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# Controlling drones over cellular networks

## LTE and 5G are enabling secure and reliable drone control in parallel to high throughput applications

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Cellular networks are an attractive alternative for providing reliable communications for drones or UAS.[1] The main reasons for using cellular networks are the ready-to-market infrastructure and the almost ubiquitous coverage provided, which minimizes the need for additional investments. As reliable communications are one of the main requirements for Beyond Visual Line of Sight (BVLOS) operations for drones, they will enable further use cases and possibilities on top of the ongoing boom in new drone applications. This emerging market makes drone operators and service providers attractive customer groups for cellular operators. In this short paper we present how cellular networks can provide reliable connectivity to UASs and how high throughput applications from drones can be supported at the same time.

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1    UAS stands for "unmanned aircraft system" as defined by the US Federal Aviation Administration and covers drones and the equipment used to control them remotely.

# Contents

# Introduction

Drones and the drone services market are anticipated to register a CAGR of 15.37% in the coming years to reach USD 47 billion by 2025 [1]. Currently, regulations in most countries only allow for operating drones when there is Visual Line of Sight (VLOS) between the drone pilot and the drone. It is expected that Beyond Visual Line of Sight (BVLOS) operations will be allowed in the near future, provided there is a reliable Command and Control (C2) link to the drone. This C2 link is very important to ensure safe drone operations and is an important part in the provisioning of reliable end-to-end (E2E) drone communications.

One attractive way to provide the C2 link is to use existing cellular networks as the infrastructure, which will minimize the investments required. Such networks are not designed, however, for aerial coverage, as they are optimized for ground users; for instance, they typically use down-tilted antennas on 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 communications to drones and play an important role in provisioning the E2E reliability for drone communications. In other words, cellular networks can safely and reliably support BVLOS drone flights. For the operators of those cellular networks the increasing number of drone operators is a small but lucrative addressable market.

# 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 appear continuously [2]:

- **Medical supply delivery.** This can range from transporting medications to remote hard-to-access areas, to transporting blood or biological samples from one medical facility to another, especially in congested urban areas.

- **Agriculture surveillance.** Drone agriculture applications range from mapping and surveying, to crop dusting and spraying, leading to efficient use of sparse resources and maximum production.

- **Traffic surveillance and real-time notifications.** While cars can report congestion, a drone captures the bigger picture; a drone with a camera can be very helpful in getting an overview of accident sites.

- **Search and rescue.** Drones can be used to find missing persons. A group of drones flying in formation has been 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 as well as last-mile urban delivery can be efficiently performed by drones, thus saving the environment by reducing mileage travelled. Delivery trucks can deliver packets to centralized places, from which the packets are delivered by drones.

Figure 1. Example drone use cases.
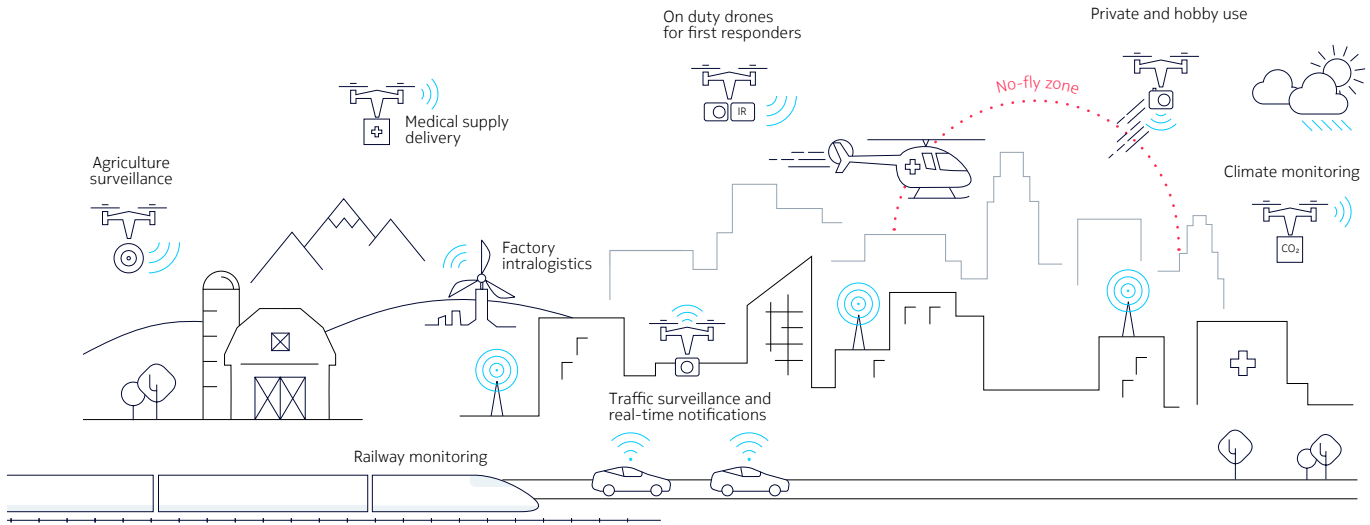


Common to all use cases is that a reliable C2 link is required for controlling the drone and redirecting it in case of interference with other aircraft — for instance, a first responder helicopter landing at an accident site — or simply for optimizing the route to avoid known congestion.

To ensure high reliability, the 3GPP has set the C2 requirement in Release 15 LTE studies on aerial connectivity so that 99.9% of the time a packet needs to reach its destination within the delay budget, which was set to 50 ms (i.e., 99.9% reliability within 50 ms). The estimated C2 link throughput is estimated at 100 kbps by 3GPP [3], which is rather low compared to other cellular applications. However, on top of the C2 link there may be other applications running on the drone that require radio communications. Often these payload applications require high uplink throughputs such as high-quality video live streaming during the drone's mission.

# Providing reliability

Cellular networks are designed to serve users on the ground and are highly optimized for this purpose. Base station antennas are typically tilted down to ensure a good tradeoff between coverage and interference for users on the ground. These propagation conditions, however, are different from the propagation conditions experienced by devices and users in the air. 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 from multiple surrounding base stations, resulting in higher levels of interference. Somewhat offsetting this interference, LOS to the primary serving cell also improves the desired signal levels [5].

Already today, a cellular network can provide good C2 link reliability for drones. This can be seen from figure 2, which shows the results from measurements taken of a drone flying in an urban environment during busy hour at 40 m height while being connected to two live LTE networks. The reliability measure shown is based on the number of packets in uplink and downlink that are received correctly within the 50 ms delay budget at the application layer. Details can be found in the video footage "Drone control over public LTE" [4].

It can be seen that the LTE networks (operator 1 and operator 2), although not optimized for devices in the air, can deliver high reliabilities (88.5% and 98.5%). While not fulfilling the 3GPP Release 15 requirement of 99.9%, a simple enhancement can achieve this standard. By simultaneously connecting to both networks and sending the data packets over each of them, 99.99% reliability is achieved (see figure 2 under the label 'dual LTE'). This packet duplication can also be achieved within one network through Packet Data Converged Protocol (PDCP) duplication, where packets can be transmitted simultaneously to and from different cells within the same cellular network.

Figure 2. C2 reliability of a drone flying at 40 m height in an urban environment for two separate LTE networks (operator 1 and 2) and when using packet duplication over the two networks (Dual LTE) from measurements [4].
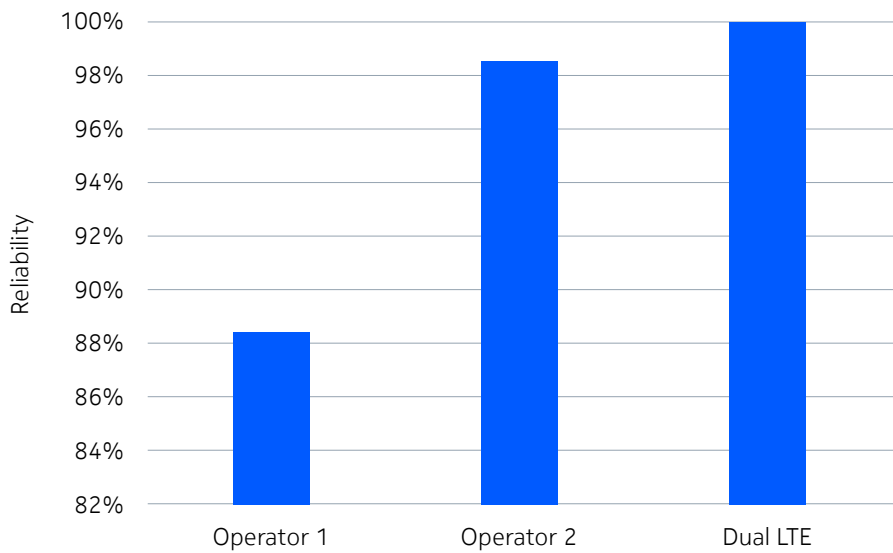


Other methods exist to improve the reliability, like interference coordination, the use of advanced receivers with interference cancellation and beamforming from the drone and potentially from the network side. All these have been shown to improve the reliability of the C2 link for airborne drones [6].

# Co-existence with terrestrial users

Applications on drones often generate a lot of data that need to be uploaded, typically leading to high uplink data rates. The fact that an airborne drone sees many more cells than a terrestrial user means that a drone can cause significant uplink interference [7].

An example of this can be seen in figure 3, which shows the increase of interference due to a rural user uploading data from 100 m in the air compared to being on the ground; results are shown for the 20 most interfered cells. It shows that the interference increase is significant, up to 8dB, and the eight most interfered cells see four times more interference.

Figure 3. Interference increases for the 20 most interfered cells due to an aerial user at 100m altitude compared to a user on the ground
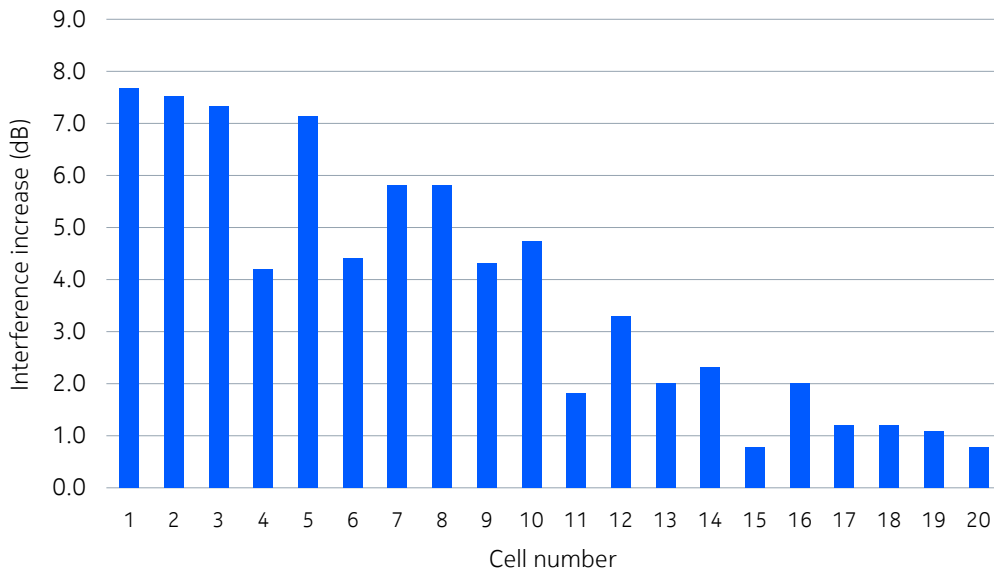


This level of interference can cause coexistence issues, leading to lower throughputs for the users on the ground being served by these interfered cells. One solution is to lower the output power of the user in the air, which is one of the mechanisms introduced for drones in the Release 15 LTE specifications. This will, however, also lower the potential throughput of the aerial user, which might be undesirable.

Another solution is illustrated in figure 4. In this scenario there is a large group of people together at an event such as a concert or a sports match who are uploading pictures from the event. A camera drone is also live streaming the event. If this drone is using an omnidirectional antenna, it will interfere with the cells serving the users on the ground, thereby interfering with their uploads. However, using a directional beam from the drone and pointing it to a cell further away from the location of the event will provide more resources for the streaming drone and at the same time avoid interfering with the users on the ground.

Figure 4. An example of steering interference away from loaded cells through beamforming from the drone, thereby decreasing interference for terrestrial users.
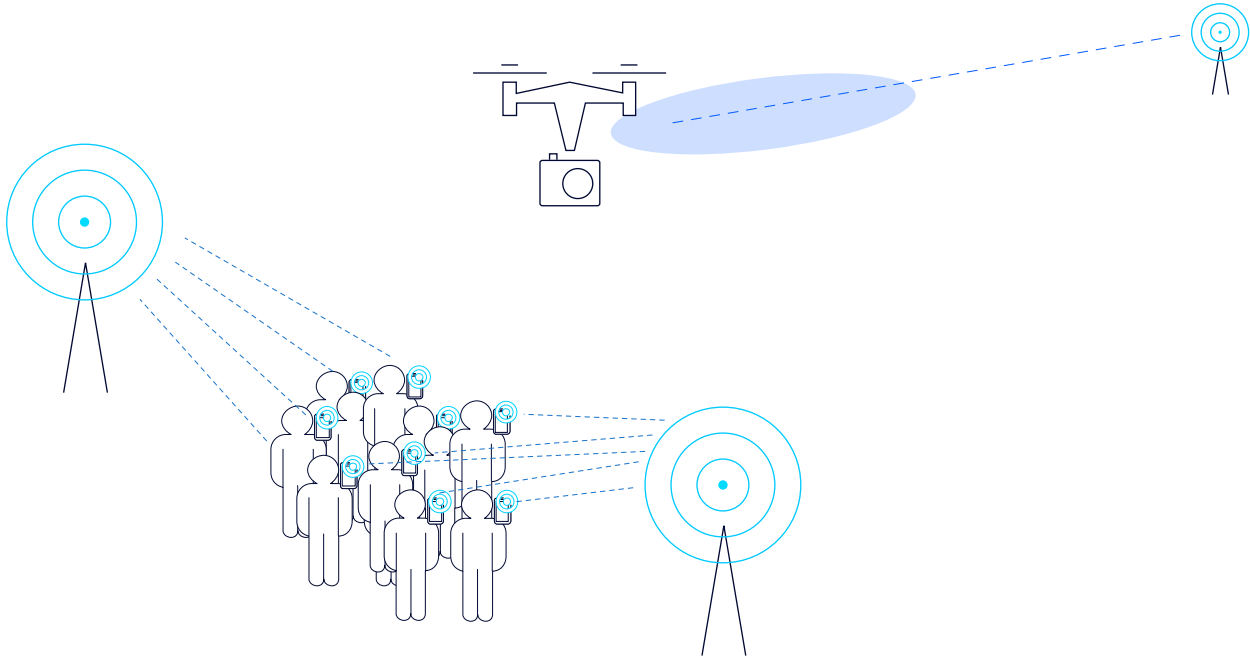


# Drone solutions as-a-Service

5G enables critical applications to run seamlessly through simple intent-based API calls exposing real-time network resources in an as-a-service model. When this is used for drone services, i.e., drone solution as-a-service, it means that one or more specific slices are setup in the network to deliver the required services at the required Quality of Service (QoS).

For the controller of the drone, the 5G network will transparently take care of things like:

- Communication to UAS Traffic Management (UTM) or UAS Supplier (USS) related to flight authorization, which contains verification of the communication link reliability along the planned flight path

- Verification of the reported location of the drone, as 5G comes with a variety of positioning methods

- Tracking of the drone along the flight path and reporting any potential issues related to the availability and reliability of the communication link to the USS/UTM

- Setting up the right security levels

- Delivering the data from the drone to the end user in an efficient manner according to the QoS and SLA.

These different functions will run at the appropriate places in the network such as the RAN, MEC or CN. All these functions are transparent to the drone controller, who can focus on the actual mission to be performed by the drone.

# Summary

The number of drones is increasing rapidly. It is well understood that in order to allow for BVLOS, which opens up for further use cases, a reliable command and control (C2) link is needed. This C2 link requires high reliability and wide area coverage to guarantee the safety of the drone missions. A natural candidate for providing this C2 link are cellular networks. They already provide near-ubiquitous coverage, making it economically attractive, and the fast-increasing number of drone operators make an attractive niche market for mobile network operators to address. Cellular networks also provide excellent security and authentication mechanisms. 4G and 5G cellular networks today can already provide a high degree of reliability for the C2 link, and this can be further improved by features such as multi-cell connectivity, mobility mechanisms and beamforming. The latter can also be used to improve co-existence of drones with terrestrial users. Overall, we believe cellular networks can enable safe and reliable controlled operation of drones for BVLOS use cases.

# References

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# Abbreviations

| | |
|---|---|
| BVLOS | Beyond Visual Line of Sight |
| C2 | Command and Control |
| CN | Core Network |
| E2E | End to End |
| LOS | Line of Sight |
| LTE | Long Term Evolution |
| MEC | Multi-access Edge Computing |
| PDCP | Packet Data Convergence Protocol |
| RAN | Radio Access Network |
| UAS | Unmanned Aircraft Systems |
| UE | User Equipment |
| UTM | UAV Traffic Management |
| VLOS | Visual Line of Sight |