5G empowering Uncrewed Aerial Systems

White paper

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Executive summary

Cellular networks are usually designed to serve users on the ground, for example, base station antennas are typically tilted down to ensure a good tradeoff between coverage and interference. Such network designs, however, may not be optimal for users in the air (e.g., UEs used in drones) and may result in higher levels of interference as the propagation conditions experienced by them are different compared to ground-based users. 3GPP introduced the concept of Aerial UE subscription in LTE Release 15, to identify UEs used with aerial vehicles such as drones or uncrewed aerial vehicles (UAV). At the same time, 3GPP also introduced RAN features like flight path reporting, which helps ensure reliable communications for UAVs over cellular networks. This opens up a large number of use cases for UAVs such as package delivery, power line inspection and emergency response, among others.

These LTE RAN features, however, are currently not available in 5G NR. In Release 17, 3GPP has introduced system architecture enhancements to support integration of aviation level application servers or systems, e.g., UAS Service Supplier (USS) and UAS Traffic Management (UTM) systems. These provide various services like identification, authentication and authorization, and tracking of UAS. The basic idea is to encourage adoption of 3GPP technologies for various UAS communications and use cases. This can be accomplished by exposing some of the proven 3GPP capabilities, such as identification, authentication and authorization, through industry standard open interfaces for integration with the aviation entities. Further, the Open Generation consortium was created in the US to focus initially on use cases related to operating 5G-equipped drones over the United States [8].

In this white paper, we highlight the motivation for supporting UAS, describe different deployment models and explain the features that were introduced by 3GPP Release 17. We also look at some of the aspects that will be addressed as part of 5G-Advanced in upcoming releases (i.e., Release 18 and beyond) to bring UAV support in NR on par with LTE and, in time, beyond.
Motivation for supporting UAS in 5G

Uncrewed Aerial Systems (UAS) consist of an aircraft or drone, also popularly known as Uncrewed Aerial Vehicle (UAV), and the equipment needed to control it remotely, also called the UAV controller (UAV-C) or sometimes referred to as a ground station controller. The UAS market is anticipated to register a CAGR of around 15% in the coming years to reach USD 47 billion by 2025 [7]. Over the last few years, the UAS market has moved from being primarily driven by either military or individual entertainment devices to a more significant presence in the commercial world. There are numerous use cases for commercial UAS operations, which are illustrated in Figure 1. UAVs are increasingly used in agriculture (e.g., surveying, crop dusting, spraying of insecticides), commercial delivery, property surveillance, traffic monitoring, medical supply delivery and many more. UAVs can also play a significant role in public safety and mission-critical services, for example, to localize and rescue people by gathering visual and sensory information. From the network operations point of view, UAVs can be used for network maintenance and various network measurements. UAVs carrying base station equipment on board (i.e., movable or flying base stations), are also seen as a possible alternative for providing 5G network capabilities to improve connectivity services in a highly crowded environment (e.g., during large events) or for extending coverage in areas with otherwise limited coverage.

Figure 1. UAV use cases

Due to the huge number of potential applications of UAVs in commercial use cases and the anticipated increase in the number of UAVs flying around, the regulatory authorities from most regions and countries are coming up with rules and policies related to UAV registrations, flight permissions, remote identification, tracking and traffic management, including the operation of UAVs both in and beyond visual line of sight (BVLOS). Safely operating a UAV BVLOS requires an extremely reliable command and control (C2) link between the controller and the aircraft, even more in the case of a swarm of drones. 3GPP-defined cellular networks are seen as an attractive way to provide the C2 link for BVLOS flight operations, due to their global presence and inherent capability of providing ultra-reliable and real-time long-distance data transmission capabilities.
The Global UTM Association (GUTMA), a consortium of worldwide UAS traffic management (UTM) stakeholders, has published a high-level UTM architecture document. Its purpose is to support and accelerate UTM interoperability with an aim to foster the safe, secure and efficient integration of UAVs in national airspace systems. The UTM system is integrated with various other communication infrastructures (see Figure 2) and needs to collect data or communicate with many other systems to provide the UTM services. Some of the key functionalities of the UTM include UAS registration and identity management, flight plan, permissions and directives, surveillance and tracking, conflict detection and contingency management, and airspace management.

When a UAV is using cellular connectivity, the 3GPP network can be used to facilitate or support the UTM in performing some of these tasks. For example, the 3GPP has a proven identification, authentication and authorization framework that can be extended to the aviation industry for UAS identification, flight permissions and authorization of air space. The 3GPP network can also provide reliable, secure, stable and real-time air-to-ground or ground-to-air communication capability for enabling BVLOS operation of UAS. Supervision systems for UAVs is not well established currently, and there is always the threat of unregulated drones flights. 3GPP can assist the aviation industry with its real-time location and tracking features.
3GPP Release 17 system architecture enhancements

3GPP Technical Specification Group Service and System Aspects Work Group 1 (TSG SA WG1, Services) has specified the service requirements identified for operation of UAS via the 3GPP system, which includes requirements for meeting the business, security and public safety needs for the remote identification and tracking of UAS. Based on this work, in 3GPP Release 17, the Technical Specification Group Service and System Aspects Work Group 2 (TSG SA WG2, System Architecture and Services) has studied the impacts on system architecture and has completed the work of specifying the first phase of architectural enhancements needed to support UAS operations using cellular networks (Support of Uncrewed Aerial Systems Connectivity, Identification and Tracking [1]). The corresponding stage 3 specification (i.e., APIs definition) is expected to be completed by June 2022. The work done by TSG SA WG2 in 3GPP Release 17 has no impact or dependency on the radio access network (RAN) and supports seamless 5GS to EPS interworking [2][3]. In what follows, we look at some of the system architecture enhancements specified in Release 17.

UAV identification

At the aviation level a UAS is identified using a unique identifier assigned by the regional authorities (e.g., CAA Level UAV identifier) or the USS (e.g., USS ID). The unique identifier could be a hardware serial number or registration number or a session ID. This unique identifier can be seen as similar to a car registration number plate. Using this identifier, one can find out information such as the owner of the UAV and its registered address. One of the typical requirements for safely operating UAVs in an airspace is remote identification. Any person on the ground should be able to identify a UAV flying nearby.

Various regional regulations require the UAV to be able to broadcast its identification information for the purpose of remote identification (RID). The remote identification information contains information apart from the UAV identifier, such as the ground station controller location, its take off location, its current location (including altitude) and emergency state indication. Any person on the ground should be able to intercept the broadcasted information and fetch the necessary information to identify the UAV, where it is going and where its controller is located. This enables people on the ground and other airspace users to identify who is using the airspace around them.
From an operator’s network (or 3GPP) perspective, however, this remote Identification (RID) of UAVs is not sufficient. The network operator (3GPP) needs to identify when user equipment (UE) is used with a UAV, so that differentiated services can be provided to the UE when it is accessing the network for various UAS operations. The UAV may use an operator’s network for various types of communication. These communications can be grouped into two broad categories based on their requirements. First is a payload communication, which can be any application data such as surveillance data collected by a surveillance drone, 4K video or sensor data. From the perspective of safe UAS operation, this category of (payload) communication can be considered as non-critical and can be delivered depending on the type of application. The second category of communication is control and non-payload communication (CNPC), sometimes also referred to as command and control (C2) communication. This is critical for UAS operation and safe airspace usage and requires very high reliability. It must also have very low end-to-end latency.
The 3GPP network can differentiate these various types of communication (see Figure 4) based on factors like the Data Network Name (DNN) or the Network Slice that the UE is trying to access. 3GPP Release 17 has defined aerial UE subscription to distinguish UEs that are allowed to be used with aerial vehicles such as UAV. The subscription enhancement also includes an indication in the subscription information of the data network name (DNN) and network slice to indicate if the DNN or slice is used for such critical UAS communications, such as C2/CNPC or communication with USS.
UAV authentication and authorization

The regulatory and aviation authorities in many countries have defined, or are in the process of defining, rules for registration of UAVs with a central entity. Additionally, there are region- and country-specific regulations for prior flight path approval and flight permissions before flying a UAV, sometimes also referred to as “no permission, no take-off” (NPNT). Currently all processes, such as authorization of UAVs and flight permissions, require direct human interaction and may not be sustainable considering the huge potential growth in the number of UAVs and other flying objects (e.g., urban air mobility or UAM) in the future.

There is a need for a more dynamic way to authorize a UAV to use the airspace. From the 3GPP network point of view, when a UE with “aerial subscription” is trying to access UAS-specific services through the network, it may want to verify that the UE is used with an authorized UAV. Some regional regulations may also require the network to authenticate and authorize the UAV identity by an aviation-level application server (e.g., USS/UTM) before providing any cellular service to the UE used with the UAV. If 3GPP connectivity is also used for a C2 link between the UAV and the UAV controller, the 3GPP network can also provide mechanisms where a third-party application can control whether and when the C2 communication can be allowed. For example, the 3GPP network can give the control to the regional aviation-level applications managing the airspace (e.g., USS/UTM) whether to allow the UAV to get airborne and have a C2 link setup with the UAV controller. To support such use cases, 3GPP Release 17 has defined an authentication and authorization framework that can be utilized by the aviation industry to automate and provide dynamic authorization for flight path and airspace usage.

The 3GPP Release 17 system architecture is enhanced to provide an industry-standard open API-based framework (see Figure 5) for the aviation entities managing the UAV registration, flight planning and authorization, using the exposure services framework. The APIs provide an optional capability at the 3GPP network to first get the UAV identities authenticated by an external aviation entity before allowing any connectivity services to UE(s) used with UAV. It also enables dynamic flight path planning and authorization to use the airspace and controlling the pairing of the UAV and UAV controller link for C2 communication. The framework can also be used to request specific quality of service (QoS) characteristics and policy configuration for the communication link. The framework is designed independently of the application protocol, and the 3GPP network can transparently relay the authentication key exchanges and other authentication and authorization data between the UAV and the aviation level entity (e.g., USS/UTM), in a secured manner.

Figure 5. API-based service exposure from 3GPP
As a ubiquitous 5G network may not be available everywhere, a common identification, authentication and authorization framework has been designed for both 5GC and EPC to provide seamless mobility between 5G and 4G networks that is independent of the access network and has no impact on legacy EPC network elements.

**UAV tracking**

As the UAV is using a UE for cellular connectivity, the 3GPP system can support the aviation entities responsible for planning and managing the airspace, controlling the air traffic, and tracking the UAV(s) by exposing various location services and event monitoring capabilities. 3GPP Release 17 provides enhancements to the existing location services and event exposure framework to provide capabilities catering to the unique requirements from the aviation industry (see Figure 6).

**Figure 6. Location and tracking services provided by 3GPP**

**Location services:** This can be used by an authorized application server outside the 3GPP network to request current (and periodic) location of a UE, using an open API. The USS/UTM or other aviation-level application and any public safety or law enforcement agencies can use the network-provided location information to complement the existing mechanisms for tracking a UAV.

**Presence Monitoring:** The 3GPP network can be configured to monitor the movement of a UE used with a UAV and report when the UAV moves into, or moves outside of, a specified geographic area. This can be useful to support use cases like geo-fencing or no-fly-zone monitoring. This feature can be used in two different ways. First, it can monitor and prevent a UAV from entering sensitive and no-fly zones such as airports, police stations and government complexes. Second, it can monitor and restrict the movement of a UAV within a specified geographic area or corridor, for instance, allowing the UAV to fly only over an agriculture field in rural areas or to restrict the movement of the UAV within a pre-defined drone corridor.

**List UAVs operating in an area of interest:** Let us assume that a police van notices many UAVs flying in an area. It would be a tedious task for it to read the RID broadcasts from each UAV and then find out the total number of UAVs in the area or their identity. 3GPP Release 17 provides open APIs that any authorized application server outside the 3GPP system (e.g., hosted by USS/UTM, public safety or the police) can use to query the 3GPP network and find out the list of UAVs served by the network in a specific geographic area.
5G-Advanced outlook

3GPP has already defined a set of functionalities and features that will be a part of the 5G-Advanced Release 18 package. These functionalities can be grouped into four areas: providing new levels of experience, network extension into new areas, mobile network expansion beyond connectivity, and providing operational support excellence (see Figure 7). Extending UAV support in Release 18 will be an important part of the ‘extension’ block of features. This will not only enable 5G-Advanced networks to expand their reach to new areas geographically but, in the case of UAV, to new service areas.

Figure 7. 5G-Advanced, Release 18

While the UAV-related studies in Release 15 for LTE showed that cellular networks could be used for connecting UAVs, 3GPP Release 17 provides further architecture enhancements for supporting identification, authentication and tracking of UAS, and it allows both LTE and NR to provide extra information to the UTM. This is only a first step towards improving the safe and secure integration of UAVs with cellular communication capabilities into the network. 5G-Advanced (starting from Release 18) will introduce holistic support for UAVs. Both the radio (5G NR) and core network will provide carrier-grade UAV managed services capabilities, taking them beyond what is already provided by LTE.

3GPP TSG SA WG2 has agreed on a study item in Release 18, where it will investigate how to leverage existing mechanisms of device-to-device direct discovery and device-to-device direct communication for meeting remote identification (RID) broadcast requirements and for UAV-to-UAV direct communication to support requirements related to detect-and-avoid (DAA) mechanisms that are currently being developed by the aviation community (e.g., GUTMA). The study will also investigate mechanisms to support C2 communications between the UAV and the UAV controller using the device-to-device (D2D) direct communication.

The 3GPP TSG RAN has also agreed on a Release 18 work item, with Nokia as rapporteur, for 5G NR enhancements to support UAV. The RAN is generally highly optimized for users on the ground and further enhancements will be introduced in Release 18 on the RAN side. Similar features as introduced in release 15 for LTE for UAV will be brought to NR first, such as reporting of flight path, location, height and speed and measurement optimizations. Subscription-based identification will then be specified and whether
enhancements are needed to improve co-existence between users on the ground and UAVs, as UAVs at heights of 50–100 meters cause considerably more interference than users on the ground. One solution for interference mitigation from UAVs is to utilize beamforming capabilities on the UAV. It will also be investigated whether enhancements are needed for UAV identification broadcast or if existing mechanisms are sufficient.

Looking beyond Release 18, 3GPP will likely expand support for emerging use cases and requirements coming from different fora of the aviation industry. One such forum is the Aerial Connectivity Joint Activity (ACJA), which is a joint initiative by GSMA [6] and GUTMA (Global UTM Association) [4]. ACJA is defining various UAS models where both the UAV and its controller will use cellular connectivity [5]. Further, the UAVs can also be grouped into different categories and mission types such as public safety, commercial payload vehicle and critical surveillance. UAVs are also seen as a future means for urban mobility (e.g., drone taxis), also popularly referred to as urban air mobility (UAM). Each category of UAVs will have different communication and KPI requirements. The 3GPP network will need to provide support for these UAS models and provide differentiated services and prioritization of services based on various UAS or UAM categories and mission types.

In summary, while current cellular networks can be used to serve UAVs, Release 17 has introduced enhancements to fulfill the increased requirements coming from the aviation authorities. Release 18 of NR and other system features will improve the co-existence with terrestrial users even further and extend support for UAVs into new areas and use cases.

Conclusion

5G cellular networks are a natural connectivity choice for UAVs due to the huge, anticipated growth in the number of UAVs and the realization of new use cases, which will require ultra-reliable and real-time communication. Nokia has promoted the use of 5G for UAVs in ACJA (see our earlier white paper). While current cellular networks can be used to serve UAVs, safe integration and operation of UAVs needs system features like UAV identification, authentication and flight authorization and tracking. Adding these various system features in combination with RAN features will accelerate the adoption of cellular communications for critical drone communications such as command and control (C2), broadcast remote identification (BRID) and networked remote identification (NRID). These additional features will also enable new use cases and service capabilities, as well as dynamic airspace management, flight planning, authorization, tracking, conformance monitoring and conflict detection and contingency management. Finally, Release 18 of NR, where Nokia is the rapporteur for the RAN work item on UAV enhancements, will also bring further improvements for co-existence of aerial users with terrestrial users.
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Abbreviations

3GPP  3rd Generation Partnership Project
ACJA  Aerial Connectivity Joint Activity
API   Application Programming Interface
BVLOS Beyond Visual Line of Sight
C2    Command & Control
CAA   Civil Aviation Authority
CNPC  Control and Non-Payload Communication
DAA   Detect and Avoid
DN    Data Network
DNN   Data Network Name
GSMA  Global System for Mobile communications Association
GUTMA Global UTM Association
LTE   Long Term Evolution
NR    New Radio
NRID  Networked Remote Identification
QoS   Quality of Service
RAN   Radio Access Network
RID   Remote Identification
UAM   Urban Air Mobility
UAS   Uncrewed Aerial System
UAV   Uncrewed Aerial Vehicle
UAV-C UAV Controller
UE    User Equipment
USS   UAS Service Supplier
UTM   UAS Traffic Management

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