Communications for Massive UAV Scenarios

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Abstract— **In this article, we look 20 to 30 years ahead and provide some thoughts about communication technologies for future massive Unmanned Aerial Vehicle (UAV) scenarios in the Very Low Level (VLL) airspace. We use the term "massive" to stress that the number of UAVs will be in the order of the number of cars as of today: we treat scenarios where the number of UAVs is about 1 UAV per person. We expect UAVs to fly autonomously. Onboard sensors, communication and software will be key elements to ensure a safe operation. We address fundamental questions and provide thoughts on communication solutions.**

Keywords-component; UAV communications; drone-to-drone communications; massive UAV scenarios.

I. INTRODUCTION

In a near future, autonomously operating small to mid-sized Unmanned Aerial Vehicles (UAVs) enable prompt parcel delivery to every household and fast delivery of goods to shops, companies, restaurants, hospitals and the like. The Very Low Level (VLL) airspace will accommodate millions of UAVs. We may see scenarios which have been described so far only in science fiction novels. However, we are progressively getting closer to such a world: since many years already, UAVs support commercial, military and private purposes, and their number is dramatically growing.

In this article, we take a closer look on appropriate communication technologies for massive UAV scenarios. These scenarios are described in Section II and are very different from those of controlled airspaces: the density of UAVs will be considerably higher than today's density of aircraft in crowded regions. In Section III, we discuss fundamental aspects in terms of communications load and the number of simultaneously received messages. We sketch first results on the communication performance in Section IV.

II. THE MASS MARKET UAV SCENARIO

We consider scenarios with 1 UAV per person. This figure reflects our vision that the number of UAVs will be similar to the number of road motor vehicles as of today. The motorization rate in major European countries and in the United States is in the order of 60 to 70 % [1], respect. 80% [2], including automobiles, trucks, vans, buses, commercial vehicles and freight motor road vehicles.

Eventually, we look on a selected region and consider a UAV scenario in a larger city with 1.5 million inhabitants and dense traffic situations. Such a city can be Munich, Germany, and Philadelphia, Pennsylvania, United States. These cities have about 1.5 million inhabitants [3][4] and an area of about 310 and 350 km^2 [3][4], respectively. Thus, both cities have a similar number of inhabitants per km^2. And both cities have about the same number of road motor vehicles [3][5], i.e., about 700,000.

We follow our analogy of today's car usage pattern and the fact that the layout of cities does not dramatically change during the next decades. In our analysis, we assume that UAVs have a maximum speed of 15 m/s, that the average length of their flight paths is 7 km, and that 10 % of all UAVs are airborne during a UAV rush hour. Thus, we get an average flight duration of 8 minutes. For a UAV rush hour 150,000 UAVs are airborne over an area of about 300 km^2 resulting in a density of 500 UAVs per km^2; we also obtain about 0.75 million flights in the UAV rush hour.

From these numbers, it becomes obvious that traffic control of massive UAV scenarios cannot be handled in the same way as traffic control for today's IFR (Instrument Flight Rules) flights: due to the tremendous number of airborne UAVs a manual and semi-automated way of control is not feasible. Therefore, only fully automated traffic control systems are an option which in turn require robust and highly reliable Communication, Navigation and Surveillance (CNS) technologies. We also need very robust collision avoidance techniques which rely on the robustness and suitability of CNS technologies. In this contribution, we present a de-centralized communication concept for collision avoidance.

III. COMMUNICATION LOAD

We estimate the communication load for a city like Munich or Philadelphia. Thus, following our vision of 1 UAV per person, we get 1.5 million UAVs for such a city. Assuming that 10 % of all UAVs are airborne simultaneously during a UAV rush hour, we will have 150,000 UAVs in the air.

In order to get an estimate for the data volumes to be handled we refer to car-to-car communications technologies where cars broadcast periodically messages at 1 Hz (normal operation) to 10 Hz (in emergency situations). We believe that these rates can be transferred to UAV communications. A data packet shall encompass 500 bit (optionally 5000 bit) and contains the current position and orientation of the UAV, its future way points, its destination, information about its size, volume, freight type, priority mode and flight characteristics. Each UAV shall broadcast such a data packet with 1 Hz. Thus, the overall bit rate, i.e., the bit rate simultaneously transmitted by 150,000 UAVs is obtained as 75 Mbit/s.

We see that the overall bit rate is relatively small. A single LTE-Advanced Pro base station provides a total bit rate of up to 1000 Mbit/s and 500 Mbit/s for down- and uplink, respectively. Thus, the overall amount of data (and even ten times more in case of data packets of 5000 bit) is manageable even with today's technologies. The decisive question is whether a de-centralized or a centralized communication architecture shall be applied.

In this article, we promote direct communications between drones as in other traffic control systems: TCAS, the Traffic Collision Avoidance System for air traffic; AIS, the Automatic Identification System for maritime users; RCAS, a new Railway Collision Avoidance System acting as additional safety system; and ITS G5, a car-to-car communications standard. Traffic participants periodically broadcast data to surrounding aircraft, ships or vehicles, communicate directly with each other and use neither a central communications entity nor a centralized communication infrastructure. Beaconing, the periodic or quasi-periodic broadcast of information, is an established transmission mode.

An important issue to look at is the question up to which range the transmitted data shall be correctly received. We derive the communication range from two parameters: (1) UAVs will travel with a velocity of up to 15 m/s; (2) a potential collision course shall be detectable at least 33 seconds prior to the time instant at which this collision would occur when no action is taken. From a collision avoidance perspective, the worst case happens when both UAVs are heading directly towards each other resulting in the highest relative velocity and, hence, in the shortest amount of time to detect and solve this situation; this worst case requires a communication range of

$$R_{com} = 2 \cdot 15\mathrm{m}/s \cdot 33s \approx 1000m \,. \qquad (1)$$

Assuming all UAVs are equally distributed, the number of UAVs within the communication range is obtained as

$$N_{UAV} = R_{com}^2 \cdot \pi \cdot 500\mathrm{km}^{-2} \approx 1600 \,. \qquad (2)$$

The result reveals that each UAV must be able to correctly receive data from 1600 neighboring UAVs every second. Since the transmission rate is 500 bit/s, each UAV has to process a total of 0.8 Mbit every second. In view of these figures, we do not expect that it will be a problem for future UAV communication systems to receive, decode, and read 1600 data packets per second carrying a total of 0.8 Mbit of data. Also, managing the communication load for larger cell sizes or larger data packets should not be a problem: e.g., doubling the cell radius results in 6300 UAVs per cell and, in turn, in 6300 data packets carrying a total of 3.2 Mbit.

We are also confident that it won't be a problem to check 1600, respectively 6300 flight trajectories for potential collision courses every second and to suggest alternative routes if needed. Note that it is not required to repeat checking for potential collisions as long as trajectories remain unchanged. Thus, trajectories from only those UAVs have to be checked which either enter the communication range or have changed their trajectories.

IV. FIRST RESULTS

At the workshop, the author will provide first results on the performance of slotted ALOHA [6] when applied to a massive UAV scenario with UAV densities of 100 to 500 UAV/km^2. He will present a relation between communication failures (i.e., non-received messages) and the expected number of UAV collisions and will apply it to two different scenarios: one where all UAVs choose a direct flight path between departure and destination locations and one where UAVs fly on a grid-like pattern. All UAVs fly above rooftops and have line-of-sight conditions. In our first assessment, we consider neither multipath propagation although it may degrade the communication performance nor take-off and landing maneuvers although they are crucial due to shadowing situations. The communication system may operate at C-band.

The analysis will follow a framework which has been presented in [7] and is based on the missed detection probability that not a single beacon message is received correctly at a UAV while approaching another one on a collision course. Both UAVs have at least 30 opportunities (during 33s) to detect beacon messages of the other UAV before the collision happens, and a collision is unavoidable of none of the two UAVs correctly receives at least one data packet at least 3s prior to the potential collision.

The first investigations reveal that an ALOHA-type beaconing system with 1 MHz bandwidth and 1 Hz beaconing rate can support UAV densities up to 150 UAV/km^2 when UAVs fly direct paths and more than 500 UAV/km^2 when UAVs fly along a predefined grid while guaranteeing less than 1 accident per year for a city like Munich. With larger packets the bandwidth increases linearly. Note that self-organized Time Division Multiple Access (TDMA) or Location-Based TDMA may allow even higher UAV densities.

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REFERENCES

[1] European Automobile Manufacturers Association. https://www.acea.auto/files/ACEA_Report_Vehicles_in_use-Europe_2019-1.pdf

[2] Bureau of Transportation Statistics of the U.S. Department of Transportation (DOT). https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances

[3] City of Munich. https://www.muenchen.de/

[4] U.S. Census Bureau of the U.S. Department of Commerce. https://www.census.gov/quickfacts/fact/table/philadelphiacity pennsylvania,US/PST045219

[5] Pennsylvania Department of Transportation. http://www.dot.state.pa.us/public/dvspubsforms/BMV/Registration%20Reports/Reportofregistration2019.pdf

[6] N. Abramson, "The ALOHA System - Another Alternative for Computer Communications" in Proc. 1970 Fall Joint Computer Conference, 1970, pp. 281–285.

[7] L. M. Schalk, "Techniques for improving the cooperative Traffic Conflict Detection among Drones." In Proc. of IEEE 89th Vehicular Technology Conf. (VTC Spring) 2019, Kuala Lumpur, Malaysia, doi: 10.1109/VTCSpring.2019.8746350