INCREASED OPERATIONAL SAFETY CONCEPT OF UAV BY CONNECTING TO 3G/4G NETWORK

Ing. Tomáš VOLČKO, doc.Ing. Václav MOUCHA, CSc., Ing. Pavol LIPOVSKÝ, PhD., Ing. Katarína DRAGANOVÁ, PhD.
Faculty of Aeronautics, Technical University of Košice,
E-mail: tomas.volcko@tuke.sk

Summary: The communication link between the UAV and its ground station is a critical part of the complete UAS and has a great impact on operational safety. Nowadays, there are several kinds of the communication interfaces with different parameters such as operational frequency, data throughput, transmitting power etc. This article deals with the possibility of use the latest generations of mobile telecommunication systems, specifically UMTS and LTE, for the purpose of increase operational safety of UAV. The document consist of five parts. The first and second part describe UMTS and LTE technology. Considerable attention is given to their internal network structures, data throughput and the network security features. Next part describe EC20 UMTS/LTE module which we have tested. Test results are contained in the fifth part of these article. The penultimate part is given to MAVLink communication protocol. UMTS/LTE network uses IP (Internet Protocol) protocol but many of today's UAV uses MAVLink as it was specially designed for purpose of UAS (Unmanned Aerial System) communication.

The main contribution of this work is to introduce the idea of use the existing mobile telecommunication architecture for purpose of increase UAV operational safety.

Keywords: Universal Mobile Telecommunication System (UMTS); Long Term Evolution (LTE); Unmanned Aerial Vehicle (UAV); communication

1. INTRODUCTION

The development of the UAVs (Unmanned Aerial Vehicles) has achieved a great progress in recent years. It is possible to use the UAVs in different areas of interest. However, there still remains the question of how to integrate a UAV into the airspace (especially urban areas airspace) and not significantly impair the safety of the existing infrastructure of the airspace. For a reliable and safe operation of UAVs, mainly in the autonomous mode, at first it is necessary to resolve multiple problems in the area of the communication, the signal processing and the visualization of the signals.

In this article we will focus on the area of communication and will analyze the possibility to use the UMTS (Universal Mobile Telecommunication System) and LTE (Long Term Evolution) communication technology as the latest generation of the GSM (Global System for Mobile Communications) communication network.

2. UMTS NETWORK

The UMTS is the 3rd generation of a wireless telecommunication system, which includes the interconnection of the voice and data services. The UMTS network is divided into two parts. The core network part (CN – Core Network) represents the central part of the system and the radio part (UTRAN – Universal Terrestrial Radio Access Network) represents the network antenna system. The UMTS core network is divided into two domains: Circuit Switched Domain (CS) and Packet Switched

Domain (PS). These two domains share some segments, other belong to only one domain. The CS domain procures transmission of the voice and CS data. It provides connection to other networks such as the classic fixed public phone network or fixed digital ISDN (Integrated Services Digital Network) network. The PS domain is responsible for the packet data transfer and connection to networks such as the internet or intranet. It includes a SGSN (Serving GPRS Support Node) serving as the mobility management, authentication, encryption, pricing and routing of the GPRS packet communication via the GGSN (Gateway GPRS Support Node) to the IP (Internet Protocol) network [1],[4].

The UMTS uses the W-CDMA (Wideband Code Division Multiple Access) to carry the radio transmissions, and often the system is referred to by the name W-CDMA. However, the system makes use of the TD-CDMA (Time Division CDMA) and TD-SCDMA (Time Division Synchronous CDMA). The UMTS is a complete network system. It also covers the radio access network, the core network and the authentication of users using the USIM cards. It employs a 5 MHz channel bandwidth. The ITU (International Telecommunication Union) has not provided a clear definition of the data rate that users can expect from the 3G equipment or providers. A minimum data rate, stated in commentary, is 2 Mbit/s for stationary or walking users and 384 kbit/s for a moving vehicle. In market implementation, 3G downlink data speeds defined by telecommunication service providers vary depending on the underlying technology deployed; up to the 384 kbit/s for W-CDMA, up to 7.2 Mbit/s for HSPA (High Speed Download Packed Access) and the theoretical maximum of 21.6 Mbit/s for HSPA+ [6],[8],[9].

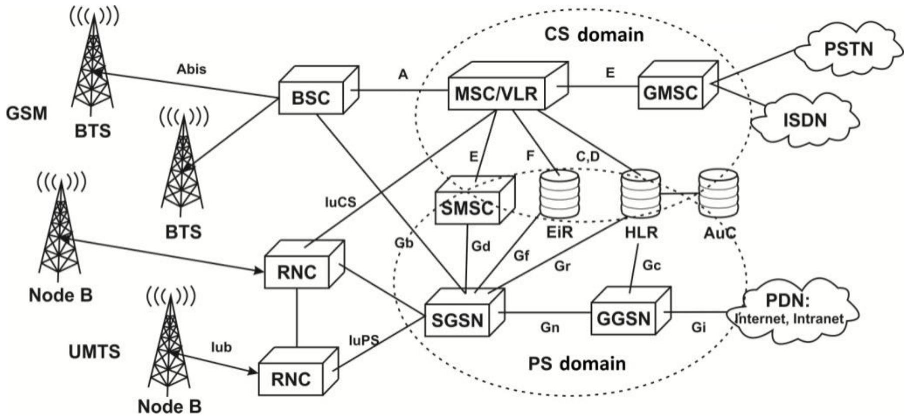

Figure. 1 The UMTS network structure

The security functions of the UMTS are based on what was implemented in the GSM as the UMTS is a successor of the GSM. Some of the security functions have been added and some of the existing functions have been improved. This maximizes the compatibility between the GSM and the UMTS. The UMTS also provides a solution to the weaknesses of GSM security and adds security features for new 3G radio access networks and services [7],[10].

The encryption algorithm is stronger and it is included in the base station's (NODE-B) radio network controller (RNC) interface, the application of authentication algorithms is stricter and subscriber confidentiality is tighter. The UMTS consists of five security feature groups:

1) Network Access Security provides the users with secure access to the UMTS services and protects against attacks on the radio access link.

2) Network Domain Security protects against attacks on the wireline network and allows the nodes in the provider domain to exchange signaling data securely.

3) User Domain Security provides secure access to mobile stations.

4) Application Domain Security allows the secure exchange of messages among applications in the user and in the provider domain.

5) Visibility and configurability of security allows the user to observe whether a security feature is currently in operation and if certain services depend on this security feature [4],[9],[11].

3. LTE TECHNOLOGY

The LTE is the set of 3GPP (3th Generation Partnership Project) standards, which defines a new mobile telecommunication system. The LTE is the successor of the UMTS, the GSM EDGE and their extensions the HSPA and the HSPA+ and the path followed to achieve true 4G speeds.

The goal of the LTE is to increase the capacity and speed of wireless data networks using new DSP (Digital Signal Processing) techniques and modulations that were developed past year 2000. A further goal is the redesign and simplification of the network architecture to an IP-based system with significantly reduced transfer latency compared to the 3G architecture [6],[8],[9].

The LTE wireless interface is incompatible with 2G and 3G networks, so that it has to be operated on a separate radio spectrum. The LTE specification provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s and QoS (Quality of Service) provisions permitting a transfer latency of less than 5 ms in the radio access network.

The LTE has the ability to manage fast-moving mobiles, such as the UAVs and supports multi-cast and broadcast streams. The LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both frequency division duplexing (FDD) and time-division duplexing (TDD). The IP-based network architecture, called the Evolved Packet Core (EPC) designed to replace the GPRS Core Network, supports seamless handovers for the both voice and data to the cell towers with older network technology such as the GSM, the UMTS and CDMA2000 [11].

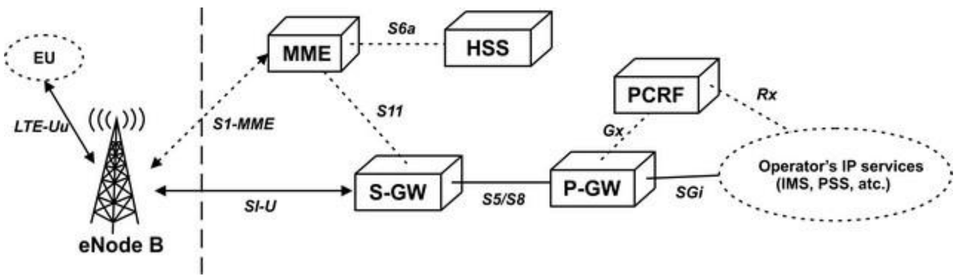

Figure. 2 The LTE network structure

The LTE uses the Orthogonal Frequency Division Multiplexing (OFDM) for the downlink – that is, from the base station to the terminal it transmits the data over many narrow band careers of 180 KHz each instead of spreading one signal over the complete 5 MHz career bandwidth, so the OFDM uses a large number of narrow sub-carriers for multi-carrier transmission to carry the data. The OFDM symbols are grouped into resource blocks. The resource blocks have a total size of 180 kHz in the frequency domain and 0.5 ms in the time domain [7], [8].

4. EC20 UMTS/LTE MODULE

EC20 series is the new generation of the Quectel's LTE modules. The modules adopted the 3GPP Rel. 9 LTE technology, which delivers theoretically 100 Mbit/s downlink and 50 Mbit/s uplink data rates [8]. From the point of view of the connection with the transfer of information from the UAV for the purposes of surveillance, these data rates are more than sufficient. The MAVLink (further described in next chapter), a commonly used communication protocol in the area of micro and small UAVs applications, has the maximum message length of 264 bytes. Assuming that the UAV will be sending 2 status messages per second with maximum length of 264 bytes, the required data throughput will be less than 1 kB/s per UAV. The EC20 is supporting, among other protocols, TCP/IP stack and

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AT commands, which allow to communicate with the control server by the TCP segments or the UDP datagram.

The antennas at each end of the communications circuit are combined to minimize errors and optimize the data rate. The module also combines the high-speed wireless connectivity with embedded multi-constellation high-sensitivity positioning GNSS (Global Navigation Satellite System) receiver (GLONASS + GPS). Enabling the GLONASS and GPS system at the same time makes the GNSS module time saving for acquisition and improvement of accuracy and precision in the position determination.

Because the module can be controlled via AT commands, it is necessary to use the microcontroller, but this gives the user the possibility to create some kind of a standardized approach in programming. In our case, we have decided to use the Arduino Mega with the ATMega 2560 microcontroller as we use the Arduino-based autopilot board ArduPilot Mega. The ATMega is a 8-bit microcontroller with the clock frequency of 16 MHz and it has integrated the 256 kB flash memory. It is sufficiently powerful to not only communicate with the LTE/UMTS module but it can also provide execution of some other tasks such as creating, previously mentioned, status messages and others. The biggest advantage of the UMTS and LTE networks is their coverage area. The LTE/UMTS signal covers almost the whole city and because the UAV operates in the open air where there are much less obstacles that could interfere the radio signal, we can expect good and stable connectivity over the city.

5. MAVLINK COMMUNICATION PROTOCOL

Therefore, the UAV is multi sensor system, it produce a lot of information from the sensors and additional various calculations. In order to be able to identify from which device, sensor or processing results is information received it is necessary to use message structures. It is set of communication rules commonly known as the communication protocol. MAVLink protocol (Micro Aerial Vehicle Link) has been developed for civilian UAS. It is a protocol for communication with small UAVs (MAV). MAVLink is very lightweight, header-only message marshalling library. It can pack C-structs over serial channels with high effiency and send these packets to the ground control station or to another UAV. The effectiveness of this protocol is that it contains only 8 overhead bytes (header bytes and checksum). The communication protocol is used on commercial platforms such as ArduPilot Mega, PixHawk, Parrot AR and many others. MAVLink is not only used for communication with the ground station, but also for communication of UAV subsystems and other in-process communication. The anatomy of an MAVLink packet is inspired by the CAN bus and SAE AS-4 standard. One advantage is that it does not need any additional hardware. MAVLink is a header-only library, which means that you don't have to compile it for your MCU. You just have to add `mavlink/include` to the list of your include directories [12].

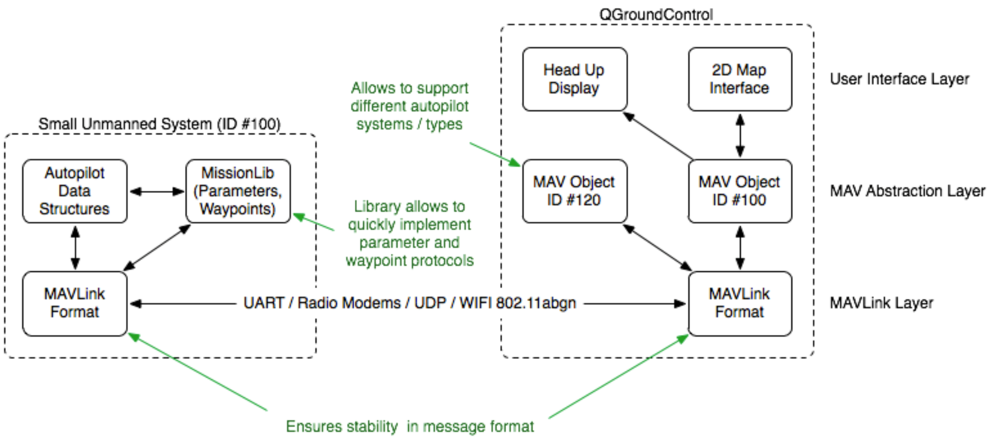

Figure. 3 The MAVLink integration architecture

As the diagram below shows, integrating MAVLink is non-intrusive. MAVLink does not need to become a central part of the onboard architecture. The provided missionlib handles parameter and mission / waypoint transmission, the autopilot only needs to read off the values from the appropriate data structures.

MAVLink has a very stable message format, one of the primary reasons so many GCS and autopilots support it. If QGroundControl is used for a non-standard application, the UAS object can be sub-classed and QGroundControl can be fully customized to not only use a custom set of MAVLink messages, but also to handle them in a custom C++ class [12].

6. LATENCY TESTING

If we want to use the MAVLink and the EC20 module, at first we need to measure the transfer latencies in the LTE network, as probably main communication link. The UMTS network will then serve as a communication backup. The basic principle of the test is to send a data packet to a server, wait for the response and measure the time between sending and responding.

The test has been performed in one-hour intervals for period of five working days since we expect different network loads during the day and week. The four packets with a length of 32 Bytes were sent to our experimental server. In future, this server will be equipped with hardware with a better performance so it will perform all surveillance and collision avoidance tasks. The results of our test measurements are shown in the Figure 4.

The LTE network latencies are ranging below 40 ms. It is necessary to state that the values we were measured represented round-trip times, which means a sum of times from the module to the server and back. Assuming the priority only in the receiving messages from the UAV, it was possible to divide these values by 2. So the resulting average latencies divided by 2 are shown in Figure 4.

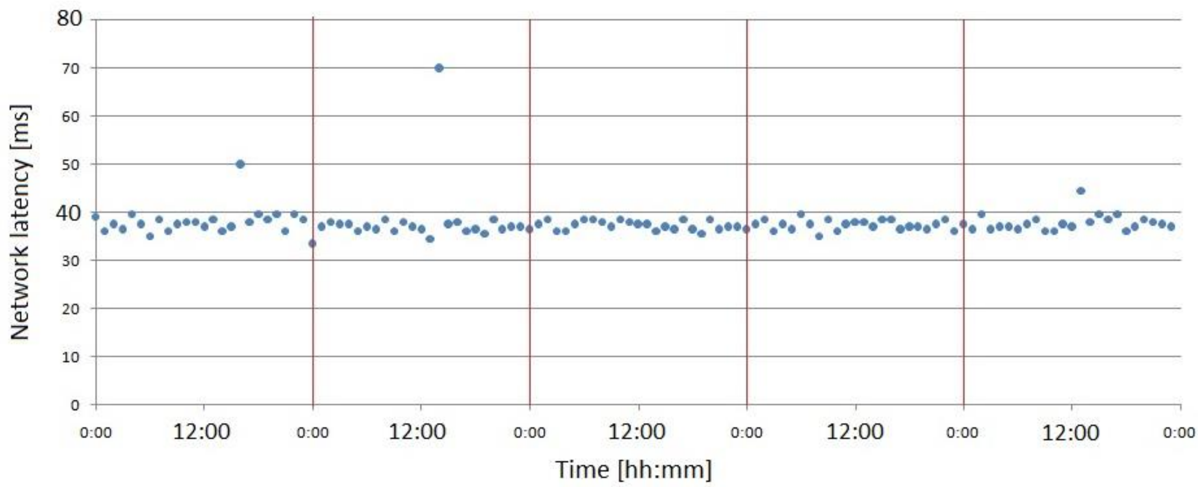

Figure. 4 Graph of latencies in LTE network

Based on the results we can expect that we will be able to send up to 20 messages per second in the LTE network. But due to the variable network load, we are going to use 2 status messages per second.

The status message has to consist of important information that will help to specify the risk of a mid-air collision of the UAVs. The most important information regarding to the surveillance are, for example, the position of the UAV in the airspace, such as the GPS location; registration number of UAV that uniquely identify each UAV; the priority level that will specify which UAV has more

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important mission in case of solving the conflict in the trajectory between two and more UAVs, the remaining battery capacity and others like a route destination, flight plan and so on. The block diagram of our planned surveillance and collision avoidance module is shown in Figure 5.

As the UAV is only controllable by the communication link, the UMTS/LTE network has its place in terms of the communication link between the UAV and the ground station. We think that one of the best ideas is to use it in the application similar to the secondary radio-location for the UAV, preferably the small UAV, operated in the urban areas.

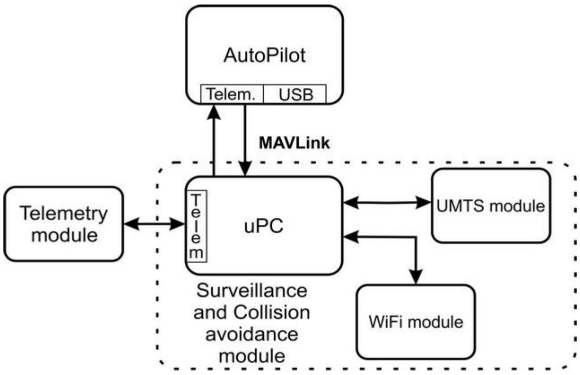

Figure. 5 Block diagram of Surveillance and Collision avoidance module

Another idea is to use the UMTS/LTE network for the surveillance and the collision avoidance application. In the autonomous mode, each UAV holds its flight plan that can be uploaded prior to the takeoff to the control server. By comparing the flight plans the server will be able to determine whether the flight plans of drones overlap or a collision situation is approaching. If so, it will be calculated, at which point and at what time the trajectories will intersect.
As the collision avoidance stack represents many calculations it will probably be better to create a central server with powerful computing resources in the future, because the UAVs usually have only limited computing resources. The server will receive status messages directly through the UMTS/LTE network, and search for the collision. If the risk of collision achieves the determined level, the server will, based on the on-board equipment of the UAV, automatically send a modified flight plan to one of the UAVs or a message to the operator.

7. CONCLUSION

Usage of the LTE and UMTS network has a great potential in terms of the UAV communication. Based on the previous and actual results of tests we have performed show that the short latencies, high level of security and data throughput gives these networks prerequisites for usage in the UAV applications. EC20 LTE module provides LTE and UMTS network connection capabilities, which provide backup of each of these networks.

The concept of using the existing infrastructure of the mobile networks will probably increase operational safety and help to manage the integration of the UAVs into the airspace with minimal financial demands.

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