COMMUNICATION NETWORK FOR A SWARM OF UNMANNED AERIAL VEHICLES

[1]Jan Rajm, [2]Jiří Janoušek

[1]Bachelor Degree Programme (3.), FEEC, Brno University of Technology, Czech Republic

[2]DTEE, FEEC, Brno University of Technology, Czech Republic

E-mail: xrajmj00@vutbr.cz, xjanou09@vutbr.cz

Abstract—This paper deals with the creation of a wireless network for a swarm of unmanned aerial vehicles which enables high enough data throughput for transition of telemetric and application data between unmanned aerial vehicles and ground control station and also enables communication at a greate distance. Even when unmanned aerial vehicles are beyond visual line of sight.

Keywords—4G, 5G, cellular network, LTE, swarm of UAVs, UAV

1. INTRODUCTION

Unmanned aerial vehicles (UAVs), also called drones, have a wide area of use-cases because of their high mobility. Examples of use-cases may be filming and taking photos, transportation of small packages, military purposes, precision agriculture, surveillance, and many others. Since UAVs serve as instruments for remote tasks or as devices for data collection, a reliable communication network is essential. Only with it is it possible to control UAVs by a ground control station (GCS), where all important decisions are made. UAVs serve as peripheral devices of the GCS.

One UAV can handle a large number of tasks, adding another UAV and creating a swarm can expand the number of tasks or save time. In a single swarm can be many types of UAVs, each type with its special abilities. On the other hand, it is more challenging not only for a GCS to manage the swarm, but also demands higher robustness of the communication network.

Since ad-hoc networks are usually limited to the line of sight (LOS) communication between the GCS and its subordinated swarm of UAVs, cellular network technology is proposed as a solution for the beyond visual line of sight (BVLOS) communication. In this paper, a communication network for a swarm of UAVs, enabling BVLOS communication, is designed.

2. SELECTION OF STANDARDS

The main block of communication networks are communication modules. They are made according to a specific standard, which defines its features, such as the used frequency band, modulation, type of forward error correction, cryptography and so on. Other important aspects of communication standards are the network technology, which can be created using modules of the standard, and the topology of the network. What we are searching for are wireless communication standards with data rate enabling transmission of telemetry data and application data (data from sensors, video, etc.) in real time, communication range higher than 100 meters, the ability to communicate BVLOS and the ability to maintain a swarm containing hundreds of UAVs. Maximum allowable latency depends on the specific use-case and may range from the tens to the hundreds of milliseconds [1].

The most suitable possibility is LTE, which is the building block of 4G cellular networks. This means an advantage of already created network infrastructure, so we do not need to build our own infrastructure. In addition, there is an advantage of using commercial frequency bands, in which there is less interference. Just the subject with the permission may use these frequencies. In our case the permission belongs to network providers. The other advantage of cellular network is its coverage of an area by its signal enabling BVLOS communication between a GCS and a swarm of UAVs. Data rate for both downlink and uplink of 4G LTE network may be in orders of hundreds of Mb/s and theoretically can be data rate for downlink up to 1Gb/s and uplink 500 Mb/s. That is the opposite of our requirement.

For UAVs it would be better to have a higher data rate for uplink (because of sending application data back to the GCS), than downlink (the only data the UAV receive are control data). Data rate closely depends on the environment. Higher levels of noise, obstacles and many other phenomena will decrease data rate. Nevertheless, data rate of hundreds (even tens) of Mb/s for uplink is still high enough to stream a video and transmit telemetric data. The only limitations of using 4G networks are the maximal height and the fee for using a provider's network. Since a base transceiver station (BTS) is supposed to deliver a terrestrial signal, the signal level above BTS is minimal. The latency of 4G networks ranges between 30 to 80 milliseconds, which is good enough for a most of use-cases. Telemetry requires data rate ranging 60-100 kb/s for both uplink and downlink [1][2].

Use-cases closely depend on network properties and the technology of the network. The use of 4G networks is more suitable for urban areas than for rural areas. It is also worth mentioning that the 4G network allows the swarm of UAVs to be spread over a large area. In general, the use-cases, for which our network is most suitable, require both large range and high data rate, for example delivery, surveillance, infrastructure control, first aid, and so on.

Other considered cellular standards for this paper included LTE Cat-M, NB-IoT and LoRaWAN. For ad-hoc network technology are suitable standards ZigBee (802.15.4), HaLow (802.11ah), RFD868, FrSky and many others. For satellite network technology is suitable for example SPL Satellite Telemetry.

3. SOFTWARE FOR UAV COMMUNICATION

Mission Planner is a software for a GCS, enabling planning a mission for one and more UAVs, enabling configuration of flight controller settings for UAVs, including control of mission commands. Mission Planner also provides an overview of telemetry data of every single UAV of our swarm and can run its own system in the loop (SITL) simulation as shown in a Figure 1. Mission Planner is an open-source software [3].

Figure 1: Mission Planner running SITL simulation

Mission Planner communicates with UAVs using a MAVLink protocol, which is an open-source protocol used not only by UAVs, but also by other unmanned vehicles, such as boats, rovers, submarines, and others. MAVLink provides methods for detection of lost packets, damaged packets, and authentication. MAVLink is optimized for hardware with limited RAM and flash memory, such as microcontrollers [4].

ArduPilot is an open-source autopilot software used in flight controllers, which is the brain of the UAV. ArduPilot receives and processes tasks transmitted by MAVLink from the GCS. ArduPilot provides advanced functionality including a real-time communication with the GCS [5].

4. COMMUNICATION NETWORK

Proposed communication network consists of a swarm of UAVs, which is connected with a GCS over the Internet. The topology of this network is the star topology since every UAV communicates with the GCS. The wireless connection between the GCS and the swarm is implemented by a 4G network. Current 5G networks operate in non-standalone (NSA) mode, so they still use 4G cores in their architecture, which limits their maximal data rate, so it is still better to use 4G networks because of their coverage of area and availability of modules. The time of use of 5G networks is yet to come, but when it comes, an upgrade means simply just replacing the 4G module with a 5G one. The software infrastructure is the same. 5G will offer low latency (in order of ones of milliseconds for end-to-end connection), data rate of Gb/s, high reliability and some useful features for UAVs (e. g. remote identification of UAVs) since 3GPP (The 3rd Generation Partnership Project) includes UAVs among other use-cases of 5G networks. Figure 2 shows a block diagram of a single UAV communication network [6][7].

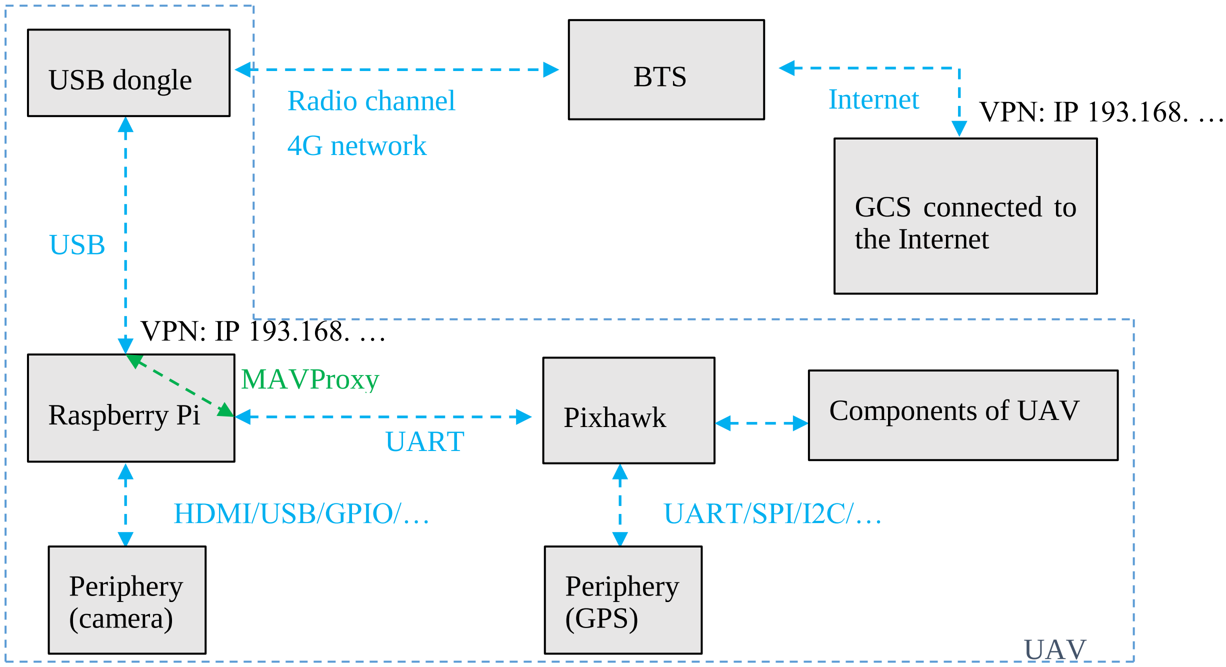

Figure 2: Block diagram of the network

In order to connect the flight controller of the UAV with the 4G network, a companion computer is needed. The companion computer is the Raspberry Pi 4 and for 4G signal reception will be used a USB 4G LTE dongle. Within the Internet, the network will be implemented by the virtual private network (VPN). Within the VPN, the GCS and companion computers have their unique IP, which is used when creating connections. The companion computer is connected with the flight controller via the UART interface. Companion computer also enables a peripheral connection of many other peripheral devices, which flight controllers cannot handle, such as a camera or other sensors producing large amount of data. The companion computer can also perform on-board tasks, such as signal processing or decision-making processes. Decision-making allows transmission of a lower amount of data and thus the GCS can handle more UAVs in the swarm.

Within the companion computer it is necessary to forward telemetric data between the serial port (in our case the UART port), connected to the flight controller, and the remote GCS, which is represented by its VPN IP address. For this purpose, an open-source software MAVProxy is used. MAVProxy also can emulate an UAV by its own SITL, which can be used during tests of communication infrastructure and offers the possibility of fully controlled tests [8].

5. CONCLUSION

This paper aimed to create a communication network for a swarm of UAVs, which enables BVLOS communication between UAVs and a GCS, and also provides sufficient data rate for not only telemetry data, but also for application data. The 4G network showed as the most suitable solution for our UAV communication network because of its coverage of an area, high data rate and sufficiently low latency. In combination with a companion computer, our network is very flexible and can be used to control a numerous swarm of UAVs in use-cases such as delivery, surveillance, infrastructure control, first aid, and others. 4G network provides a well secured and reliable network for our swarm.

Another motivation for the use of the cellular network is its perspective future. The use of cellular networks by UAVs is counted by 3GPP. So, UAVs are included among other use-cases of 5G networks during ongoing standardization and 5G networks will provide some useful features for UAVs. 5G networks will also provide a great enhancement in data rate, latency, reliability, connection density and much more.

It is possible to build on this work by many enhancements. The designed network is suitable for tasks requiring high data rate and computing power. An example of an enhancement can be UAVs with their own subordinated UAVs or UAVs serving as a mobile access point.

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