is defined as the ratio of the average received power from the serving cell to the sum of the average interference power and noise power. The average interference power is computed as the sum of average received power from all non-serving cells. The degraded downlink geometry experienced by the aerial UEs is a result of receiving downlink inter-cell interference from multiple cells.

Due to the increased downlink interference, the downlink throughput performance of aerial UEs degrades. The degraded downlink throughput of aerial UEs when coupled with increased aerial UE ratios increases the downlink resource utilization level in the network. An increased downlink resource utilization level inherently means an increased level of downlink interference in the network, which in turn degrades the downlink performance of both aerial UEs and terrestrial UEs. The corresponding downlink results demonstrating the degraded downlink performance are given in Annexes D.1.1 and D.1.2 of [1].

To address the challenges due to the uplink and downlink interference, 3GPP studied interference detection and mitigation techniques, mobility enhancements, and UAV identification. We overview these solutions in the remaining parts of this article, with a summary being presented in Table 1.

VI. POTENTIAL SOLUTIONS FOR INTERFERENCE DETECTION

In this section, we first discuss how to detect the uplink/downlink interference caused/observed by an airborne aerial UE. Interference detection is a useful prerequisite for applying interference mitigation. In the context of aerial UEs, interference detection is also linked with flying mode recognition, as when the aerial UE is above certain height, both uplink and downlink interference increase. The threshold here depends on network deployment and scenario.

During the Release-15 study, potential solutions for interference detection were broadly categorized into either UE-based or network-based solutions. In this section, we briefly summarize these solutions described in Section 7.1 of [1].

A. UE-based Solutions

In an LTE network, UE can perform neighbouring cell measurements such as reference signal received power (RSRP), reference signal received quality (RSRQ), reference signal—signal to interference plus noise ratio (RS-SINR). Downlink interference can be detected based on these UE measurements reported to the eNodeB. One key aspect is to link the triggering of measurement reports to the changing interference conditions. An enhanced triggering condition could be a function of more than single cell RSRP. For example, the measurement can be triggered when multiple cell RSRP/RSRQ values are above/within a threshold or when a sum of RSRP/RSRQ values is above a threshold.

Uplink interference can be detected either based on measurements at eNodeB or based on measurements reported by the UE. Furthermore, maximum output power and physical resource blocks (PRBs) utilized may also be useful.

Since these solutions are based on UE measurements, existing measurement reporting mechanisms can be enhanced to improve interference detection. Potential enhancements

![Figure 3. Illustration of LOS pathloss models derived in the Release-15 study for different aerial UE heights denoted by \( h_{\text{UE}} \) in meters. Note that a carrier frequency of 2 GHz is assumed for UMa-AV and UMi-AV, while a carrier frequency of 700 MHz is assumed for RMa-AV.](image-url)
include new triggering events, enhancements of triggering conditions, and the inclusion of more results in the measurement report.

Lastly, UE related information such as mobility history reports, speed estimation, timing advance adjustment values and location information were also found to be useful.

B. Network-based Solutions

In the network-based solutions, interference detection is performed via the exchange of information between eNodeBs. For example, measurements reported by UE can be exchanged between eNodeBs.

Another example is exchanging uplink reference signal configuration information of aerial UEs. By exchanging this information, a neighbouring eNodeB can measure the uplink interference caused by an aerial UE via measuring the power of the uplink reference signal.

Information on eNodeB’s downlink transmission power can also be exchanged between eNodeBs. With neighbor eNodeB’s transmission power, the uplink pathloss between an aerial UE and the specific target neighbor eNodeB can be determined assuming reciprocity and from the UE’s measurement reports. The uplink interference then can be estimated from the transmission power and the uplink pathloss.

It should be noted, however, that the feasibility of exchanging all this information depends on factors such as the type of backhaul and the feasibility of exchanging such information over a large number of eNodeBs.

VII. UPLINK INTERFERENCE MITIGATION

In this section, we summarize the various uplink interference mitigation techniques that were evaluated during the Release-15 study.

A. Uplink Power Control

UE specific fractional pathloss compensation is one of the power control techniques evaluated during the Release-15 study. As the name implies, this technique requires the introduction of a UE specific fractional pathloss compensation parameter which is an enhancement to the existing open loop power control mechanism in LTE (see Clause 5.1 of [15] for details of the existing power control mechanism in LTE). With this technique, the aerial UEs can be configured with a different fractional pathloss compensation factor compared to that configured to the terrestrial UEs. Note that depending on the aerial UE height, different aerial UEs can also be configured with different fractional pathloss compensation factors. Based on Release-15 evaluations, it was observed that applying height dependent fractional path loss compensation factors to aerial UEs can significantly improve terrestrial UE performance while yielding notable performance gains for the aerial UEs. Details and evaluation results corresponding to this technique can be found in Section 7.3.2.1 and Annex F.1.1 of [1].

A second power control technique evaluated during the Release-15 study is the use of UE specific $P_0$ parameter (note that $P_0$ is an open loop power control parameter specified in LTE). With this technique, the aerial UEs can be configured with a different $P_0$ parameter compared to that configured to the terrestrial UEs. Based on the Release-15 evaluations, it was observed that applying a lower $P_0$ parameter to aerial UEs can improve terrestrial UE performance at the cost of reduced aerial UE performance. Since the $P_0$ parameter can be UE specifically configured in LTE, this technique does not require specification enhancements. However, it was found that the range of values supported in LTE for UE specific $P_0$ may need to be extended. Details and evaluation results corresponding to this technique are given in Section 7.3.2.2 and Annex F.1.2 of [1].

During the Release-15 study, closed loop power control based technique was also evaluated. In this technique, the target received power of the aerial UEs was adjusted considering measurement reports received from both serving and neighbor cells. Based on the Release-15 evaluations, it was observed that closed loop power control can result in mean throughput performance gains for both terrestrial UEs and aerial UEs. Details and evaluation results corresponding to this technique are given in Section 7.3.2.3 and Annex F.1.3 of [1]. During the Release-15 study, the need for closed loop power control to cope with potential fast signal change in the sky was discussed. Such fast signal changes are possible in the sky given the aerial UEs may be served by the sidelobes of eNodeB antennas. To
cope with such fast signal changes, the step size of the transmit power control command may need to be increased which in turn may require specification enhancements to the existing power control mechanism in LTE.

During the Release-15 study, other power control techniques requiring modifications to the power control mechanism in LTE to consider interference from neighbor cells were also discussed. However, solutions based on these techniques were not evaluated during the study.

B. FD-MIMO

With full dimensional multi-input multi-output (FD-MIMO), multiple receive antennas at the eNodeB can be used to mitigate interference in the uplink. Based on Release-15 evaluations, it was observed that, FD-MIMO can limit the mean uplink terrestrial UE throughput performance loss when compared to the case when FD-MIMO is not deployed at the eNodeB. As FD-MIMO is supported in LTE since Release-13, this technique does not require any specification enhancements. Details and evaluations corresponding to this technique are given in Section 7.3.3 and Annex F.2 of [1].

C. Directional Antennas at UE

During the Release-15 study, the use of directional antennas at the aerial UE was shown to reduce the uplink signal power from the aerial UE in a broad range of angles. This in turn helps reduce the uplink interference caused by the aerial UEs. The following types of aerial UE LOS tracking were considered:

- the antenna direction of the aerial UE is aligned with the direction of travel (DOT) of the UE
- the LOS direction to the serving cell is either ideally tracked by steering its antenna boresight towards the serving cell or non-ideally tracked UE with errors due to practical constraints

Release-15 evaluation results showed that with the antenna direction of the aerial UE aligned with the DOT, the mean terrestrial UE throughput performance loss can be limited when compared to the case when the aerial UEs are equipped with omnidirectional antennas. Furthermore, this technique was also shown to significantly improve the mean aerial UE throughput performance. As the use of directional antennas at the aerial UE is an implementation issue, this technique does not require any specification enhancements. Details and evaluation results corresponding to this technique are given in Section 7.3.4 and Annex F.3 of [1].

VIII. DOWNLINK INTERFERENCE MITIGATION

In this section, we summarize the various downlink interference mitigation techniques that were evaluated during the Release-15 study.

A. FD-MIMO

With FD-MIMO, multiple transmit antenna ports at the eNodeB can be used to mitigate downlink interference to the aerial UEs. Based on Release-15 evaluations, it was observed that FD-MIMO can limit the impact on mean terrestrial UE throughput performance while providing downlink aerial UE throughputs that satisfy the aerial UE throughput requirements discussed in Section II. This technique does not require any specification enhancements as FD-MIMO is supported in LTE since Release-13. Details and evaluation results of this technique are given in Section 7.2.2 and Annex E.1 of [1].

B. Directional Antennas at UE

In the Release-15 study, the use of directional antennas at the aerial UE is shown to reduce the downlink interference to the aerial UEs from a broad range of angles. From the evaluation results in the Release-15 study, it was observed that with non-ideal LOS tracking at the aerial UEs, the mean downlink terrestrial UE throughput performance loss can be limited when compared to the case when the aerial UEs are equipped with omnidirectional antennas. The mean aerial UE downlink throughput performance was also shown to be significantly improved with this technique. This technique does not require any specification enhancements since the use of directional antennas at the aerial UE is an implementation issue. Details and evaluation results corresponding to this technique are given in Section 7.2.3 and Annex E.2 of [1].

C. Receive Beamforming at UE

When the aerial UEs are equipped with more than 2 receive antennas, receive beamforming can be an effective interference mitigation technique in the downlink. From Release-15 evaluations, it was observed that receive beamforming with 8 receive antennas at the aerial UEs can improve mean downlink throughput performance of all UEs notably. Specification enhancements are not needed for this technique as the application of receive beamforming can be done via implementation. Details and evaluation results corresponding to this technique are given in Section 7.2.4 and Annex E.3 of [1].

D. Intra-site JT CoMP

In the intra-site JT CoMP (joint transmission coordinated multiple points) scheme, data are jointly transmitted to the UEs from multiple cells that belong to the same site. From Release-15 evaluations, it was observed that intra-site JT CoMP can improve mean downlink performance of all UEs at low offered traffic load when compared to the case when intra-site JT CoMP is not employed. Specification enhancements are not needed for this technique as intra-site JT CoMP can be already supported by LTE. Details and evaluation results corresponding to this technique are given in Section 7.2.5 and Annex E.4 of [1].

E. Coverage Extension

In the Release-15 study, coverage extension techniques were studied to enhance synchronization and initial access performance of aerial UEs. From Release-15 evaluations, it was observed that the proportion of UEs achieving synchronization and initial access can be improved via coverage extension techniques. Specification enhancements are not needed for this technique as coverage extension is already supported in LTE since Release-13. Details and evaluation results corresponding to this technique are given in Section 7.2.6 and Annex E.5 of [1].

F. Other Schemes

In the Release-15 study, other schemes such as coordinated transmission of control and data from multiple cells was briefly discussed. It was concluded that the details of the specification
Table 2. Summary of Issues and Potential Solutions

| Issue | Solution | Specification Impact |
|-------|----------|----------------------|
| Interference Detection | Interference detection using existing UE measurement reports such as RSRP, RSRQ, RS-SINR. Power headroom reports may also be used for uplink interference detection. | Already supported in LTE up to Release-14 and no specification enhancements needed. |
| | Interference detection using enhanced measurement reporting mechanisms such as definition of new events, enhancements to triggering conditions and inclusion of further measurement results in measurement report. | Requires specification enhancements to define new events, enhanced triggering conditions, etc. |
| | Interference detection using UE based information such as mobility history reports, speed estimation, timing advance adjustment values and location information. | No specification enhancements needed. |
| | Interference detection via exchange of information between eNodeBs. Examples of information that can potentially be exchanged include the following: (1) uplink scheduling information or uplink reference signal configuration, (2) target eNodeB’s downlink transmission power, (3) UE measurement reports such as RSRP, RSRQ, RS-SINR | Specification impact may depend on the type of backhaul. For instance, with non-ideal backhaul, the exchange of target eNodeB’s downlink transmission power will need specification enhancements. |
| Uplink Interference Mitigation | Uplink power control schemes such as applying UE specific fractional pathloss compensation, applying UE specific $P_0$ parameter, and applying closed loop power control with increased step size of the transmit power control command. | The introduction of UE specific fractional pathloss compensation parameter requires specification enhancement. Similarly, for closed loop power control, the introduction of increased step size of the transmit power control command requires specification enhancement. The application of UE specific $P_0$ parameter does not require specification enhancement, although the range of values supported in LTE for UE specific $P_0$ may need to be extended. |
| Directional Antennas at UE | FD-MIMO | Already supported in LTE up to Release-14 and no specification enhancements needed. |
| Downlink Interference Mitigation | FD-MIMO | Already supported in LTE up to Release-14 and no specification enhancements needed. |
| | Directional Antennas at UE | An implementation issue and no specification enhancements needed. |
| | Receive Beamforming at UE | An implementation issue and no specification enhancements needed. |
| | Intra-site JT CoMP | Already supported in LTE up to Release-14 and no specification enhancements needed. |
| Coverage extension | Other Schemes | Already supported in LTE up to Release-14 and no specification enhancements needed. |
| Mobility Performance Improvement | Enhancements to handover procedure such as conditional handover and/or handover related parameters considering such as location information, airborne status, flight path plans, etc. | Specification enhancements needed. |
| | Enhancements to existing measurement reporting mechanisms such as definition of new events, enhancements of triggering conditions, etc. | Specification enhancements needed. |
| Aerial UE Identification | Identifying a flying aerial UE based on such as flight mode indication, altitude or location information, or implicitly via enhanced measurement reporting. | Specification enhancements needed. |
| | Identifying a flying aerial UE based on mobility history reports/patterns. | No specification enhancements needed. |
| | Identifying an aerial UE based on subscription information in combination with radio capability indication from the aerial | Specification enhancements needed. |

Impact depend on the details of the coordinated data and control transmission scheme which needed further study. Evaluation results corresponding to this technique are given in Section 7.2.7 and Annex E.6 of [1].

IX. MOBILITY PERFORMANCE AND POTENTIAL ENHANCEMENTS

During the Release-15 study, mobility simulations were performed (see Annex J of [1]) and measurements from field trials were collected (see Annex H of [1]). From these results, the mobility performance of an aerial UE is shown to be worse...
when compared to that of a terrestrial UE especially when the number of aerial UEs in large. Due to the increased downlink interference, the downlink signal to interference plus noise ratio (SINR) for the aerial UEs is much worse than the downlink SINR for the terrestrial UEs. Hence, the aerial UEs may experience more handover failures, more radio link failures, longer handover interruption time, etc. The mobility simulation results showed a better mobility performance for aerial UEs in the RMa-AV scenario than in the UMa-AV scenario. It should be noted however that interference mitigation techniques listed in Sections VII and VIII were not considered in the mobility simulations of the Release-15 study and the use of such techniques is expected to improve the aerial UEs’ mobility performance.

In the Release-15 study, the following techniques to improve mobility performance of aerial UEs were identified:

- enhancements to handover procedure such as conditional handover and handover related parameters considering such as location information, airborne status, flight path plans, etc.
- enhancements to existing measurement reporting mechanisms such as new events, enhancements of triggering conditions, etc.

More detailed discussion can be found in Section 7.4 of [1].

X. AERIAL UE IDENTIFICATION

Depending on country-specific regulations, an aerial UE may need to be identified by the network in order to allow the use of LTE networks for aerial UE connectivity. Another aspect is that there may be drone specific service or charging by the operator. In the Release-15 study, aerial UE identification was discussed; see details in Section 7.5 of [1].

Aerial UE identification solution discussed during the study item is a combination of user based identification via subscription information and device functionality based identification via LTE radio capability signaling. The mobility management entity (MME) can signal the subscription information to the eNodeB which can include information on whether the user is authorized to operate for aerial usage. In addition, an aerial UE as LTE device can indicate its support of aerial related functions that will be introduced in the Release-15 work item [12] via radio capability signaling to the eNodeB. The combination of the subscription information and the radio capability indication from the UE can be used by the eNodeB to identify an aerial UE, and then perform the necessary control and the relevant functions.

The LTE capability indication plays a role in the flight mode recognition. An aerial UE capable of Release-15 enhancements may be able to explicitly indicate flight mode if that is specified. Alternatively, the measurement triggering enhancements used for interference detection may be used to implicitly aid flight mode detection. Flight mode detection of a UE that does not have Release-15 aerial UE capability needs to rely on existing standardized metrics from UE such as mobility history, speed, existing RSRP/RSRQ measurement events. In some networks, this is also equivalent to drone detection where a non-aerial UE is not allowed to use the network for connectivity while airborne.

XI. CONCLUSIONS

In Release-15, 3GPP has dedicated a significant effort during its study on LTE connected drones and concluded that it is feasible to use existing LTE networks to provide connectivity to low altitude drones despite some challenges, as overviewed in this article. Providing efficient and effective connectivity to the aerial UEs while minimizing the impact on terrestrial devices requires a rethinking of many of the assumptions, models, and techniques used to date for cellular system. This article has particularly focused on the 3GPP state-of-the-art findings on LTE connected drones, although most of the lessons herein would likely apply to any cellular systems (such as 5G) providing connectivity to the sky.

REFERENCES

[1] 3GPP TR 36.777, “Enhanced LTE support for aerial vehicles,” Online: http://www.3gpp.org/ftp/Specs/archive/36_series/36.777.
[2] GSMA, “Mobile spectrum for unmanned aerial vehicles; GSMA public policy position,” white paper, October 2017. Online: https://www.gsma.com/spectrum/wp-content/uploads/2017/10/Mobile-spectrum-for-Unmanned-Aerial-Vehicles.pdf. Accessed on December 14, 2017.
[3] X. Lin, V. Yajnanarayana, S. D. Muruganathan, S. Gao, H. Asplund, H.-L. Maatuanen, M. Bergström, S. Euler, Y.-P. E. Wang, “The sky is not the limit: LTE for unmanned aerial vehicles,” IEEE Communications Magazine, vol. 56, no. 4, pp. 204-210, April 2018. Available at https://arxiv.org/abs/1707.07534.
[4] X. Lin, R. Wiren, S. Euler, A. Sadam, H.-L. Maatuanen, S. D. Muruganathan, S. Gao, Y.-P. E. Wang, J. Kauppi, Z. Zou, and V. Yajnanarayana, “Mobile Networks Connected Drones: Field Trials, Simulations, and Design Insights,” submitted to IEEE Communications Magazine, February 2017. Available at http://arxiv.org/abs/1801.10508.
[5] M. Gharibi, R. Boutaba and S. L. Waslander, “Internet of drones;” IEEE Access, vol. 6, pp. 1148-1162, March 2016.
[6] S. Chandrasekharan, K. Gomez, and A. Al-Hourani, et al., “Designing and implementing future aerial communication networks,” IEEE Communications Magazine, vol. 54, no. 5, pp. 26-34, May 2016.
[7] FAA, “UAS traffic management research transition team plan,” technical report, January 2017. Online: https://www.faa.gov/uas/research/utm/media/FAA_NASA_UAS_Traffic_Management_Research_Plan.pdf. Accessed on January 30, 2018.
[8] U.S. DOT and FAA, “UAS integration pilot program,” October 2017. Online: https://www.faa.gov/uas/programs_partnerships/uas_integration_pilot_program/. Accessed on January 30, 2018.
[9] Goldman Sachs, “Drones: Reporting for work,” 2017. Online: http://www.goldmansachs.com/our-thinking/technology-driving-innovation/drones/. Accessed on January 30, 2018.
[10] V. Yajnanarayana, Y.-P. E. Wang, S. Gao, S. Muruganathan, X. Lin, “Interference mitigation methods for unmanned aerial vehicles served by cellular networks”, IEEE 5G World Forum, to appear. Available at https://arxiv.org/abs/1802.00223.
[11] RP-170779, “Study on enhanced LTE support for aerial vehicles,” NTT DOCOMO, Ericsson, March 2017. Online: http://www.3gpp.org/ftp/tsg_ran/tsg_ran/RAN/TSGR_75/Docs/RP-170779.zip. Accessed on December 14, 2017.
[12] 3GPP RP-172826 “New WID on Enhanced LTE Support for Aerial Vehicles,” Ericsson, December 2017. Online: http://www.3gpp.org/ftp/TSG_RAN/TSG_RAN/TSGR_78/Docs/RP-172826.zip. Accessed on January 30, 2018.
[13] 3GPP TR 38.901, “Study on channel model for frequencies from 0.5 to 100 GHz,” Online: ftp://ftp.3gpp.org/specs/archive/38_series/38.901
[14] R1-1715084, “Summary of Email discussion [89-10] on remaining details of channel modelling;” Ericsson, August 2017. Online: http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_90/Docs/R1-1715084.zip. Accessed on January 4, 2018.
[15] 3GPP TS 36.213, “Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 15),” V15.0.0. Online: ftp://ftp.3gpp.org/specs/archive/36_series/36.213/