Connecting the Skies

Air-To-Ground connectivity – a breakthrough for professional UAV/AAVs

SkyFive GmbH
Im Birkenwald 25
D-70435 Stuttgart
info@skyfive.world

Connectivity for unmanned and autonomous aerial vehicles

Unmanned Aerial Vehicles (UAV), often called “drones”, Remotely Piloted Aircraft (RPA), and Autonomous Aerial vehicles (AAV) rely on wireless connectivity for control and payload data. A great prospect is anticipated for Urban Air Mobility (UAM), with thousands of passenger drones already in the next few years, adding new demands on safety critical communications.

The requirements vary drastically between different types of UAV, RPA, and AAV:

- Safety critical, safety critical with restrictions, non-safety critical
- Line-of sight operation (LOS), non-line of sight operation (NLOS, also referred to as beyond visual line-of-sight, BVLOS)
- Subject to traffic control (due to flight height) versus not subject to traffic control
- Low speed (< 100 km/h), medium speed (100 … 300 km/h), high speed (>300 km/h)
- Short distance (in sight), medium distance (few kilometers ... within one country), long distance (across continents)

UAV, RPA, and AAV connectivity is mostly realized

- using license exempt bands (for example, Wi-Fi)
- connecting to existing mobile networks (mainly 4G LTE-A and 5G)
- linking via satellite
- relying on Air-to-Ground (A2G)

In this paper we investigate the different possibilities to provide connectivity, the pros and cons for each of the possibilities, and map out a matrix to help selecting the most appropriate technology for each of the scenarios above.

Please also refer to the corresponding SkyFive article in the news magazine “Air Traffic Management”, issue 2/2020 (can be found here: https://airtrafficmanagement.keypublishing.com/).

License-exempt bands

Some parts of the Radio Frequency (RF) spectrum are not regulated and open for everyone without the need to obtain a license. These bands are called license-exempt bands. Anyone can use these bands subject to stringent requirements, for example, on maximum RF power and spurious emissions.

The requirements deviate from country to country. Mainly the 2.4 GHz band is used, as it is available worldwide and most requirements are standardized by international bodies. This band is used by all Wi-Fi devices, Bluetooth, NFC, and ZigBee, to name just a few of the applications.

As no one controls this band, the devices must be able to look for spectrum resources in a collaborative way and sustain in-band interference. To allow as many devices as possible to use the band, the allowed RF power is low, therefore the possible range is low as well. There is no guarantee of coverage, spectrum availability, and performance.

The pros:	The cons:
• No spectrum license required, no spectrum fees, therefore fast to deploy • Low latency • Many products available • Potentially high capacity • Low cost • Low power consumption	• Limited range due to low RF power, mainly Line-of-Sight and Near-Line-of-Sight • Many use cases sharing the same spectrum (Wi-Fi, Bluetooth, …), therefore no guaranteed service and availability

Target market:

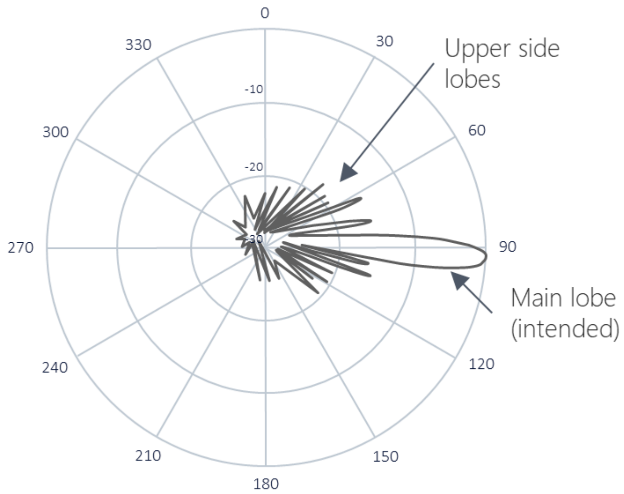
- Non-safety critical use for amateurs and semi-professionals for short distance between control station and UAV, low UAV altitude and low UAV speed.

Typical applications:

- Private usage for hobby activities, for example, photographer using a camera drone to take wedding pictures from an unusual angle

Existing cellular networks

Terrestrial cellular networks are designed to cover mobile subscribers on the ground and in buildings. Their main antenna lobe is tilted downwards to minimize interference between neighbouring base stations. Still, a certain amount of RF energy is transmitted towards/received from above. The reason are imperfections of the antennas (unwanted side lobes) as shown below:



Additionally, RF energy is reflected from obstacles on the ground, partially towards the sky. Results from different trials suggest a good mobile network coverage at heights of up to 600 m (2000 ft) above ground.

This makes mobile cellular networks a good candidate for UAV, RPA and AAV support at lower heights and beyond line of sight conditions. This is especially true for LTE and 5G. For GPRS/EDGE (2G) and UMTS (3G), the delay of control messages is much higher due to the frame structure used; these standards are therefore less favoured for UAV/AAV support.

The pros:	The cons:
• No own infrastructure, no own spectrum required • Wide area coverage, Non-Line-of-Sight operation possible • Low latency for 4G and 5G • Broadband and high capacity • Depending on network and condition, altitudes up to 600 m feasible • LTE and 5G modems for UAVs are low cost • Low power consumption.	• Subscription to mobile network operator required, fees • No control over the radio network planning, not possible to rely on coverage at different altitudes • As mobile networks permanently evolve and are being optimized for terrestrial coverage (remote tilting of antennas, …) and are re-planned for extensions, even trial results from one day can't be replicated another time • Capacity and performance depend on network load (busy hour versus low traffic time).

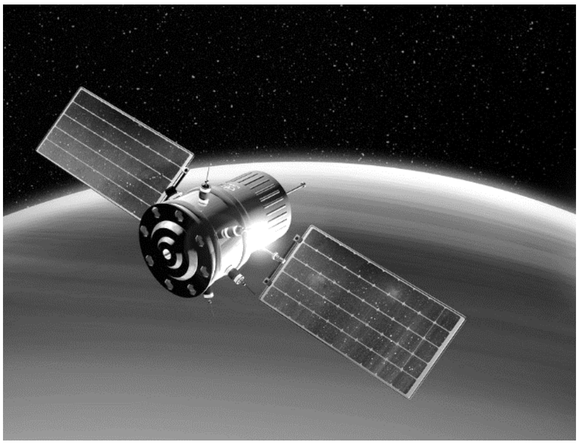
Target market:

- Non-safety critical professional use under Non-Line-of-Sight conditions, potentially for long distance operation. Limited to low and medium UAV speed.

Typical applications:

- Delivery drone for pizza-service, traffic supervision via camera drone by police, agriculture use cases for large and dispersed farms

Use of satellite transmission



Satellites provide wide area coverage; some operators provide even worldwide services. Modern high-throughput satellites (HTS) multiply their capacity by using comparatively narrow spot beams. Satellites have been used for many years to provide data services to commercial and military aircraft.

Today, communication satellites use a geostationary orbit (referred to as GEO satellites) roughly 36,000 km above ground. The large distance and the need of the radio waves to travel first form a ground station to the satellite and then back to the receiver leads to a very long latency.

This will improve with low-earth orbit (LEO) satellites that are presently being launched. Such satellites are much nearer to the ground leading to much shorter delays. Such satellites are not stationary anymore, instead a large network of many (hundreds to thousands) satellites is required. The high number of satellites lead to a higher performance for the users.

Satellites, whether GEO or LEO, are not dedicated to aviation but also provide services to terrestrial and maritime users.

The pros:	The cons:
• Very wide area coverage (some satellite operators offer worldwide service) • Can be operated in regions without ground infrastructure • Non-Line-of-Sight operation possible • Can be used from ground to very high altitudes • Suitable for high-speed UAVs	• Expensive, big and heavy equipment at the UAV/RPA/AAV, high power consumption • Long latency for existing GEO satellites, no real-time data exchange • No coverage underneath bridges, in hangars etc. • Even narrow spot beams of GEO satellites and spots of LEO satellites are comparatively large, so the capacity is shared between many users • Capacity is shared between use cases (terrestrial, maritime, aviation)

Target market:

- Large UAVs, often for military use, where coverage from ground is not feasible. Safety critical with restrictions (latency, requires a minimum of autonomy of UAVs).

Typical applications:

- Military drones for observations deep inside enemy areas.

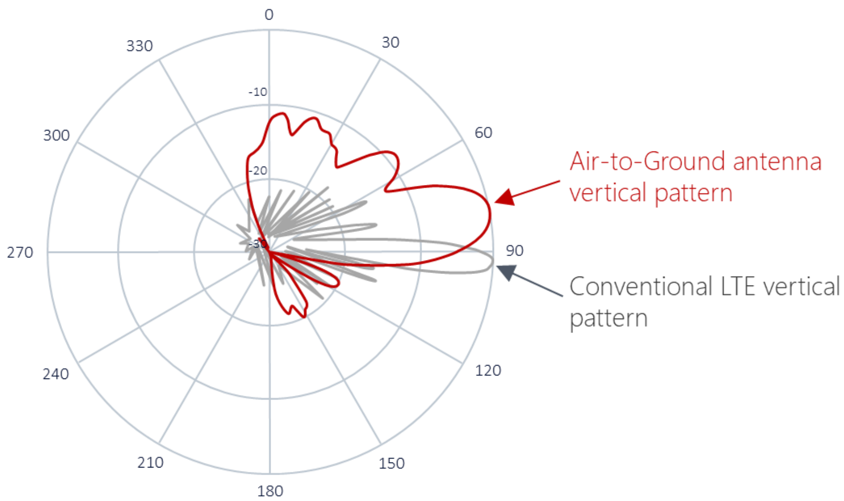
Use of Air-to-Ground (example EAN)

Air-to-Ground (also referred to as Direct Air-to-Ground, DA2G) is a rather new development. The first Air-to-Ground network was a 3G-based low bandwidth - low performance system in the United States. The modern variant is based on 4G technology and provides a high-performance solution up to 100 Mbps with very low latency. It is deployed today across 41 countries in Europe.

The network in Europe is called "European Aviation Network" (EAN) and a hybrid satellite - Air-to-Ground solution. The major capacity is provided by the Air-to-Ground segment over land and up to 150 km out to the sea, while the satellite segment closes the holes farther out to the sea (the Bay of Biscay, or the North Sea between the UK and Norway, for example).

Regarding UAV/AAV, there are two major differences between a dedicated Air-to-Ground network and a standard terrestrial mobile network:

- Air-to-Ground uses a spectrum dedicated for aviation purposes. It is the only solution not shared with other users (neither terrestrial nor maritime users). This allows a higher availability and quality of service.
- Air-to-Ground uses antennas specifically made for this purpose. These antennas provide coverage towards the horizon up to directly above the base station and therefore a controlled and reliable connection independent from network configuration for terrestrial coverage:



Other countries and regions have shown a strong interest in this technology. There are talks to extend the EAN network to neighbouring geographies. Spectrum assignment application are running in the Middle East. Active interest comes from, for example, Australia, New Zealand, Indonesia, Vietnam and India. In China, activities for a 5G-based Air-to-Ground solution in the 4.9 GHz band were started early in 2019, and the first rollout is envisaged for 2021.

The Air-to-Ground technology is highly reliable and secure, following the same design rules as for public safety networks used in volumes already all around the world. Both together (low latency and high availability) are crucial when considering use cases for unmanned aircraft system traffic management (UTM).

The pros:	The cons:
• Dedicated network exclusive for aviation • Quality of Service (QoS) control • Low latency • Low power consumption • Good even for high-speed UAVs and altitudes of more than 50.000 ft / 16,000 m • Can be complemented by standard commercial Ground networks.	• New technology, new eco-system

Target market:

- Air-to-Ground covers most market requirements: From mass market up to safety critical and professional use cases under Non-Line of-Sight conditions, potentially long range, and high UAV speed.

Typical applications:

- Remote control and supervision of passenger drones, high altitude drones for wide area monitoring like pollution control, camera and surveillance drones for public safety. Overcoming most shortfalls of other technologies, the possible applications are virtually unlimited.

Conclusion

A variety of connectivity requirements for different UAV, RPA and AAV classes exist, for which different technologies are available. The table below provides a typical mapping:

Application class	license-exempt bands (Wi-Fi, …)	Mobile networks (LTE, 5G)	Satellite	Air-to-Ground
Non-safety critical, amateur and semi-professional use, very low cost, line-of-sight	+	O	-	o
Non-safety critical, (semi-)professional use, low cost, Non-Line-of-Sight	-	+	-	+
Safety critical, professional use, not cost sensitive, wide area	-	-	+ (but requires some autonomy due to long latency)	+ (where coverage is provided)
Extremely safety critical (manned UAV), professional use, not cost sensitive, known flight areas	-	-	o	+

\+ appropriate
o possible
\- not suitable

None of the means to connect UAV/RPA/AAVs is universal. Some use cases can be covered by ubiquitous and shared technology like Wi-Fi, but safety-critical connectivity as required for example for passenger drones requires professional and dedicated solutions.

With Air-to-Ground deployments going on around the world, a technology disruption is ongoing, in which enables the smooth integration of traditional and new aerial vehicles on a single, highly reliable broadband network. Commercial Air-to-Ground networks are being increasingly considered for many of the UAV, RAP and AAV use cases, with first trials starting in 2020.

Acronyms	Definition
4G	4th Generation 3GPP network, also referred to EUTRAN for RAN or LTE
A2G	Air-to-ground
AAV	Autonomous Aerial Vehicles
BVLOS	Beyond Visual Line Of Sight
DA2G	Direct Air-to-Ground
EAN	European Aviation Network
GEO	Geostationary Orbit
HTS	High-Throughput Satellites
IFC	In-Flight Connectivity
LEO	Low-Earth Orbit
LOS	Line Of Sight
LTE	Long-Term Evolution
Mbps	Mega Bits Per Second
NFC	Near-Field Communication
NLOS	Non Line Of Sight
OBE	On-Board terminal Equipment
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RPA	Remotely Piloted Aircraft
SLA	Service Level Agreement
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System (UAV plus control station)
UAV	Unmanned Aerial Vehicles
UTM	Unmanned Aircraft System Traffic Management