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Concept for a Short-Range Fallback Communication System for Drones in Medical Applications

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Abstract

Goal of the research project KIMoNo is the implementation of a drone based delivery system for medical products and samples. To ensure the communication between drone and a ground team even in remote areas, a fallback communication system is required. In this paper a brief overview of communication systems for drones is presented and a concept for the fallback communication system is proposed.

1 Introduction

Using unmanned aerial vehicles (UAVs) for delivery of various kinds of goods is becoming an increasingly popular approach. Although this promises advantages (e.g. saving time or resources), only a few commercial applications have been established so far. The reasons for this are, legal restrictions, as well as, the lack of technical implementations. Overcoming these obstacles is the goal of the project KIMoNo, which focuses on the mobility optimization in medicine to improve the quality and efficiency of the medical care for patients in rural and remote areas. Therefore, inter-modal transport concepts, including vertical take-off and landing (VTOL) drones, are researched. This includes the transport of (time-)critical medical goods and samples. As one aspect of this delivery system, an information exchange between the drone and authorized third parties must be established (e.g. to set landing / drop-off locations). This is achieved with a web-based information system, which can be accessed via mobile internet (4G/5G). However, the system shall also be suitable for very remote application scenarios (such as rescue operations in mountainous areas), where lack of cellular network coverage can't be ruled out. Therefore, a fallback communication system is required to ensure a reliable communication between the unmanned aerial system (UAS) and a field team (e.g. mountain rescue service) on the ground. This system must not interfere with the drone's other communication systems. It has to be lightweight and energy efficient, in order not to limit the payload capacity or range of the UAV. A concept for the fallback communication system is proposed in this paper.

In the next section of this paper a short overview of some related work in this field of research is given. This section is followed by information on the UAS and the proposed concept for the fallback communication system. Finally, a look ahead at the future work is presented.

2 Related Work

Using drones has been proposed for various applications in the public health sector. An UAS for delivering an automated external defibrillator is presented in [1]. The system offers a time advantage compared to the arrival of an ambulance. The drone is equipped with a camera and 433 MHz and 3G communication links. It is operated by two pilots. A SWOT analysis of UAVs for public health applications is presented in [2]. Use cases such as the transport of blood and essential medicines in remote areas (e.g. in Africa) are shown. The idea of an urban first and last mile transport using UAVs with prioritization of time-critical jobs, including the delivery of vaccine supplies in rural areas, is presented in [3].

A very detailed survey of wireless communication systems for aerial applications is available from Baltaci et al. [4]. In the following a short overview of some of these communication systems is given.

Cellular networks: With the increasing bandwidth and availability of cellular networks, their application to UAVs have gathered a lot of research interest [4]. A few examples can be found in [1], [5], [6] or [7]. For this purpose, NB-IoT, which uses a sub set of the LTE cellular standard, has also been suggested [4]. Sigfox is a so called 0G-technology specifically designed for low-power, low-energy internet of things (IoT) applications. From an infrastructural point of view, Sigfox also requires a network of base stations. Thus, it's comparable to other cellular networks. The coverage of Sigfox is continuously increasing, but is still not at 100 % as shown by the coverage map [8].

IEEE networks: IEEE standardized networks are vastly available, use unlicensed spectrum and provide flexible low cost solutions [4]. Wi-Fi is widely used for UAV communications. Due to the short range, these applications are mainly limited to line of sight scenarios. The IEEE 802.11ah standard which uses the sub 1 GHz band is designed for IoT applications and provides an extended range up to 1 km [4]. ZigBee (based on IEEE 802.15.4) is designed for machine type communication, but is also used in short-range UAV applications (like flight formation control) [4]. With less than 100 m, ZigBee's range is rather limited. Worldwide Interoperability for Microwave Access (WiMAX), which is standardized as IEEE 802.16, provides a data rate up to 75 Mbit/s and a range up to

30 km [9]. It can operate both in licensed and unlicensed frequency bands and supports point-to-multipoint and mesh systems. It is designed for mobile environments with velocities up to 120 km/h. Aeronautical Mobile Airport Communication System (AeroMACS) is an internationally standardized adaption of the WiMAX standard, specifically for aeronautical applications. It has been suggested as a solution for congested very high frequency (VHF) bands at airports [10]. It operates in licensed aeronautical frequency bands. Like WiMAX, AeroMACS is designed to work in a cellular-type network with base stations. An exemplary UAS application, which requires communication capability between two types of drones (short and long range) and ground side rescue teams in alpine environment is proposed in [9]. For this, communication systems such as IEEE 802.11, ZigBee or XBee are disregarded due to insufficient range or data rate. Due to the need for licensed spectrum, 4G is also disregarded. Instead a WiMAX based solution is proposed.

LoRa: LoRa is a proprietary low-power communication system for IoT applications, developed by Semtech Corporation. It uses chirp spread spectrum (CSS) in the license free industiral, scientific and medical (ISM) band at 868 MHz (Europe) or 915 Mhz (USA) and can achieve a maximum data rate of 300 kbps (with 500 kHz-Channel) [11]. Godoy et al. present an use case using MAVLink protocol and LoRa for the communication link between drone and ground control station (GCS) [11]. They achieve communication with a 10 km range. "LoRaWAN defines a Media Access Control (MAC) protocol for low-powered devices that utilize LoRa modulation for wide area networks. LoRa Alliance issued the first LoRaWAN specification in January 2015" [12]. LoRaWAN is used as secondary telemetry communication system for drone delivery in [12]. The UAV is equipped with a LoRaWAN device and communicates with the gateway on the ground. Using the lowest chirp factor, transmissions with a range up to 14.6 km are possible. It is concluded that LoRaWAN is a feasible solution for transmission of UAV control data in a 2-3 second interval with tolerable packet loss.

RFD868 / RFD900 modem: These 'ultra long range radio modems' are developed by RFDesign [13] specifically for telemetry transmission in UAV applications. They provide an air data rate up to 500 kbit/s and up to 30 dBm transmit power. The line of sight range is advertised with up to 40 km. The modules utilize frequency hopping spread spectrum (FHSS) with frequency shift keying (FSK) modulated carriers in the 868 MHz (Europe) or the 915 Mhz (USA) ISM band. They provide two antenna connectors for spatial or polarization diversity and allow single-point, multipoint and mesh connections. The module weighs 14.5 g and draws ≈800 mA peak at max transmit power and ≈60 mA receive current. For data security, 128-bit Advanced Encryption Standard (AES) with an user settable key is used. Schellenberg et al. present a beyond visual line of sight (BVLoS) application using the RFD868+ module [14]. A fixed-wing UAV (Skywalker X8) is used to collect volcanic ash from plumes of a volcano in Guatemala. The flights are performed up to 4200 m above mean sea level with a distance between the GCS and the crater of approximately 8 km and an altitude difference of 2700 m.

Concepts using redundant or multi-link approaches in UAS applications are considered in various research projects. For the very low level airspace a solution with a triple redundant encrypted communication link using the mobile network, a 2.4 GHz and a 868 MHz connection is used in the City-ATM project [5]. In this concept all the data is sent through all three radio links in parallel. The first received data is then processed. Furthermore, an approach with meshed repeater nodes for long range applications is presented. But there seem to be technical problems with the 868 MHz link, which performed less satisfactory than expected. The authors of [7] focus on an automatic and intelligent switching algorithm for different UAS communication links (2G, 3G/4G, satellite link). They adapt and improve the Jacobsen algorithm which is known from the TCP protocol, in combination with a heartbeat to optimize the time-out level for their application. The concept is based on an always stable satellite link as backup link. A different approach, using multi-link aggregation for reliable UAV communication is proposed in [15]. The authors show a solution for maritime search and rescue missions with UAVs. Multiple links like LTE, Wi-Fi and LoRa are aggregated using Multipath TCP (MPTCP) to maximize the throughput or the robustness depending on the setting of the scheduler.

3 Used Unmanned Aerial System

In the project KIMoNo the UAV manufacturer Quantum-Systems GmbH is partner. Therefore, it is planned to use their VTOL system Trinity F90+ [16] with a maximum take-off weight of 5 kg, a wingspan of ≈ 2.4 m and a maximum flight time of 90+ min. The maximum payload of the system is 700 g. To carry the payload, different types of storage boxes (including a refrigerated version) for the medical goods are available. The optimal cruise speed of the VTOL is 17 m/s (≈ 61 km/h). The retail version of the system offers a command and control range up to 7.5 km. However, in the project KIMoNo Quantum-Systems will use a customized version with a much higher range which can cover the planned operation area of about 60 km.

4 Concept

An overview of the propose communication scheme is illustrated in Figure 1. If available, the field team communicates via a web-based information system which is connected by a 4G or 5G cellular network. To interact with the information system, the field team uses a tablet computer. However, in remote operation areas this link can not be assured. Then, the fallback link shall be used. The UAV activates this link once it's inside the theoretical range of the system.

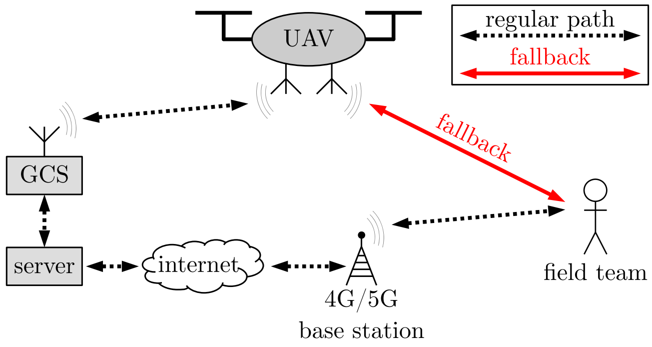

Figure 1. Overview of the communication paths between GCS, UAV and the field team.

For the fallback communication system, the following requirements are defined:

- Communication range shall be higher than 2 km (this equals ≈2 min flight time at cruising speed).
- Frequency band shall be license-free.
- The system shall not require any external communication infrastructure.
- Communication shall be encrypted and require authentication.
- The typical bandwidth requirement for telemetry data is in the range between 5-150 kbps [4]. The bandwidth requirement in the project is not fixed yet, but expected to be at the lower end of this range.
- A latency of up to 5 s is allowed, as the onboard controllers perform the flight-related decisions [17].
- It shall be possible to integrate the system in the existing VTOL. Payload size and weight, as well as, the range of the UAS shall not be constrained more than necessary. Thus, the system has to be light-weight, small-sized and energy-efficient.

In the related work several communication options and aspects are examined. Based on this and the requirements of the project, the best suited system is selected. Several aerial communication projects rely on cellular networks like 4G or 5G. However, the limiting factor for KIMoNo is the network coverage of the ground team. Especially in remote areas, the coverage is not given at every location. This means, the system must be independent of any 3rd party or public infrastructure. Therefore, approaches which depend on the cellular network are not feasible for the fallback communication in this project. This restriction also excludes approaches like NB-IoT, which is available in many areas, but especially not in remote ares as it also relies on a cellular network and therefore on a public infrastructure. Sigfox is a special form of cellular network for IoT devices, but also doesn't provide 100 % coverage [8]. Therefore, it is not usable in the scope of this project, due to the same reason as other solutions requiring public infrastructure. The IEEE standardized networks such as ZigBee and Wi-Fi don't satisfy the range requirements. Only IEEE 802.11ah standard could be a possible solution under ideal conditions with a relaxed range requirement. But it's certainly not the optimal solution. Similar to cellular networks, WiMAX requires an infrastructure, analog to cellular networks. Same is true for AeroMACS which is based on the WiMAX standard and in addition, uses licensed aviation frequencies. Thus, neither systems is suitable for the project.

Similar to cellular networks and WiMAX, LoRaWAN requires an infrastructure with gateways. However, the LoRa technology can also be used for point-to-point connections. Petajajarvi et al. examine the performance of a low-power wide-area network based on the LoRa technology. They consider among others, the influence of the Doppler effect on the LoRa technology. LoRa is based on CSS technology with adaptable spreading factors in between 7 and 12. Simplified, a low spreading factor enables a higher velocity than high spreading factors (e.g. SF 12: 38 km/h; SF 11: 76 km/h). However, lower spreading factors enables higher data transmission rates, with the drawback of requiring higher receiver sensitivity and therefore a smaller transmission range [18]. As the chosen VTOL has a cruise speed of about 61 km/h, a spreading factor of 11 or lower would be needed. LoRa and LoRaWAN are designed for the low power and bandwidth transmission of small data packages (like sensor data) at relatively long intervals which should be in the range of several minutes. Therefore, LoRa is not recommended for the transmission of data in short intervals or even for realtime data [19].

The RFD868 module is specifically designed for drone applications and can fulfill the defined requirements. Based on the research of different communication schemes, LoRa and the RFD868 modem are selected as feasible candidates for KIMoNo. Between these two systems, it's a trade-off between the RFD868's higher range and the lower energy consumption of LoRa. The RFD868 modem is specifically designed for UAV applications, which is deemed the decisive factor to chose it over LoRa. To avoid unauthorized access, the fallback data stream is secured by a pre-shared key concept and the onboard AES of the RFD868 modem.

To manage the communication paths shown in Figure 1, some considerations regarding the traffic management are necessary. As long as the UAV is outside the communication range to the field team, the fallback link is switched off, to preserve energy of the flight system. In this case, all traffic is sent to the GCS. As soon as the UAV comes into the theoretical fallback communication range to the field team, the communication module in the UAV is activated. As the fallback link is optimized to low power and long distance transmission, the possible data rate is limited. Thus, it may not be possible to transmit the information over the fallback link in full detail. For the 4G/5G link in normal operation this is not an issue. This means, the data set must be split in a reduced essential data set with the most important information which can be sent on both links and an extended data set which can be only transmitted in the cellular network (compare Figure 2). In many cases the field team will be able to establish the fallback link, as well as, the 4G/5G regular link. To merge both data streams an approach using Multipath TCP with scheduling on improved robustness is included in the concept.

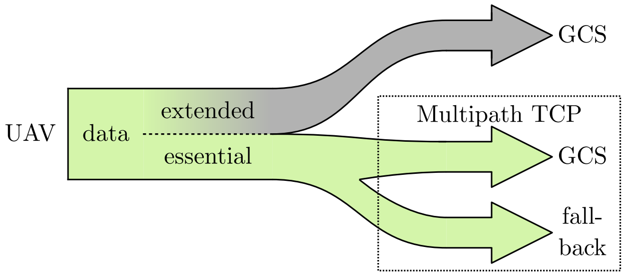

Figure 2. Proposed traffic management

5 Future Work

Based on the proposed concept a prototypical implementation of the fallback communication system will be integrated in the Trinity F90+ drone. Additionally, a counterpart will be integrated into a handheld device for the ground team. This prototype will be evaluated during test flights under realistic conditions in various remote areas, such as the Bavarian Forest in south-east Germany.

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