National Public Safety Telecommunications Council

Using UAS for Communications Support – Spectrum and Technology Considerations

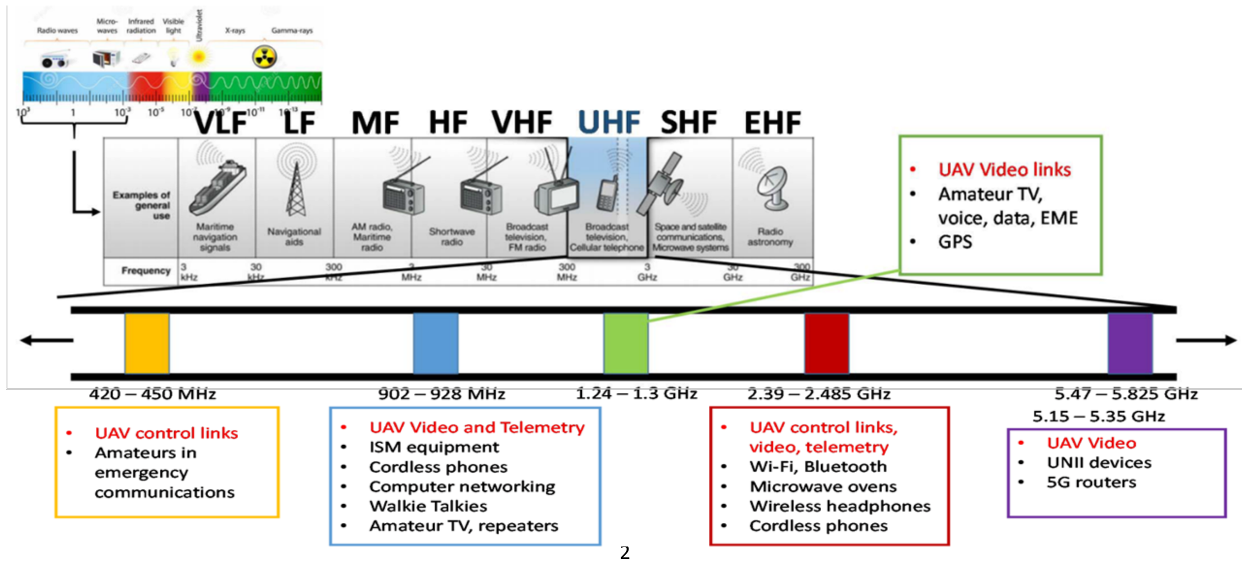
The NPSTC UAS/Robotics Working Group published the "Using Unmanned Aircraft Systems for Communications Support"[1] on (insert date here). This companion document to that report is intended to provide the reader with more detailed information on the spectrum and technology issues that should be considered in contemplating the use of UAS as an aerial platform.

1. Spectrum Issues

One of the issues affecting the effort of safely integrating Unmanned Aircraft Systems (UAS) into the national airspace is the lack of dedicated radio frequency spectrum. Daily users of RF spectrum are multiple, as the following list shows.

- Cell phone
- Cordless phone
- Garage door opener
- Car key remote control
- Standard time broadcast
- Mobile radio
- GPS navigation
- Microwave oven
- Broadcast television and audio
- Vehicle-speed radar, air traffic radar, weather radar
- Satellite TV reception, backend signal dissemination
- Toll-road payment vehicle transponders
- Citizen's band radio and Family Radio Service
- Radio control, including radio-controlled model aircraft and vehicles
- Wireless microphones and musical instrument links
- RFID devices such as active badges, passports, gasoline token, no-contact credit cards, and product tags

[1] NPSTC Using Unmanned Aircraft Systems for Communications Support Report - http://npstc.org/download.jsp?tableId=37&column=217&id=4117&file=Using_UAS_for_Comm_Support_180530.pdf



[2]

As the spectrum chart above illustrates, UAS currently use unprotected radio frequency spectrum and remain vulnerable to unintentional (i.e., environmental or technological) or intentional (i.e., terrorist or hostile) interference. This is of paramount security concern for public safety users as interruption of radio transmissions of the command and control signal can disengage the UAS control mechanism which may result in loss of a communications link or a "lost link" scenario.

In a "lost link" scenario, UAS generally have pre-programmed maneuvers that direct the aircraft to hover or circle in the airspace for a certain period of time to reestablish its radio link. If the link is not reestablished, then the UAS will return to its launch location or execute an intentional flight termination at its current location.

Several categories of control, status, and data messages are required in order to ensure successful UAS missions:

- Initialization, configuration, and mission upload messages exchanged pre-flight or during flight as necessary if the operating mode or configuration of the aircraft is changed.
- Control messages sent to adjust the aircraft and its engines which occur at a frequency relative to the level of autonomy of the aircraft control mechanism.
- Status messages sent back by the aircraft.
- Payload, i.e., video, photographs, aerial communications, environmental, and/or sensory measurements, etc.

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[2] Graphics: Spectrum Issues, "Daily Users of RF Spectrum," used by permission from: www.afcea.org/events/documents/MILCOM2015PPTDrozd-ANDROIII.pdf
http://www.androcs.com ANDRO Computational Solutions, Andrew Drozd, President

These data messages report dynamic changes in aircraft movements, direction, orientation, engine operation, and valuable mission information. These messages can be sent in varying frequency depending upon manufacturer specifications, aircraft operations, and aircraft control mechanism.

For example, typical update rates range from 1 to 20 times per second for critical parameters according to UAS manufacturers, where 1 per second would be appropriate for a fully autonomous aircraft and 20 per second would apply to a manually flown UAS. These update rates are the major drivers in determining aggregate aircraft to ground data rate, or bandwidth.

Command and telemetry bandwidth is considered separate from payload (such as video camera, photography, and aerial communications) bandwidth.

Command and telemetry bandwidth can be accommodated by a 56 kb/sec link, while payload bandwidth is usually much larger, up to 8 Mb/sec for a high quality video link.

For continuous safe and secure operations of UAS under both Line of Sight (LoS) and Beyond Line of Sight (BLoS) conditions, three types of radio communications between UAS and Unmanned Aircraft Control Station (UACS) are required:

- Air traffic control (ATC) relay.
- Command and control (C2 or C&C).
- Sense and avoid (S&A) functionality (ITU-R), or detect and avoid (DAA) functionality (ICAO, RTCA).

It is dependent upon each UAS vendor whether to combine two or more of these functions into a common physical link, so designs may vary based upon manufacturer.

2. Spectrum Needed for Command and Control

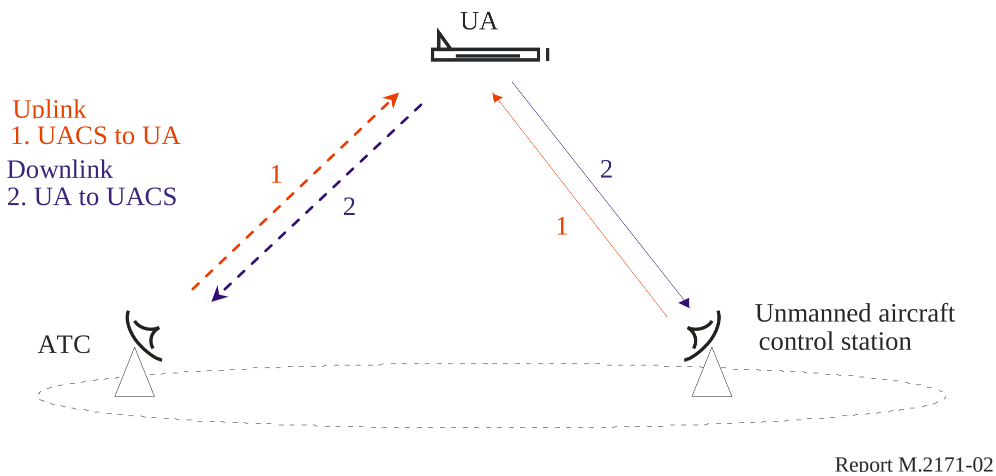
Command and control (C2) represents the link between the Unmanned Aircraft Control Station (UACS) subsystem and the UAS. There are two types of C2 communication links, see example.[3]

- Uplink**:** Sends commands to aircraft for flight / navigation equipment control (NAVAID); UACS to UAS allowing UACS to communicate with ATC; DAA data uplink allows UACS to control operation per flight conditions; typically, small amounts of data/bps.

- Downlink**:** Sends telemetry (e.g., flight status) from the UAS to UACS; ATC information from the UAS to the UACS; DAA data downlink from UAS to UACS which indicates DAA

[3] ITU-R M.2171, "Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non-segregated airspace,"2009.

function operates as desired; may send video in some cases (C2, DAA); typically, larger amounts of data/bps.



The above illustration is for line-of-sight (LoS) communications with no reliance on a satellite or any wide-area wireless infrastructure, e.g., a cellular network. Reliance on the latter scheme is needed for Beyond LoS.

Spectrum requirements for UAS command and control as determined by ITU-R in REP-M.2171-2009, Table 8., are estimated at 34 MHz total, which is comprised of UACS to UAS = 4.6 MHz (Uplink) and UAS to UACS = 29.4 MHz (Downlink), excluding payload video.[4]

NASA estimates this spectrum requirement slightly lower in NASA/CR – 2008-214841 at a total of 24 MHz, so estimates of spectrum requirements run between 24 MHz – 34 MHz for UAS command and control, for terrestrial or LoS operations.

For Satellite (SAT) operations or BLoS, ITU-R estimates a total maximum requirement of 56 MHz, according to methodologies estimating total spectrum requirements.

For examples of ITU-R LoS terrestrial simulations, refer to the table below, with addition of safety margin computation *E*, from ITU-R in REP-M.2171-2009, indicates an aggregate spectrum estimate falling between 24 MHz to 34 MHz estimate.[5]

[4] This is an aggregate bandwidth estimate for multiple UAS, not for a single UAS. Estimates assume frequency reuse.
[5] https://www.itu.int/en/ITU-R/space/snl/Documents/R-REP-M.2171-2009-PDF-E.pdf

Functional Category	Traffic class	Number (M) of mutually visible equipped UA	Assumed frequency-assignment efficiency E	Aggregate bandwidth (MHz) $W = VM/E$
Command and control	Control data	128	0.7	1.36
	NavAid data	77	0.7	0.25
ATC relay	ATC voice relay	98	0.7	2.69
	ATS data relay	98	0.7	0.03
Sense and avoid	Target tracks	116	0.7	6.05
	Airborne weather radar data	37	0.7	0.46
	Non-payload video	116	0.7	17.00
Total				**27.84**

4. Spectrum Needed to Carry Data to Network

Public safety payload data requirements for UAS business cases include video for surveillance, infrared and night vision, communications links, and auto recording of sensor information for privacy audits and use as evidence.

The FCC regulates the use of LMR frequencies in airborne vehicles including limitations on radiated power and height of operations.

Airborne LMR platforms operating at higher altitudes have the potential of causing significant interference to other networks.

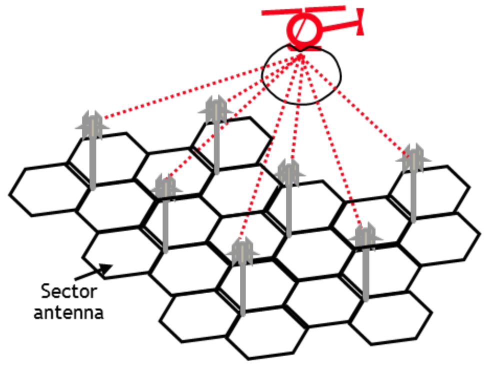
5. Technical Issues

Flying a UAS high above ground, i.e., above the terrestrial infrastructure and other obstacles, is likely to create higher levels of interference than engineers expected during the design and planning of the terrestrial network. Interference is higher because, as they propagate through the air, signals from the UAS do not suffer as much attenuation or variations as signals transmitted for ground operations. More particularly, any attempt at operating a UAS in the same spectrum block as the terrestrial system represents a high risk to ground operations.

6 UAS and LTE

Because of favorable propagation conditions, which are not unique to LTE, an airborne LTE device could block the receiver of the terrestrial base station(s) as well as interfere with adjacent services.[6] This is depicted below.

[6] LTE uses power control but a UAS can go up and down and often will have line of sight (except in dense urban areas) to more than one site/sector.



Although interference risks are much reduced when UASs are deployed in times of disaster, i.e., when the terrestrial infrastructure is partially down, the potential for disrupting device-to-device communications exists. The (interference) risk is higher when multiple UASs are hovering in the same area, which may be the case if multiple agencies bring their own UAS to an incident scene.

This is not to say that the use of in-band (or same band) LTE operation by UAS will never work with an existing LTE infrastructure designed for terrestrial services, but the use of in-band UAS operations cannot be generalized to all situations and for all environments.[7]

What applies to an airborne device is certainly applicable to the (higher-power) airborne base station. Since the base station transmits a variety of signaling information, which are essential for basic connectivity, the case for a dedicated air-to-ground spectrum block becomes more critical for proper, and consistent, UAS operations.[8]

All wireless systems intended for air-to-ground operations, including LMR networks, use dedicated spectrum. While the buildout of a custom infrastructure for air-to-ground services will provide adequate interference protection from airborne devices transmissions, an airborne base station presents a higher interference risk.[9] The interference risk is reduced if the airborne base station is hovering over an area with no ground base stations, e.g., to provide coverage, but it increases if there is an attempt a deploying the same platform over an existing network footprint, e.g., to augment the system capacity.[10]

More importantly, except for satellite links, a dedicated wide-area network infrastructure represents the only approach for beyond visual line of sight operations. The use of technologies

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[7] In-band: The same spectrum frequencies are used for air-to-ground and ground operations (e.g., FirstNet's Band 14).

[8] See for example the future UK Emergency Services Network (ESN) network which will use the dedicated 2.3 GHz band for air-to-ground LTE services. The number of required sites represents a fraction of the number of sites required for terrestrial operations.

[9] See Use-Cases 5a, 5b, and 5c for "Search and Rescue" which are described in the 2017 NPSTC BBDS Report.

[10] The use of autonomous UAS each carrying base station, or a full LTE system, arranged in a cluster with potential for UAS-to-UAS communications links is certainly a future possibility. The mobile-satellite Iridium system is a perfect example.

such as WiFi or Bluetooth, however practical, lends to very localized approaches. If the desire is to pilot a UAS over a wide area network (in BVLOS), rules pertaining to the use of unlicensed technologies become limiting factors. Finally, it is worth mentioning that all command, control, and communications functions can be performed by means of LTE all within the same frequency band.

The type of payload required will be a function of the mission, i.e., need for communication or intelligence, and the type of aerial platform, i.e., supported payload and autonomy. To summarize on the LTE approach:

a. Device Payload. The communications payload could include so-called UE and UE-to-Network relay (see 3GPP). The latter would act as a 'bridge' between ground UEs and the remote base station or network. There will be the possibility for a ground device to communicate directly with the airborne UE, as with today's WiFi drones.

There is minimal risk of interference, whether in urban or rural environments, when the UAS is served by a dedicated infrastructure in a dedicated spectrum band (distinct from the terrestrial system's).

b. Base Station or Network Payload. In contrast, an onboard base station, or system, could operate in stand-alone mode with embedded applications. There could be multiple variants contingent on the maximum payload supported by the UAS platform, which may result in a tether or tether-less solution. Backhaul to a remote entity may or may not be needed. Irrespective of the solution employed, deploying such a UAS over a live network, with both systems operating in the same spectrum band, will create an interference coordination challenge. Except for operation in remote and unserved areas, a UAS operating in a dedicated band (and exclusive, at least for the given operational area) is the most appropriate approach.[11] Owing to its large coverage footprint (up to 100 km range for LTE), the capacity required by such a UAS will need to be determined based on the traffic demand.[12]

Because of the wide geographic footprint served by a single UAS, coordination is likely needed.[13] It includes situations such as the presence of multiple UAS from different jurisdictions, the rollout of deployables on wheel, and the repair activities to restore the terrestrial infrastructure.

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[11] The allocation of the dedicated band may be temporary, hence limited for the duration of an event. The use of such an airborne platform could evolve to a UAS 'following' ground users, by providing communications services while on the move.

[12] Since the capacity is finite and the coverage spread is over a large area, consideration must be given to the traffic demand.

[13] See e.g., FCC, PS Docket No. 11-15, "Utilizing Rapidly Deployable Aerial Communications Architecture in Response to an Emergency". 05/24/2012.