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Forecasting Spectrum Demand for UAVs Served by Dedicated Allocation in Cellular Networks

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***Abstract*—In this paper, the usage of dedicated portions of cellular spectrum to provide the high-reliable Command and Control (C2) link for Unmanned Aerial Vehicles (UAVs) is evaluated. Simulations are performed using data settings of a real operating Long-Term Evolution (LTE) network in Denmark, in order to assess the reliability of the C2 link. Up to date databases of drone registrations and market projections are used to infer the drone densities and estimate the future traffic demand. Based on these estimations, network capacity results show that, deploying a sparse network with reservation of 1.4 MHz is sufficient for most cases according to current demands. In the next 20 years, the increase in demand can be followed by a continuous deployment of sites and an increase in the bandwidth up to 5 MHz. The paper also presents a discussion about which solutions can be used to further boost network capacity, and help to achieve high reliability even for the most stringent traffic demand cases.**

I. Introduction

The market for Unmanned Aerial Vehicle (UAV) applications is expanding rapidly, driven by advancements that make the technology more affordable to large audiences. By regulations, most of their applications shall guarantee direct visual line of sight (VLOS) — not to be confounded with radio line-of-sight (LOS) — between flight controller and UAV. In most cases, UAV and controller are connected over 802.11 or proprietary standards in unlicensed band. The lack of a long-distance reliable communication link for UAVs make authorities unwilling to allow beyond visual line-of-sight (BVLOS) flight ranges missions. In order to enable BVLOS ranges, in recent years, significant attention has been invested in creating a reliable Command and Control (C2) link between UAVs and flight controllers.

A feasibility study led by National Aeronautics and Space Administration (NASA) [1], argues that a nationwide Command and Control (C2) terrestrial network would entail prohibitive costs of operation and maintenance for the government. Additionally, the lack of an established demand for UAV traffic may impose risks for commercial entities interested in a Public-Private Partnership (PPP). The GSM Association (GSMA) presented cellular network as a potential solution to this problem in its official position released after a European Aviation Safety Agency (EASA)'s consultation [2]. In this document, three advantages of cellular networks are presented by GSMA: 1) a ready-to-market ubiquitous infrastructure; 2) 4^{th} Generation (4G) networks can already meet high-bandwidth and low latency requirements with good quality, which can enable not only the C2 link but innovative services through different payload applications; 3) operators have extensive experience and a long track-record in data privacy and security issues. The Third Generation Partnership Project (3GPP) has made enhancements further improving cellular networks for UAV service in its work item to promote enhanced support for aerial vehicles [3].

On top of this, the Single European Sky ATM Research Programme (SESAR)[1] has launched a framework for UAVs flying at very low levels, with the goal of ensuring their safety in the airspace. Among the projects launched by SESAR, DroC2om is especially oriented to investigate and design a hybrid architecture that combines cellular and satellite networks to provide a reliable C2 link [2].

However, cellular networks are commonly designed for terrestrial users, whereas propagation studies have shown that UAVs are subjected to different radio conditions. In [4], [5] authors show that airborne UAVs above rooftops are more likely to experience LOS and freespace propagation to the surrounding base stations. Therefore, the signals from the neighbor cells are stronger which can raise the interference level, as shown by the measurements in [6], [7].

When legacy cellular users and UAVs are sharing the same network resources, the broadband traffic generated by the first group is a source of interference for the second group and it can harm the reliability of the C2 downlink (DL) link or affects the radio usage's efficiency [8], [9]. In the uplink (UL), the signal transmitted by the UAVs will affect several neighboring base stations which will impact the legacy users [10], even though the LOS likelihood can reduce the required transmit power.

In this paper, the performance of UAVs in cellular networks is evaluated assuming a resource reservation approach, which aims at a middle ground solution between an expensive new dedicated network and the high interference resource sharing solution. In this approach, instead of licensing a large portion of the spectrum for C2 communications, operators can reserve a fraction of a carrier to the C2 link, while maintaining the remainder of the carrier available for legacy uses.

[1]https://www.sesarju.eu/
[2]https://www.droc2om.eu/

It is also discussed how this approach tends to be future proof, by adapting to the UAVs traffic demand as they increase over time, either by adjusting the density of deployed sites or the bandwidth reservation. For this exercise Federal Aviation Administration (FAA) projections for the US fleet, found in [11], is used as a reference number to project the UAV market size for the next 20 years.

The remainder of this paper is organized as follows: Section II presents traffic projections for airborne UAVs for the next 20 years. Sections III and IV present, respectively, the simulation scenario and the discussion of the results for the capacity of cellular networks to serve airborne UAVs. Further considerations on the assumptions and results are discussed in Section VI, while the conclusions are presented in VI.

II. UAV's Traffic Projection

This paper uses data from a real operating network in Aalborg, Denmark, to perform simulations and evaluate the reliability of the C2 link. Due to the scarcity of data in the number of UAV devices commercialized, it is generally difficult to estimate the UAV traffic demand. For this reason, the FAA has been chosen as a source, once it is one of the most complete databases that has been made publicly available. Based on their data, it is possible to roughly estimate the density of UAVs in use in the different US counties. These estimations cover a wide range of scenarios, from very dense areas such as Manhattan to rural areas in the countryside. By offering a multitude of scenarios, they provide a good generalization of the market size, and it is our understanding that the average figures for European scenarios should not differ much from these estimations, therefore, the scenario available for simulations fits the purpose of our evaluation. Section V-B discusses how the results should be weighed in according to discrepancies between the scenario in Aalborg and large metropolitan areas in US, such as Manhattan.

At the time of writing, there is no established demand for C2 links, as UAV's major applications are still limited to VLOS. Therefore, the assessment of estimations for spectrum requirements must be performed over forecasts.

In this paper, forecasts are based on FAA current numbers for the UAV market in the US. This is motivated on the grounds that FAA issues an early update on their forecasts and maintains a database that is publicly available with current drone registrations. The database, which contains the number of drones registered per US zip code[3], is used to estimate the density of registered drones. Henceforth, all mentions to this database refers to the class of non-hobbyist drones. The hobbyist drones, mostly used for leisure, are not considered part of the scope of the present work, because they are used much more infrequently, especially within the "busy hours" considered for the traffic prediction. Moreover, there is no indication that such class of drones will engage in BVLOS activities.

[3]Available online in: https://www.faa.gov/foia/electronic_reading_room/

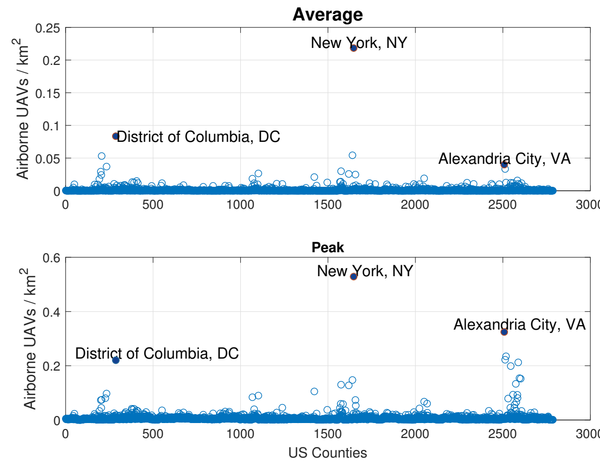

Fig. 1. Densities of estimated simultaneous airborne UAVs (average and peak) per US County (april 2018).

A. Today's Market

According to the FAA, there were right over 156 000 drones registered on US addresses as of April 2018. For reference, this corresponds to 1 drone for approximately 1300 personal cars. Regarding today's business models and assuming availability of C2 links, we estimate that each drone would be used on average 3 times per workweek (Monday to Friday, from 9 to 17 hs), with an average flight duration of 20 minutes.

Given such assumptions, and mapping the zip codes of drones registrations to US counties using the data from the Census Bureau[4], it is possible to determine what would be the UAV traffic demand today. Fig. 1 shows the average and the peak values expected for the density of simultaneous airborne UAVs. Counties with less than 30 km^2 were filtered out of the analysis, as few UAVs could yield a misleading high density of UAVs, but in reality they would require just a few radio resources.

In New York county, the one with highest UAV density, there average density projected for airborne UAVs is 0.2 UAV / km^2, with peaks of 0.52 UAV / km^2. It is important to note that the numbers for average and peak densities are based on assumption of an independent and identical exponential distribution of the take-off times. It does not cover the case of an event where massive take-offs could be observed, for example, to support or assist a parade. Such events would require different planning and a specific solution.

B. 20 years projections

The FAA in its recent forecast has released their expectations for the increase in the UAV's fleet for the next 5 years [11]. Because there are several uncertainties to be considered, such as fluctuations on economy and disruptive technological achievements, FAA provides two different projections: a "base"

[4]https://factfinder.census.gov

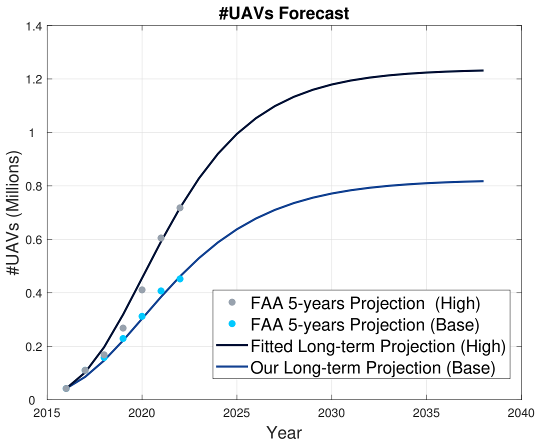

Fig. 2. Projections for UAVs fleet size in the next 20 years, extrapolating FAA 5-years projection.

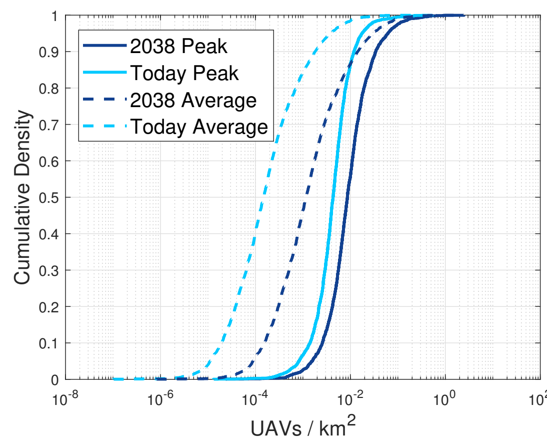

Fig. 3. CDF plots for the average and peaks projected density of UAVs in the air for US Counties.

scenario, expected to be the most likely outcome, and the "high" projection, which embodies a high potential for UAVs given more sophisticated uses are identified and successfully deployed. They represent, respectively, 33 % and 46 % of cumulative year-on-year growth rates. These numbers were taken as reference and, by fitting them with a "S-shaped" Gompertz function, which has been proved a good model for mobile traffic projections [12], the projections are extrapolated for the next 20 years. Figure 2 shows that, according to the long-term projections the fleet size is expected to increase from 5 to 7.5 times. In the high projection, the fleet exceeds 1.2 million UAVs around 2038. It is worth noting that these numbers represent a more agressive projection than the one provided by SESAR in November 2016, which projected 395 thousand commercial drones in the EU area for 2030.

Assuming that the increase of drones registered in each area is proportional to the national growing numbers, figure 3 shows the CDF plots for the expected average and peak densities of drones in the air for the high growth projection in 2038 in comparison with today's numbers. The peak density of drones, observed in New York County, is around 2.5 UAVs / km^2, while it is below 1 UAV / km^2 for the rest of the cases.

III. Simulation Scenario

In order to evaluate the capacity of cellular technologies to provide connectivity for UAVs, system level simulations were performed, using a framework built to investigate user mobility with focus on the 3GPP LTE technology and that has been previously described in [9].

The scenario chosen for the simulations reproduces the settings of a real network deployment in 2018 in an area of 40 x 40 km centered in the city of Aalborg, Denmark's fourth largest city. The scenario choice was motivated by the fact that network data containing sites heights, locations and antenna patterns, was made available for a real LTE operator, which makes the results more realistic. Different site densities were simulated in order to investigate how a continuous deployment of sites can cope with the boost in connectivity demand from the UAV side. From the 100 sites available in the simulation area, two were enabled from the first simulation: one arbitrarily chosen in the center of the grid, and the other being the farthest from the first one. Then, continuously the next site enabled was the one that maximizes the inter site distance to the enabled set. Four different network sizes were evaluated: 2, 10, 25 and 100 sites, which correspond to site densities of 1 site for 800, 160, 64, and 16 km^2, respectively. For each case, four different LTE compatible bandwidths were evaluated: 1.4, 5, 10 and 20 MHz. Table I shows the average parameters for the network data.

TABLE I
LTE Network Layout - Average Parameters

Parameter	Number of Sites			
	2	10	25	100
Site Height (m)	22.3	31.0	33.6	30.0
Downtilt (degrees)	6	4.6	4.6	7.2
Inter Site Distance (km)	25.0	10.6	6.3	1.9

For these simulations, the C2 link between UAV and the network is modeled as a constant bit-rate traffic, with average throughput of 100 kbps and packet inter arrival time of 100 ms, in both, UL and DL directions. These values are based on 3GPP's requirements for UAVs' C2 traffic [3]. Informations about the network layout used in the campaign are described in Table II, whereas the open-loop power control mechanism used in uplink, whose parameters are listed in Table III, is implemented as described in [13]. Readers interested in more detailed simulation parameters can refer to [9]. It is worth noting that the transmitter antennas were not uptilted to provide coverage for the airborne UAVs. For the purpose of this paper it is assumed that the legacy cellular network infrastructure is used to minimize the installation costs, but a frequency band is reserved to the UAVs use case.

In our simulations, one UAV reaches outage if its throughput is below 100 kbps for a 50 ms window, which is the maximum

TABLE II
SCENARIO LAYOUT

Parameter	Value
Simulation area	40 x 40 km
Maximum number of sites	100
Number of sectors	3
Transmit power	49 dBm
Carrier frequency (MHz)	800 and 2500
MIMO configuration	2x2
Propagation Model	UAV Height Dependent Model [4]

TABLE III
UPLINK POWER CONTROL PARAMETERS

Parameter	Value
Maximum Transmit Power	23 dBm
P0	-89 dBm per PRB
α	0.8

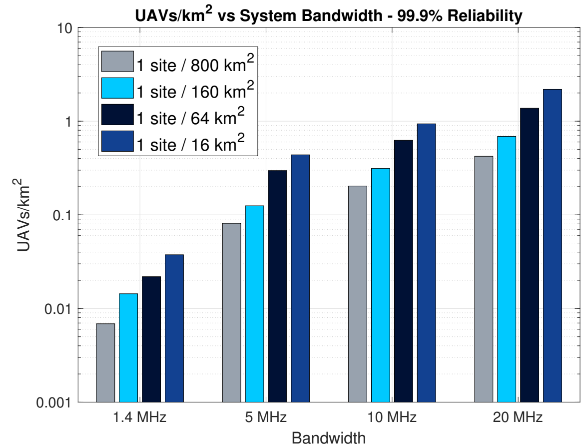

Fig. 4. System capacity with 99.9 % of reliability per bandwidth and site density.

transmission time of each C2 packet according to [3]. The reliability is defined as the number of UAVs that never reached outage divided by the total number of UAVs simulated for the duration of 4000 C2 packets transmitted. UAVs were uniformly distributed in the simulation area at a constant height of 120 m, and their number gradually increased to elevate the system load until the C2 reliability fell below the 99.9 % [3]. The main goal of the simulations was to find the maximum capacity for each network deployment. The UAVs' height in the simulations was chosen to be compatible with the maximum allowed for flight in many countries as of the time of writing.

IV. RESULTS

No significant frequency dependent variations is expected between 800 and 2600 MHz for the height-dependent channel model [14]. Therefore the results obtained by simulating 800 and 2500 MHz bands were very similar. Fig. 4 shows the maximum density of airborne UAVs achieved with a coverage reliability of 99.9 % for different bandwidths in the 800 MHz band.

Overall, simulations showed that due to the radio path clearance, the lack of signal is not a problem for flying UAVs even under very sparse networks. On the other hand, the good propagation conditions to several surrounding base stations causes a strong direct link interference, which is the main limiting factor for the system, as outlined in [9].

By loading up the network with more UAVs, the likelihood that two or more base stations are transmitting simultaneously in the same resources is increased, degrading the overall system signal to interference plus noise ratio (SINR). Therefore, the UAVs require more physical resources to transmit the same amount of data, and some users may get unserved if they are connected to a cell that runs out of radio resources. Increasing the bandwidth, not only provides more physical resources to the users, but it also decreases the likelihood of mutual interference, improving the overall SINR and therefore the spectrum efficiency. This last factor explains the nonlinear gains in system capacity provided by increases in the bandwidth. One example of such nonlinear gains are experienced when increasing the bandwidth from 1.4 MHz to 10 MHz for the most dense deployment case. This represents a 7 fold increase in the bandwidth, while the supported density increases from 0.0375 UAV / km^2 to 0.9375 UAV / km^2, a 25-fold increase.

On the UL, due to the power control mechanisms, the UAVs transmit power is, to a certain extent, proportional to their distances to the base stations. Therefore users close to the base stations transmit with less power, limiting the amount of interference radiated into the system. Because of this, the UL can handle more users before failing than the DL, which is the system's point of failure in the simulations. In all cases, the UL connection could be maintained above the 99.9 % reliability, when the DL failed to reach this requirement.

Although airborne UAVs cause interference to several base stations due to radio clearance [10], power control can be used to mitigate the overall interference increase observed on the base stations [9]. In other words, the UL power is kept at a level determined by the required SINR and the path losses, therefore there is no excess power radiated to the system. Whereas in DL users very close to the base station can experience a high SINR, beyond the point they can keep increasing the modulation and coding scheme for benefiting from it.

A. Current Spectral Requirements

By reserving 1.4 MHz of spectrum for C2 links, using a sparse setup with 1 site / 160 km^2, it is possible to offer coverage up to 0.014 UAV / km^2. Such service capacity would be capable of handling most of the scenarios under the assumptions of this paper. For reference, the peak density expected for 92.8 % of the US counties is below this capacity (fig. 3).

Moreover, a gradual increase of the sites deployment can cope even with the most stringent assumptions for today's requirements. By increasing the site density to 1 site / 16 km^2, the system capacity increases to 0.038 UAV / km^2, which is above the peak demand projected for 99.8 % of US counties. The outliers, such as the one for New York county, may need a more optimized network or additional bandwidth. Section V discusses how the system efficiency can be improved, which could allow 1.4 MHz of bandwidth to provide enough capacity for this case.

In areas where site deployment and maintenance corresponds to a high cost, the number of required sites could be kept low by offering additional bandwidth. Such scenario would enable a gradual implementation of new sites, according to the increase of UAVs demand. For example, using a 5 MHz carrier, with just 1 site / 800 km^2, the system capacity observed in the simulations is 0.082 UAV / km^2, above the most dense network scenario simulated with 1.4 MHz. Increasing the dedicated bandwidth for UAVs relies on cost and availability of spectrum, especially considering that a 5 MHz spectrum would be underutilised given the current UAV densities.

B. Future Spectral Requirements

Results in fig. 4 and 3 suggest that the reservation of 1.4 MHz may not cope with the future demand in the most stringent scenarios. The projection shows that close to 9 % of the projected scenarios cannot be served with 1.4 MHz even for the most dense network simulated. However, with 5 MHz spectrum the peak demand projected by up to 99.6 % of the counties can be served. For the outliers, a higher bandwidth may be required or, alternatively, improvements on the spectrum efficiency. For instance, the demand projected for the New York County would require 20 MHz of spectrum. In denser areas, there is a high demand for radio connectivity from several types of services and applications, and for that reason, it can be impractical to allocate such high bandwidth for a specific service. Some of the aspects discussed in Section V can be further improved to mitigate the spectrum requirements for a dedicated frequency for C2 link.

V. Discussion

In this section it is discussed which parameters can affect the results presented in Section IV. It is also presented features that can boost the network capacity and what are possible outcomes if there is a disruption in the density of airborne UAVs.

A. Dynamic Spectrum Allocation

In general, cellular networks do not use full capacity over a large area. In real deployments the network load is commonly around 10–30 % in the busy hours. But in some cases reserving resources for very large areas can affect negatively the overall network throughput. A modern strategy that are being envisioned to the future may be able to manage the spectrum allocation for UAVs, providing high reliability while being cost effective: dynamic spectrum allocation.

By dynamically reserving the spectrum in a large area, it is possible to protect the UAVs from undesired inter-cell interference. This can be achieved by monitoring the number of UAVs connected in an assigned area. Any time the interference reported by one of these devices increases significantly, the network can take two actions: increase the amount of resources reserved in the area, and/or expand the radius of the area where base stations are reserving these resources. This can prevent over-allocating resources, when the UAVs demand is very low, while providing reliable services regardless the fluctuations on demand.

B. System Improvements

In this paper, it is assumed that the transmitter antennae tilt and power was not optimized for the UAV use case. However, their optimization could lead to optimized SINR and therefore reduce the bandwidth/site density requirements. Moreover, the SINR could be further enhanced by interference management/suppression techniques. Techniques such as 3D beamforming, interference cancellation and directional transmission from the UAV side are expected to significantly improve the UAVs' SINR [9].

C. Dense Urban Scenarios

There is a caveat regarding the simulation for a very dense area like Manhattan. A more detailed model would be required to account for the tall buildings in this county. The presence of tall buildings can limit the LOS likelihood and therefore more interference insulation for the UAVs, reducing the amount of bandwidth required in comparison to the numbers presented in this paper.

D. Flight Take-off and Landing

It is important to note that, even though a very sparse network can provide connectivity for all airborne UAVs in a given area, it may face challenges in providing connectivity during the take-offs and landings phases. Cellular networks present one competitive advantage to solve this issue. They have ubiquitous coverage and a hybrid solution could be designed to explore the legacy network setup. For example, UAVs could use the legacy network during flight start and termination, up to a certain height, until they are able to connect to the reserved C2 spectrum for airborne UAVs.

The UAV cruise height also is an important factor to be considered. In this paper, all UAVs were considered to be flying at 120 m. If some UAVs are flying at lower heights, they will observe and cause less interference in DL and UL respectively, therefore, the system capacity may be positively impacted.

E. Disruptive Solutions and 5G

Disruptive technologies and solutions can cause an unexpected boost in the number of UAV solutions. In the same manner, UAVs applications such as cargo delivery, may become a very important business once the BVLOS flight range is enabled for drones, and the average utilization ratio of the drone may go above the 3 take-offs per workweek.

If the average number of flights used in the projection increase by a factor of 15, from 3 per workweek to 9 per workday, the densest network scenario simulated could still provide connectivity for the demand projected by most scenarios. Some outliers, however, project a demand beyond the capacity observed in simulations. Advancements in the technology in the next 20 years can also provide a solution to these cases, without the need for additional bandwidth. For example, 5G technologies already provide some features that can improve the efficiency of the system, such as massive MIMO, 3D beamforming, on-demand power boost in the direct link and more advanced interference suppression techniques.

VI. Conclusion and Future Works

This paper has discussed the usage of cellular networks to provide the C2 link for airborne UAVs in a dedicated portion of the spectrum. Both the infrastructure and the spectrum costs are expensive for a new network deployment. Depending on each specific case, the network design could start with a small bandwidth (such as 1.4 MHz) implemented in several sites, or with a larger bandwidth (5 MHz) implemented in fewer sites.

The paper also showed that a continuous deployment of resources, either by increasing the bandwidth reserved or the number of sites, can handle the increase in demand according to forecasts for the next 20 years, without the need to a very expensive implementation in the first moment.

Future work is being planned to investigate some of the challenges presented by having a sparse dedicated network, such as the initial and final phases of the flight. Other works also will investigate how network parameters (antennae tilt and transmit power) can be optimized and interference management/suppression techniques implemented to boost UAVs SINR and therefore the system capacity.

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References

[1] D. S. Ponchak, G. Church, E. Auld, and S. Henriksen, " A Summary of Two Recent UAS Command and Control (C2) Communications Feasibility Studies," in *2016 IEEE Aerospace Conference*, March 2016, pp. 1–11.

[2] GSMA, "GSMA Regulatory Position on Drones," Tech. Rep., August 2017.

[3] 3GPP, "Enhanced LTE support for aerial vehicles," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 36.777, Jan. 2018, version 15.0.0.

[4] R. Amorim et al., "Radio Channel Modeling for UAV Communication Over Cellular Networks," *IEEE Wireless Commun. Lett.*, vol. 6, no. 4, pp. 514–517, Aug. 2017.

[5] A. Al-Hourani and K. Gomez, "Modeling Cellular-to-UAV Path-Loss for Suburban Environments," *IEEE Wireless Commun. Lett.*, vol. 7, no. 1, pp. 82–85, Feb. 2018.

[6] B. V. D. Bergh, A. Chiumento, and S. Pollin, "LTE in the sky: trading off propagation benefits with interference costs for aerial nodes," *IEEE Commun. Mag.*, vol. 54, no. 5, pp. 44–50, May 2016.

[7] Qualcomm, "LTE Unmanned Aircraft Systems Trial Report," Qualcomm Technologies Inc., White Paper, May 2017.

[8] M. M. Azari et al., "Coexistence of Terrestrial and Aerial Users in Cellular Networks," in *Proc. IEEE Glob. Commun. Conf. Workshops*, Singapore, Dec 2017, pp. 1–6.

[9] H. C. Nguyen et al., "How to Ensure Reliable Connectivity for Aerial Vehicles Over Cellular Networks," *IEEE Access*, vol. 6, pp. 12 304–12 317, 2018.

[10] R. Amorim, H. Nguyen, J. Wigard, I. Z. Kovács, T. B. Sorensen, D. Z. Biro, M. Sørensen, and P. Mogensen, "Measured Uplink Interference Caused by Aerial Vehicles in LTE Cellular Networks," *IEEE Wireless Communications Letters*, pp. 1–1, 2018.

[11] Federal Aviation Authority, "FAA Aerospace Forecast, Fiscal Years 2018-2038," Tech. Rep., March 2018.

[12] I. Z. Kovacs, P. Mogensen, B. Christensen, and R. Jarvela, "Mobile broadband traffic forecast modeling for network evolution studies," in *2011 IEEE Vehicular Technology Conference (VTC Fall)*, Sept 2011, pp. 1–5.

[13] R. Mullner, C. F. Ball, K. Ivanov, J. Lienhart, and P. Hric, "Contrasting open-loop and closed-loop power control performance in utran lte uplink by ue trace analysis," in *2009 IEEE International Conference on Communications*, June 2009, pp. 1–6.

[14] R. Amorim, H. Nguyen, J. Wigard, I. Z. Kovács, T. B. Sorensen, and P. Mogensen, "Lte radio measurements above urban rooftops for aerial communications," in *2018 IEEE Wireless Communications and Networking Conference (WCNC)*, April 2018, pp. 1–6.