Reliable 3D connectivity for drones over LTE networks

How cellular networks can enable beyond visual line of sight drone flights

White Paper

LTE networks are an attractive alternative for providing reliable communications for drones, as they provide almost unambiguous coverage, minimizing additional investments. This paper examines in more detail the feasibility of today’s LTE networks to provide a reliable command and control link to airborne drones, which is one of the requirements for Beyond Visual Line Of Sight (BVLOS) operations. BVLOS flights will open up further use cases and possibilities on top of the already ongoing boom in new drone use cases, thereby making drones an attractive customer group for cellular operators to address. Results from both measurements and simulations are used to show that LTE networks can provide reliable connectivity for drones today, whereas at times of high load certain interference mitigation enhancements may be needed.
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Executive Summary

The drone market, which is increasing fast, is an interesting market to address for network operators, as they require connectivity for their command and control link in Beyond Visual Line Of Sight (BVLOS) operations. Cellular networks, like LTE, are an attractive candidate for providing this service to drones in the sky, as they already today provide wide area coverage, thus minimizing additional investments. LTE networks are however designed and optimized for terrestrial users and propagation in the sky is different from on the ground as signals propagate typically further in the sky compared to the ground level. On top of this, the number of visible interferers increases with increased height. For relatively low loaded networks, this is no problem, but for medium and highly loaded networks this means the required high reliability for drone communications may not be reached without additional measures. Additionally, if the drone is running an application requiring a high throughput, like streaming from an onboard camera, in the uplink (towards the base station), this causes significantly more radio interference to the other users in the network than it is caused by smartphone with similar service at ground level.

This means that interference mitigation may be needed at times of high traffic load for both up and downlink. Several solutions exist, which vary if performance and complexity. From the four studied interference mitigation techniques in this paper, the terminal side grid of fixed beams is the most attractive, giving good gains at a slightly higher complexity at the drone. Second best solution is interference coordination between radio cells, which can give good gains if enough cells are coordinated, but leads to a higher network complexity.

In general, it can be said that today’s cellular network can provide service coverage with high reliability for drones, and with certain enhancements they will be able to provide high reliability also at times of high load.

Introduction

According to [1], the sales of consumer Unmanned Aerial Vehicles (UAVs), which drones are also referred to, will increase tenfold by 2021. In [2], the commercial applications of drone technology are allowing companies from agriculture to film-making industry to create new business and operating models, which in turn creates global market value estimated over $127.3 billion. This increasing interest in drones is one of the best signs of how lower pricing in hardware can drive the Internet of Things (IoT).

Currently, regulations in most countries only allow for operating drones when there is Visual Line Of Sight (VLOS) between drone pilot and the drone, but it is expected that Beyond Visual Line Of Sight (BVLOS) operations will be allowed, provided there is a reliable Command and Control (C2) link to the drone. This link is very important to ensure safe drone operations and is an important part in the provisioning of a reliable E2E reliability for the drone communications. In the uplink, i.e. from a drone to base station, the control link is used to update the Unmanned Aircraft System Traffic Management or flight control unit with status.
messages, including the drone location, plus potentially further information from for instance sensors, which the flight control function can utilize to make its decisions. In the downlink (towards the drone), it allows the flight control function to change the drones flight plan to avoid potential collisions, enable dynamic geofencing, or to command a range of sensor/actuator functions on board of the drone. One example of downlink usage of the C2 link is when on the route of a drone, suddenly a helicopter or another drone needs to land for an emergency. In that case, the downlink C2 link can be used to notify the drone of a new ad hoc no-fly zone and redirect the drone by providing new directions.

One attractive means to provide this C2 link is to utilize existing cellular networks, in particular the LTE-based systems, as the infrastructure is in place and investments can therefore be minimized. However, such networks are not designed for aerial coverage, as they are optimized for ground users, typically using for instance down-tilted antennas at the base stations. Nevertheless, as we will explain in this white paper, existing LTE networks and future 5G networks are able to ensure reliable C2 communication to drones, and play an important role in the provisioning of a reliable E2E reliability for the drone communications, similar to other use cases requiring high reliability [References: 4.9G technologies; Developing the infrastructure and ecosystem for a 5G world]. This way cellular networks can enable beyond visual line of sight drone flights. For the operators of those networks the increasing number of drones is an attractive group of potential customers to address.

Not surprisingly various regulation committees are striving for specifying the rules which drone operations must conform to, to ensure a robust and well-organized transition towards the “Aerial Vehicles era”. Among those organizations attempting to address drone use cases, one can find also the 3rd Generation Partnership Project (3GPP), responsible for standardizing worldwide cellular technologies, such as UMTS and LTE. In December, a 3GPP work item: “Enhanced support for Aerial Vehicles” has been approved [5], aimed at preparing LTE networks to support a new type of UE, likely to emerge in cellular networks in the imminent future.

Use cases and Requirements

The number of use cases for commercial drone operations are numerous. Below, we list a few examples, which are also shown in Figure 1, but many more use cases exist and new ones may appear:

- Medical supply delivery. This can range from transportation of medications to remote hard to access areas to transport of blood from one hospital to another hospital for efficiency reasons.
- Agriculture surveillance. Drone agriculture applications range from mapping and surveying to crop dusting and spraying, leading to efficient use of sparse resources and maximization of the production.
• Traffic surveillance and real-time notifications. It is well known that cars can report congestion, but with a drone one gets the bigger picture of special congestion and a drone with a camera can be very helpful getting an overview in case of accidents.
• Search and rescue. Drones can be used to find missing persons, like for instance shown in [3] where a group of drones flying in formation is shown to efficiently search for people in a disaster area.
• Property surveillance. Drones come in handy when remote buildings and/or larger infrastructures need to be monitored. One or more moveable cameras from the sky gives a fast overview.
• Transport of goods. Delivery of packets to remote locations and in general transport in the last mile can be performed by drones in an efficient way, thus saving the environment and money, as delivery trucks can deliver packets at centralized places, from where the packets are delivered by drones.

Figure 1. Example commercial drone use cases

Common to all use cases is that a C2 link is required. The C2 link is required for controlling the drone, for being able to redirect it in case of for instance a helicopter landing at an accident spot or simply for optimizing the route to avoid congestion. In the uplink (towards the base station), the coordinates and optional sensor data is uploaded to a centralized coordinator function e.g. an UAV Traffic Management (UTM) [4], whereas in the downlink (towards the drone), the new directions and coordinates are provided, plus potential other indications to ensure a safe flight.

The C2 link requires high reliability as it is important for drone safety. The 3GPP has set the reliability requirement in its studies on aerial connectivity to 99,9%, meaning that 99,9% of the time a packet needs to reach its destination within the delay budget, which is set to 50 ms. At the same time, the required throughput is rather low. The 3GPP assumes 100 kbps
[5], whereas the ITU, taking all possible content ranges into account, considers the C2 link throughput requirements to range from 2 to 300 kbps and less stringent delay requirements of 200 ms to 1 second [6].

On top of the C2 link, there may be other applications running on board of the drone which require radio communication. These applications may have very different requirements from case to case, e.g. an autonomous transport drone will not have much extra information exchanged, except maybe a note when a packet is delivered, whereas a drone providing high quality live streaming from a certain event will require high uplink throughput. Typical requirements for these applications are more uplink heavy than downlink. The C2 control link is more symmetric. The key drone traffic characteristics are summarized in Table 1.

| Table 1. Technical comparison on aggregation capabilities |
|---------------------------------|-----------------|-----------------|-----------------|
| Downlink Throughput            | Uplink Throughput | Reliability | Delay |
| C2 link                         | 50-100 kbps      | 50-100 kbps    | 99.9%           | 50 ms |
| Application                     | < 1 Mbps         | Up to 20 Mbps  | Like MBB        | Like MBB |

Propagation Aspects

Cellular networks are designed to serve users on the ground and are highly optimized for this purpose. Base station antennas are typically down tilted to get a good tradeoff between coverage and interference for ground users and handover candidate lists are designed for ground users to name a few of those optimizations. When studying the feasibility of cellular-based communication for drones, we need to understand the difference between serving ground users and aerial users. One expected difference is the radio propagation channel. It is reasonable to assume that the channel will present different behaviors for an aerial user when compared to a regular ground user. Drones flying above rooftops, vegetation and terrain elevations, are more likely to observe radio path clearance to the base stations in the surrounding area. Therefore, they are more likely to experience line-of-sight (LOS) radio propagation for larger distances resulting in higher level of interference from a larger number of surrounding base stations, but at the same time also achieving LOS conditions to the serving cell improving the desired signal level.
To study the effects of the height above the ground on the path loss a UE experiences several radio measurement campaigns were performed in Denmark [7]. The measurements were performed by having a network scanner moved to different heights into the air by having it lifted by a drone (see Figure 2). The network scanner measured the signal levels, represented by the Reference Signal Received Power (RSRP) value, of existing LTE base stations in its surroundings. Measurements were performed in rural environments. From the measurement results, several interesting observations can be made.

Firstly, we see a reduction of the path loss slope with increased heights. This is illustrated in Figure 3, where the measurement results are shown at ground level and at 120 m heights plus the best fitted line versus the distance to the measured cell. The path loss is higher at ground level than at 120 m, confirming the increased likelihood of LOS. This is furthermore confirmed by the slope of the fitted lines, which show a path loss slope of 3.7 at ground level, while it matches 2.0 at 120 m, corresponding to free space propagation. The estimated path loss slope coefficients for the different heights are shown in Table 2.
Secondly, as can be seen from Table 2, the number of cells the measurement equipment can detect increases significantly when moving from ground level to 120 m. At ground level, on average, 5.1 cells can be detected, which is quite like what one can expect of a normal handset, whereas at 120 meters heights, the number is more than 3 times as high: 16.9 cells can be detected. This leads to the conclusion that not only the interference per cell gets stronger but also the number of potential interferers increases.

The measurements have been repeated in urban areas, and the results show similar trends. More information on the details of the measurements can be found in [8].

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Path loss model slope</th>
<th>Average number of detected cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>3.7</td>
<td>5.1</td>
</tr>
<tr>
<td>15</td>
<td>2.9</td>
<td>6.1</td>
</tr>
<tr>
<td>30</td>
<td>2.5</td>
<td>7.6</td>
</tr>
<tr>
<td>60</td>
<td>2.1</td>
<td>11.6</td>
</tr>
<tr>
<td>120</td>
<td>2.0</td>
<td>16.9</td>
</tr>
</tbody>
</table>
Downlink Connectivity

To investigate the impact of the different propagation conditions explained in the previous section, we investigated the drone downlink connectivity in both a rural and in an urban area by simulations. For the rural area, we consider a 70 x 70 km rural space in Denmark. For the urban area we study one of the major cities in Denmark, Aalborg. In both cases, we use a real world LTE network as network layout, including actual base station locations, height, antenna patterns, bearings, and down-tilting. In the rural area the base station heights range from 19 to 50 m above the ground, and down-tilting angles are from 0 to 9 degrees, while in the urban area the base station heights are around 30 m and a bit larger downtilt, ranging from 0 to 11 degrees is used. Terrain profile is considered and drones are assumed to always fly above the terrain at a constant height. The LTE system considered in our simulation has 2x2 Multiple Input Multiple Output (MIMO). For the rural area, we use the propagation model [7] deducted from our measurements mentioned in the previous section, while for the urban area the model from 3GPP [5] has been used, the main addition to a height dependent path loss slope being a LOS probability.

Figure 4 shows the average downlink SINR for both the terrestrial UEs (TUE) and drones (UAV) at different heights for the urban and rural scenario at medium and high downlink traffic load. These load levels correspond to 30% and 55-65% average resource utilization in the downlink. It should be noted that the load in today’s real LTE networks typically is lower than the values we use for medium load. Reason for using these high values is to see whether high reliability even can be achieved for drones when the load will increase in the future. The following observations can be based on these results:

- The average downlink SINR drops with increasing height for the drones. Reason for this is that the interference increases with increasing height, as more interfering sources becomes visible and the propagation becomes more advantageous when the height increases.
- The average downlink SINR of drones is more sensitive to the load in the network than that of the terrestrial users, caused by the fact that aerial users see more potential interferers.
For a UE to be able to connect to the network and stay connected, the downlink SINR needs to be above -6 dB. While the downlink mean SINR values are all above this threshold, there are variations around these mean values which make that UEs at different heights experience different levels of outage, i.e. likelihood of being unable to connect to the network. The outage levels for different heights and loads for both rural and urban scenarios can be seen in Table 3. From the numbers in the Table 3, the outage probabilities increase with height and network load. Whereas on the ground, in an urban area, the terrestrial users in a highly loaded network have 1,5% probability of experiencing outage for drones at 120 meters in the same scenario the outage probability reaches a soaring 23%. In general, it can be concluded that these outage probabilities show that the current cellular network at high load cannot provide a highly reliable connection to drones, whereas at medium load the outage probabilities may be acceptable. In other words, to ensure high reliability at all load conditions, interference mitigation is needed. Before looking at the enhancement possibilities, we will first have a look at the uplink drone communication and influence of drones on the overall network performance.

Table 3. Outage probabilities for the different scenarios

<table>
<thead>
<tr>
<th></th>
<th>Rural area</th>
<th>Urban area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medium load</td>
<td>High load</td>
</tr>
<tr>
<td>Terrestrial users</td>
<td>0,3%</td>
<td>1,5%</td>
</tr>
<tr>
<td></td>
<td>1,1%</td>
<td>2,8%</td>
</tr>
<tr>
<td>Drones at 60 m</td>
<td>1,7%</td>
<td>10,9%</td>
</tr>
<tr>
<td></td>
<td>6,9%</td>
<td>11,2%</td>
</tr>
<tr>
<td>Drones at 120 m</td>
<td>3,5%</td>
<td>23%</td>
</tr>
<tr>
<td></td>
<td>14,5%</td>
<td>21,4%</td>
</tr>
</tbody>
</table>
Impact of uplink streaming from a drone

Traffic in the uplink and the downlink differ significantly as drone applications will often be used to upload or stream data, which typically requires high uplink data rates. Combining this with the fact that an airborne drone sees many more cells than a terrestrial user leads to the fair assumption that a drone can cause significant uplink interference. To verify this, a series of measurements were performed in both rural and urban areas, using a live LTE network carrier at 800 MHz. The interference impact of full buffer transmission by a cell phone at different heights was measured: at ground level and at 100 meters (attached to an airborne drone). The cells in a wide radius around the phone location were monitored to quantify the impact on the uplink interference levels. The phone was almost all the time using the full bandwidth. In the rural case, it used maximum power most of the time, whereas in the urban location the transmission power of the phone was 10 dB lower on average, as the serving cell was closer by. In Table 4, the average interference increase over noise level is shown for the most impacted cell and the top 3 and 6 affected cells for both the terrestrial and drone. The difference between the two is an indication of how much more interference is caused by a drone compared to a terrestrial user. Interference caused by the drone is considerably higher than that of the user on the ground. Looking at the most interfered cell, it can be concluded that the drone is more than 4 times as expensive in terms of interference as a similar user on the ground. Additionally, it needs to be noted that the cells which are seeing interference from the drone can be very far away from the location of the drone: the most interfered cell in case of the rural measurements is close to 15 km away, whereas the average inter site distance in this rural area is 3 km.

<table>
<thead>
<tr>
<th></th>
<th>Rural area</th>
<th>Urban area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Terrestrial user</td>
<td>UAV at 100 m</td>
</tr>
<tr>
<td>Most affected cell</td>
<td>3.7 dB</td>
<td>11.3 (+6.3) dB</td>
</tr>
<tr>
<td>Top 3 affected cells</td>
<td>3.7 dB</td>
<td>9.5 (+5.8) dB</td>
</tr>
<tr>
<td>Top 6 affected cells</td>
<td>2.9 dB</td>
<td>8.6 (+5.7) dB</td>
</tr>
</tbody>
</table>

From the above results it is clear that airborne drones with applications requiring a large uplink throughput are challenging for the uplink in cellular networks, as there are much costlier in terms of interference than corresponding users on the ground, despite antennas being down tilted. Similarly, to downlink, interference mitigation techniques may be needed. These are discussed in the next section.
Interference mitigation

We can split the interference mitigation techniques into two categories: terminal side enhancements, enhancing the receiver and/or transmitter on the drone, and network enhancements, adding features to the network to lower the interference effects. The different methods can be seen in Table 5, and are shortly described and evaluated below for the case where we have 1 drone per 100 terrestrial users. In the evaluations, we focus on the worst case where the drone is at 120 m height and the network load is high.

<table>
<thead>
<tr>
<th>Terminal enhancements</th>
<th>Network enhancements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam steering (downlink &amp; uplink)</td>
<td>drone specific power control (uplink)</td>
</tr>
<tr>
<td>Interference cancellation (downlink)</td>
<td>Interference Coordination (downlink)</td>
</tr>
</tbody>
</table>

Beam steering / grid of fixed beams

Antenna selection with two or more antenna elements can be equivalent to a very simple beam selection when the antennas are placed on the drone at the right spacing and orientations. It is easy to increase the number of beams to four or six by adding additional directional antennas antenna elements, as depicted in Figure 5. The modeled beam patterns provide +6.6 dBi gain in the main direction and 13 dB front-to-sidelobe attenuation, which can be considered to account for the non-ideal shape of the beams.

The receiver simply picks the beam direction with the best signal quality (RSRP or RSRQ) without adjusting the orientation of the drone. By doing so, the amount of interference received in the downlink is limited to the beam width of the beam, leading to a reduced overall outage as can be seen in Figure 6 for beam steering with 6 beams and a 3dB beam width of about 50 degrees. For both rural and urban areas the achieved reliability is higher than the target 99.9%.
Figure 6. Outage probability for a drone at 120 m in urban and rural environments with and without fixed grid of beams for the high network load case.

Furthermore, beam steering also provides advantages in the uplink as it gives a gain for the drone and limits the interference impact on terrestrial users, as the signal originating from the drone is only spread in a limited angle. This has a positive effect on both the terrestrial and the drone throughputs, which is shown in Table 6 for the case where all drones are equipped with 6 beams.

Table 6. Average uplink throughput gains with a grid of fixed 6 beams in medium - high load traffic conditions

<table>
<thead>
<tr>
<th></th>
<th>Terrestrial UE</th>
<th>Drone at 120 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural environment</td>
<td>+20%</td>
<td>+36%</td>
</tr>
<tr>
<td>Urban environment</td>
<td>+51%</td>
<td>+56%</td>
</tr>
</tbody>
</table>

**Interference Cancellation**

Another obvious candidate for interference mitigation is interference cancellation at the receiver in the drone. Interference cancellation or Interference Rejection Combining receivers can be implemented from 3GPP rel. 13 and beyond. We evaluate the potential of having interference cancellation implemented in the drone, enhancing the downlink performance, by assuming that we can remove up to 3 interferers perfectly. Figure 7 shows the improvement of removing the 3 strongest potential interferers in terms of outage probability for both rural and urban environments. The observed gain is limited and the target of a reliability of 99,9% is not reached. Reason for this is that the interference comes from many more than three interferers when being up in the air.
Figure 7. Outage probability for a drone at 120 m in urban and rural environments with and without interference cancellation, removing the 3 potential strongest interferers completely.

**Drone specific power control**

A very straightforward method of limiting the uplink interference caused by a drone is to use different power control settings for drones as for terrestrial users, as the uplink LTE power control algorithm contains some adjustable parameters. We focus on the P0 parameter, which can be seen as the target received power level from the UE at the eNB. By using a lower P0 for drones compared to terrestrial users they will use a lower output power, and therefore cause less interference. As shown in Table 7 this will result in a higher throughput for the terrestrial users, as a part of the interference is removed, while the throughput of the drone decreases, since less transmit power is available. Like with the grid of fixed beams, interference to the terrestrial users is decreased, but in this case the uplink throughput of the drone is degraded, which is not the case with the grid of fixed beams.

<table>
<thead>
<tr>
<th></th>
<th>Rural environment</th>
<th>Urban environment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>terrestrial UE</strong></td>
<td>- 3 dB</td>
<td>- 6 dB</td>
</tr>
<tr>
<td></td>
<td>+ 10%</td>
<td>+20%</td>
</tr>
<tr>
<td></td>
<td>-12 dB</td>
<td>+33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-21%</td>
</tr>
<tr>
<td><strong>Drone</strong></td>
<td>- 3 dB</td>
<td>- 6 dB</td>
</tr>
<tr>
<td></td>
<td>-12 dB</td>
<td>- 6 dB</td>
</tr>
<tr>
<td></td>
<td>- 12 dB</td>
<td>- 12 dB</td>
</tr>
<tr>
<td></td>
<td>-23%</td>
<td>- 37%</td>
</tr>
<tr>
<td></td>
<td>- 60%</td>
<td></td>
</tr>
</tbody>
</table>

**Interference Coordination**

Another network based solution is the downlink inter-cell interference coordination (ICIC). Several standardized solutions for this exist. The simplest downlink ICIC scheme was introduced in 3GPP Release 8, and is purely based on intercell signaling and does not require any UE-side functionality. The general idea is to coordinate the usage of radio resources between cells to optimize the cell edge SINRs. Further possibilities were introduced with the enhanced and further enhanced ICIC (eICIC and feICIC) solutions which were included 3GPP Releases 10 and 11. These solutions can be considered as candidate solutions in the drone
scenarios as well.

The outage can be decreased by coordinating the downlink transmission from the right number of cells. Figure 8 shows the gain in outage versus the number of interferers removed for the urban and rural scenario.

![Figure 8](image)

**Figure 8.** Drone outage probability for a drone at 120 m in urban and rural environments under high load with removal of a different number of interferers.

From the Figure 8, it can be concluded that quite some cells need to be muted to reach a reliability of 99,9% in case of high load. However, one needs to keep in mind that this reliability is for the C2 link, which only requires 100 kbps. This means the data transmission to and from the drone can be concentrated in time, such that for instance every 10\(^{th}\) TTI is used for drone related transmissions. That would mean only in those TTIs the interfering cells need to be muted. An example of such a setup could be that a drone at 120 meters in the air with a 100 kbps C2 link uses every tenth 10\(^{th}\) TTI. In the high load scenario this will require muting the 8 strongest cells every 10\(^{th}\) TTI [9], corresponding to removing the 10% of the capacity of those cells.

### Comparison Interference Mitigation techniques

In the previous section, four different interference mitigation techniques for drones were discussed. These interference mitigation techniques are needed when the same spectrum as for terrestrial users is used for drones, which especially in the start with a low penetration of UEs in the air is economically attractive. Obviously when dedicated spectrum is available for drones, the situation changes, as then the load in the network only depends on the load caused by drones. In that case, especially when the number of drones is small, no interference mitigation will be needed. However, coverage needs to be built for the dedicated spectrum. To make this economically viable, this can be done by using existing cell towers. In Table 8 we compare the different interference mitigation techniques and the
The dedicated spectrum option is a very attractive solution, but it requires spectrum is available for this. From the four studied interference mitigation techniques the grid of fixed beams is the most attractive, giving good gains at a slightly higher complexity at the drone. Interference cancellation alone is not having good gain potential and the gains from power control alone are limited to the uplink. Interference coordination can give good gains if enough cells are coordinated, but leads to a higher network signaling and synchronization complexity. The latter can be lowered by taking less cells into account, but this means lower gains.

Furthermore, it needs to be noted that the different techniques can be combined to lower complexity of the different features and/or to get even better gains.

**Summary and conclusions**

The number of drones is increasing fast. It is well understood that in order to allow for Beyond Visual Line Of Sight (BVLOS), which opens up for further use cases, a reliable command and control (C2) link is needed. This C2 link requires a high reliability and wide area coverage to guarantee safety. A natural candidate for providing this C2 link are cellular networks, as they already today provide almost ubiquitous coverage, making it economically attractive, while the fast-increasing number of drone are an attractive customer group for operators to address.

Cellular networks are however designed for providing coverage for terrestrial users and not
in the sky. Antennas are for example typically down-tilted. Furthermore, signal propagate typically further in the sky compared to the ground as there is less obstruction from buildings, vegetation, etc. This means the desired signal is improved but also the interfering signal are received more strongly. On top of this, the number of visible interferers increased with increased height. For relatively low loaded networks, this is no problem, but for medium and highly loaded networks this means the required high reliability for the C2 service may not be reached. Additionally, when the drone is running an application requiring a uplink high throughput, like streaming from a video camera, in the uplink (towards) the base station, this causes significantly more interference to the other users in the network than a user device with similar service at ground level.

This means that interference mitigation may be needed at times of high load. From the four studied interference mitigation techniques the grid of fixed beams implemented on the drone is the most attractive solution, giving good gains at a slightly higher complexity at the drone. Interference coordination can give good gains if enough cells are coordinated, but leads to a rather high network complexity. The latter can be lowered by taking less cells into account, but this means lower gains. Interference cancellation at the drone is not providing sufficiently good gains and the gains from uplink power control are limited. Besides these methods, dedicated spectrum for drones is a very attractive solution, but it requires that spectrum is available for this.

In general, it can be said that in today’s cellular network can provide coverage for drones, and with small enhancements they will be able to provide high reliability also at times of high load. 5G has extended possibilities, like massive MIMO for interference mitigation and will be able to serve drones from its start.

Further reading

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVLOS</td>
<td>Beyond Visual Line Of Sight</td>
</tr>
<tr>
<td>C2</td>
<td>Command and Control</td>
</tr>
<tr>
<td>E2E</td>
<td>End to End</td>
</tr>
<tr>
<td>eICIC</td>
<td>enhanced ICIC</td>
</tr>
<tr>
<td>fICIC</td>
<td>further enhanced ICIC</td>
</tr>
<tr>
<td>ICIC</td>
<td>Inter Cell Interference Control</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>LOS</td>
<td>Line Of Sight</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>RSRP</td>
<td>Reference Signal Received Power</td>
</tr>
<tr>
<td>RSRQ</td>
<td>Reference Signal Received Quality</td>
</tr>
<tr>
<td>SINR</td>
<td>Signal to Interference and Noise Ratio</td>
</tr>
<tr>
<td>TUE</td>
<td>Terrestrial User Equipment</td>
</tr>
<tr>
<td>TTI</td>
<td>Transmission Time Interval</td>
</tr>
<tr>
<td>UAV</td>
<td>Unmanned Aerial Vehicle</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>UTM</td>
<td>UAV Traffic Management</td>
</tr>
<tr>
<td>VLOS</td>
<td>Visual Line Of Sight</td>
</tr>
</tbody>
</table>

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