GROUND SEGMENT DESIGN FOR COMMAND & CONTROL AND PAYLOAD DATA OF HIGH ALTITUDE PLATFORMS

D. Sander*, S. Bening‡, M. Wedel*, D. M. Mielke†, M. Simon†
* German Aerospace Center DLR, German Remote Sensing Data Center, Wessling, Germany
‡ German Aerospace Center DLR, Institute of Flight Guidance, Braunschweig, Germany
† German Aerospace Center DLR, Institute of Communications and Navigation, Wessling, Germany

Abstract

High Altitude Platforms (HAPs) are often discussed as a replacement or add-on technology to Earth Observation (EO) satellite networks. In order to reduce the mission costs, HAP systems could build on available satellite downlink technology and share the ground infrastructure. This would require similar downlink protocols, communication frequency ranges, data backhauling, archiving and dissemination schemes. Furthermore, a HAP needs to be monitored and controlled with a high level of safety and security. Therefore, the application of proven and existing Unmanned Aerial Vehicle (UAV) technology is useful. This work investigates how existing satellite and UAV technology and infrastructure can be applied to efficiently operate a HAP system from ground. In an initial phase, it is expected that the HAP will be operated from a ground station close to the launch site. In a later stage it is planned that only the communication technology must be located in the operating area, but the monitoring and controlling can be located in a centralized ground station complex. Therefore, this design is divided into a communication and an operation ground station. One possible design for a payload and communication and control ground segment with the focus on the specific requirements of a HAP system is discussed. A focus is set on making use of available SmallSat and UAV communication technology. Additionally, an insight into the interaction with the on-board systems as well as the operation ground station is presented. The summary of this work provides an exemplary ground segment design for an EO HAP mission.

Keywords

high altitude platform; unmanned aviation; earth observation; aeronautical communications

1. INTRODUCTION

High Altitude Platforms (HAPs) are a promising addition to traditional Earth Observation (EO) platforms like aircraft or satellites. For example, they can be used for radar-based or optical earth imaging as well as a platform for telecommunications. In the past, projects like Facebook's *Aquila* and Airbus' *Zephyr* have shown that the approach of heavier-than-air HAPs is principally feasible.

The DLR is in the process of designing and developing a complete HAP system. This system consists of the HAP platform itself and the ground infrastructure, that we will refer to as the Ground Segment (GS) in the following. Multiple DLR institutes contribute knowledge from their area of expertise to design and optimize the system [1]. In the context of this project the concept for the data link and the GS are being designed which are outlined in the present paper.

The main tasks of a GS for a HAP are monitoring and controlling the aircraft and its subsystems as well as receiving scientific data of the on-board payload instruments on the ground. The on-board systems of a HAP have to meet certain technical restrictions. This also affects the design of the on-board communication technology. The on-board hardware needs to have a low power consumption, no moving parts to decrease the complexity and mitigate risk of failure, and small, lightweight and aerodynamic parts on the outside of the aircraft. Finally, the entire system needs to be compliant with national and international radio frequency governance like the International Telecommunication Union (ITU). On the other hand, the communication design should make it possible to achieve several weeks of continuous operations, high reliability of the command and control data as well as real-time and high throughput Downlink (DL) capability of the payload data. Finally, the entire system needs to be compliant with all public airspace requirements [2]. Based on these restrictions for the on-board technology, this paper describes the design of a GS for this technology.

This paper is structured as follows: We define the requirements for a HAP GS in Section 2. The communication links between the GS and the HAP are explained in Section 3. In Section 4, the communications area of the GS is described, Section 5 describes the operations area. Finally, in Section 6 the results of the GS design are concluded.

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2. GROUND SEGMENT DESIGN

As described in Section 1, the design of the GS needs to fulfill the requirements of the communication technology that is used on the aircraft. In case of the DLR HAP project, similarities between requirements for HAP, Small-Satellite, and Unmanned Aerial Vehicle (UAV) technologies have been identified and exploited.

2.1. Application of Established Technology

The restrictions and requirements for the hardware on-board the HAP are substantial. Concurrently, there are similar requirements for Small-Satellite and UAV communication technology. For the sake of risk reduction, it was therefore decided to make use of validated operation concepts and Commercial off-the-shelf (COTS) Small-Satellite and UAV communication technology where possible.

The HAP communication technology consists of two simultaneous data links which are described in Section 3. These data links are supported by direct Line of Sight (LoS) communication with a tracking antenna customised for the respective frequencies and transmitter power.

2.2. Ground Segment Overview

Fig. 1 gives an overview of the subsystems of the GS. The GS is mainly split into two subsystems: the Ground Segment Communications (GS-Com) and the Ground Segment Operations (GS-Ops).

The GS-Com consists of a tracking antenna on top of a transportable communications container. The subsystem is described more detailed in Section 4.

The GS-Ops, which is connected to the GS-Com, consists of a facility to monitor and control the HAP and is described more detailed in Section 5.

3. DATA LINKS

The communication between the HAP and the GS involves multiple data links whose purposes and implementations are explained in the following.

3.1. Command and Control

The term Command and Control (C2) describes all data that is immediately required for operating an air vehicle. This includes the transmission of command data like operation plans in the Uplink (UL) and the transmission of status, positioning, and telemetry information in the DL. The focus of the C2 data link is on reliability and not on high throughput.

In our system, this data link is realised by a COTS data link operated in S-band. To reduce latency, we decided to use a Frequency Division Duplex (FDD) setup instead of a Time Division Duplex (TDD) setup. FDD allows us to operate UL and DL in parallel using different carrier frequencies.

The C2 data link's signal bandwidth is approximately $2\,\mathrm{MHz}$ and we run it with a data rate of $1.4\,\mathrm{Mbit/s}$. The data link provides both a transparent serial interface and a transparent ethernet interface, while the serial data are always higher prioritised during transmission. We use the serial interface of the S-band link for the exchange of all C2 data.

Both the C2 modem on the HAP and the C2 modem in the GS periodically transmit their current status to the GS network. These status messages include information on the estimated signal-to-noise-ratio of the received signal, on the achieved Bit Error Rate (BER), and on the internal system health state of both modems. All this information is aggregated on the so called Communications Control Computer (CCC) located in the GS and periodically distributed to all relevant entities – see Section 4.2 for more details.

The traffic transmitted over the S-band data link is transparently encrypted using AES-256.

3.2. Payload

Since the throughput provided by the C2 data link is not sufficient for the payload data stream, another data link is installed for this purpose: It operates in X-band, provides a data rate of up to $95\,\mathrm{Mbit/s}$, and is implemented as DL-only. Nevertheless, the operation of the payload requires some UL functionality for two reasons: First, the payload operator needs to send commands to the payload device on-board the HAP to control it. Second, the payload control computer on-board the HAP needs to be informed about a successful reception of a payload data package in the GS by an Acknowledgment Message (ACK).

We use the ethernet interface of the S-band data link (Section 3.1) for these purposes; thus, we do not have to provide another physical UL to the HAP. The internal prioritisation capability of the S-band data link ensures that payload data never blocks the more relevant C2 data. The logical data routing of C2 and payload data between the HAP and the GS is shown in Fig. 3.

3.3. Other Systems

Besides the S-band and the X-band data links, the HAP carries a transponder that broadcasts beacons on a regular base. These beacons contain Automatic Dependent Surveillance – Broadcast (ADS-B) messages, such that the HAP can be detected by other participants in the airspace and Air Traffic Control (ATC). As the ADS-B messages contain both a unique identifier of the sending entity and also the sending entity's current location, they are also of interest for the GS. The GS therefore possesses an ADS-B receiver, not only to get an overview over flight movements in the skies, but also as a backup in case the tracking antenna of the GS looses track of the HAP.

The HAP also carries a First Person View (FPV) camera which provides a dedicated data link (DL-only) to the GS. Since FPV is only required for critical flight scenarios like takeoff and landing, the data link is only available for short ($<10\,\mathrm{km}$) LoS distances.

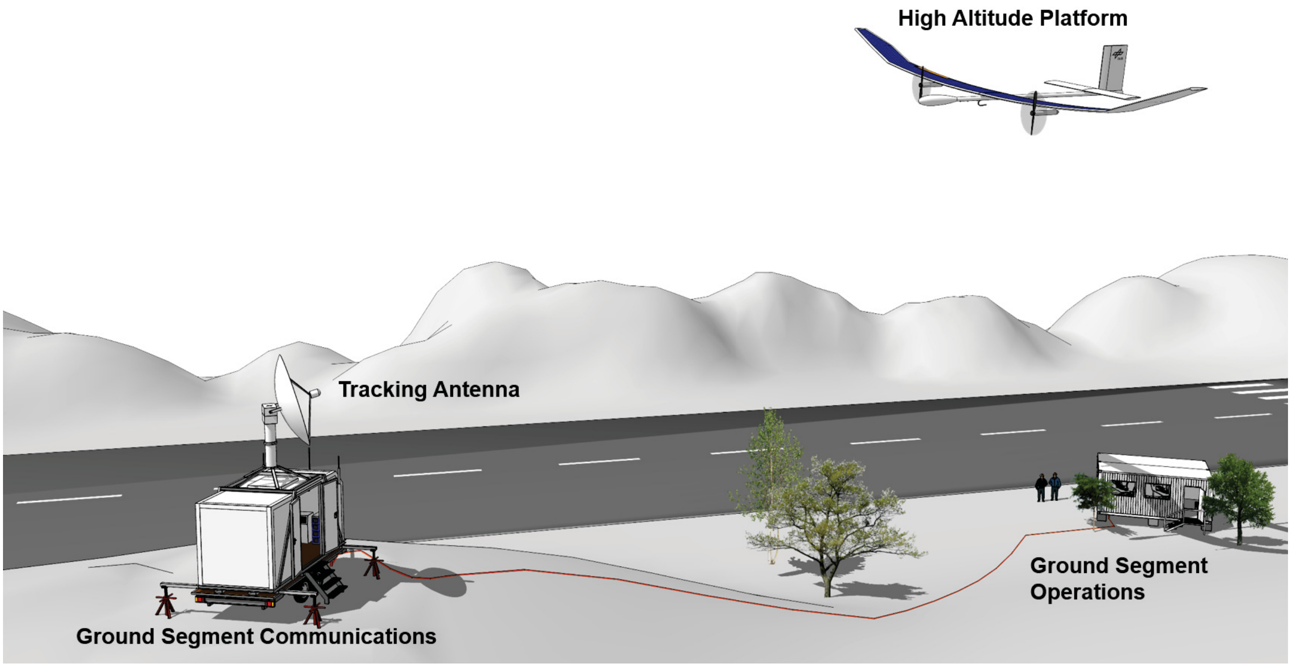

FIG 1. **Ground Segment Design Overview: The High Altitude Platform (HAP) is tracked by a tracking antenna to establish the data links. The antenna is mounted on the top of the Ground Segment Communications (GS-Com). The GS-Com is connected to the Ground Segment Operations (GS-Ops) which monitors and controls the HAP.**

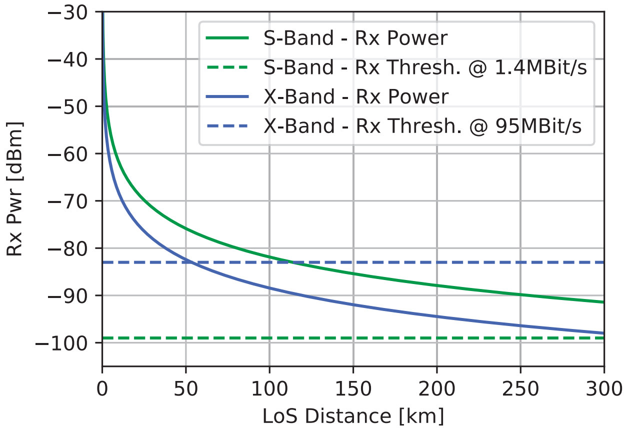

FIG 2. **Estimate of the reception power for the S-band (red) and X-band (blue) data link vs. the Line of Sight (LoS) distance. Dashed lines represent the sensitivity threshold to achieve an average Bit Error Rate of 1e-5. Calculations are based on the assumption of a** 2.4 m **parabolic antenna in the GS.**

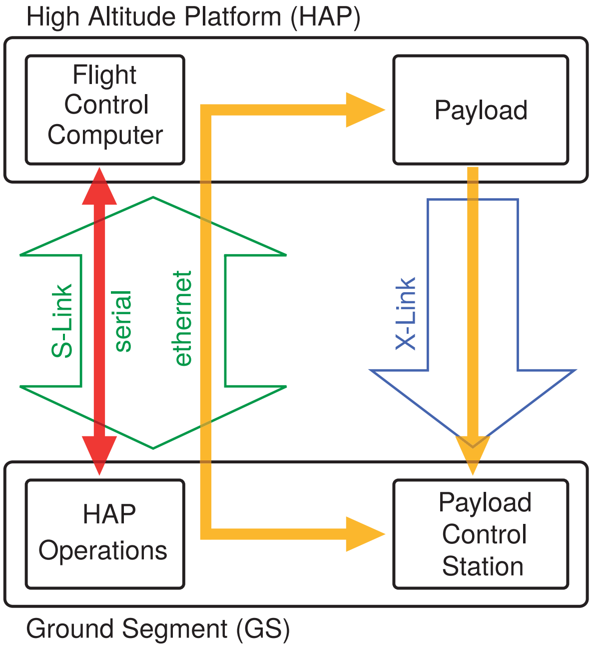

FIG 3. **Traffic routing between HAP and GS: C2 data (red arrow) are routed through the serial interface of the S-band link ("S-Link", UL and DL), payload-related data (orange arrow) use the ethernet interface of the S-band link for UL and mainly use the X-band link ("X-Link") for DL.**

For the case of a complete loss of communications between the HAP and the GS, a UL-only termination link is installed. Its only purpose is to trigger the controlled self-destruction of the HAP – independently of the availability of the other data links and the operating state of the Flight Control Computer (FCC) on-board the HAP.

4. GROUND SEGMENT – COMMUNICATIONS

The subsystem GS-Com is mainly responsible to operate and maintain the data links between the HAP and the GS. It consists of a tracking antenna and a communications container which are described in the following sections.

4.1. Antenna

The HAP shall be operable anywhere in the world. Existing stationary ground systems could be used but this scenario would not cover many region of interest in the world. Further, different stationary ground systems typically mean differing vendors which cannot realistically be served. Therefore, it was decided to make use of a transportable ground system that can be brought where it is needed.

For a reliable and efficient communication with the HAP data links, a tracking antenna on ground is necessary. This tracking antenna must provide sufficient gain and minimal noise at the same time to allow reliable LoS communication with both the S-band and the X-band link. The antenna was designed to achieve link distances of up to 250 km for the C2 link and up to 50 km for the high datarate payload link (see Fig. 2). In our case we plan to use a parabolic antenna with a dish-size of 2.4 m in diameter and a system noise performance (represented by the gain-to-noise-temperature G/T) of at least 15 dB/K. The link distance of the payload link can be extended by using a larger dish. In our case the chosen dish size is simply a trade-off between costs and performance. Fig. 4 shows an exemplary picture of a DLR owned S/X-band tracking antenna with a dish-size of 1,5m diameter. This specific antenna was used for demonstration purposes of the data links on ground.

For the near ground communication in S-band it was decided to have an additional omnidirectional antenna on the ground. This is a non-tracking antenna to overcome tracking issues during starting and landing of the HAP as during these phases, the angular speed of a tracking antenna could become critical. With this additional antenna it is possible to operate the HAP up to three kilometres of LoS distance. Within this range and when the HAP is in stable operations, the S-band link can be switched via a HF-switch from omnidirectional antenna to tracking antenna and vice versa for landing.

The antenna tracks the HAP based on Global Navigation Satellite System (GNSS) data retrieved by the C2 link. As a backup, the antenna can also track the HAP based on ADS-B data that is distributed within the ground segment.

FIG 4. Exemplary combined X- and S-band parabolic antenna with a dish-size of 1.5 m diameter. This antenna is owned by DLR and was used for first communication tests on ground.

The antenna has a combined S- and X-band feed. This feed is capable of simultaneously transmitting and receiving in S-band as well as receiving in X-band.

The S-band signals are forwarded directly to and from the C2 modem inside the communications container. The received X-band signals are down-converted to 720 MHz and forwarded to a High Data Receiver.

The antenna is monitored and controlled with the help of an Antenna Control Unit. This unit is split up into an outside part at the antenna and an inside part located in the communications container.

4.2. Communications Container

The communications container is transportable and is also capable of transporting the antenna inside the container. At the location of operations, the antenna can be mounted on top of the container to overcome obstacles around the ground system and enhance the horizon mask. For this mounting capability, the container is strengthened with an outside steel structure. Inside the communications container, there is space for two operator stations as indicated in Fig. 5. The operators can monitor and control all the equipment within the GS-Com with the help of a CCC. The CCC has an automated monitoring and control system which is mainly capable of:

- Setup and control of the antenna system and baseband equipment
- Auxiliary data management (e.g. S-band telemetry, X-band telemetry, tracking angle, etc.)
- Logging, reporting and graphical analysis of station parameter
- Remote operation and control capability through web-based interface and/or command line
- Distribution of status and telemetry information in the ground network

FIG 5. Concept of the Ground Segment Communications (GS-Com). The container is capable to hold the tracking antenna on top. Inside the container there is space for two operator stations to monitor and control the communication status.

Parts of the CCC are based on the automated Station Monitoring and Control System (SMCS) which was developed by DLR's German Remote Sensing Data Center. The SMCS has proven its reliability in several projects, e. g. during the last decade of ground station operations of the TanDEM-X satellite mission [3].

Besides the baseband equipment and indoor Antenna Control Unit, the communications container holds rack-space for further equipment. All devices that produce monitoring information, are connected via a network switch within this rack. A transponder receiver, connected to a rod antenna at the outside of the container, provides ADS-B data within the ground segment. Furthermore, the communications container is equipped with an uninterruptible power supply as well as a power generator for the case of grid power loss. It is also equipped with air condition for a comfortable workplace for operators and the equipment. Windows on the side of the container make it possible for the operators to visually check the antenna movement without the necessity to exit the container.

The container is a highly transportable system. In combination with a custom-made trailer with a gross vehicle weight of 2400 kg, the GS-Com system is highly flexible and transportable within Europe. Levelling legs allow for adjusting the container into a level position and additionally provide stability, preventing the container from shaking due to wind or a person leaving or entering. The trailer can be pulled by commonly available rental cars that feature a trailer hitch (medium to large sized SUVs or vans). The container dimensions allow for loading it into a 20ft standard sea container for international shipping. The angled forward roof of the container minimizes risk of damage while it is navigated into the container. Its dimensions also allow the container to be loaded and secured on a flat-bed transporter.

5. GROUND SEGMENT – OPERATIONS

The overall mission and the HAP are monitored and controlled in the Ground Segment Operations (GS-Ops) (Fig. 6). The concept is elucidated in the following.

FIG 6. Concept of the Ground Segment Operations (GS-Ops). The remote pilot and support station are located on the front right hand side of the operations center. The flight director and flight test engineer are placed behind. On the left hand side the payload operator station is positioned.

The GS-Ops receives the data, required to monitor the HAP, by an ethernet connection to the GS-Com. In the reverse direction, the commands to control the HAP are sent to the GS-Com via ethernet connection and forwarded to the HAP. The GS-Ops is designed in a way that it can be located in an arbitrary office with sufficient space for five operators. For the first flight test, the office space should be located close to the launch area, e.g. in office containers. In the long term, the GS-Ops can be placed anywhere in the world and connected to the GS-Com by an internet connection. This concept enables the central monitoring and control of multiple platforms during prospective continuous operations.

5.1. Operator Roles and Tasks

The concept foresees several operators for controlling the HAP from the GS-Ops for the initial trials and operations. In a later stage and with more experience in HAP operations, multiple roles may be performed by a single operator. Additionally, a safety pilot station is included for risk minimisation during the first flight experiments. It might be lapsed after gaining sufficient information about the control of a HAP. The operators responsible for the flight critical systems, are working in pairs to support each other and to achieve the four-eye principle. The roles and their tasks are described in the following sections.

5.1.1. Flight Director & Flight Test Engineer

The flight director is the highest-ranking operator, coordinating the crew members, monitoring the mission progress and the relevant systems with supplementary information. The flight test engineer is responsible for the system's health. The operator's main task is to observe the information, provided by the subsystems of the HAP, to determine the system status and to detect anomalies. During the monitoring of the system, a persistent exchange between the flight director and the flight test engineer is expected.

5.1.2. Remote Pilot & Remote Pilot Support

The remote pilot is controlling the flight path and flight relevant systems of the HAP. During high-altitude flights, the remote pilot is the only operator authorised to be pilot-in-control whereas the safety pilot or the remote pilot can be pilot-in-control during near-ground operations. The HAP can be controlled by the remote pilot manually, with autopilot commands, as well as provided with a waypoint list to be executed by the flight management system. The remote pilot support monitors the surrounding weather and plans the flight path which is verified by the remote pilot, sent to the HAP and executed by the flight management system of the HAP. Furthermore, the operator's task is monitoring the flight systems and identifying critical changes.

5.1.3. Payload Operator

The payload operator is responsible for planning and executing acquisitions with the payload. However, the use of the payload has to be permitted by the flight director. Further, the deactivation of the payload may be demanded in case of an emergency.

5.1.4. Safety Pilot & Safety Pilot Support

The safety pilot is required for increased safety during near-ground operations. The operator is able to control the HAP in the direct line of sight. This results in an increased awareness of the surroundings and potential hazards. This is especially important during takeoff and landing. The safety pilot support provides the safety pilot verbally with auxiliary information about the HAP system status. Thereby, the safety pilot can stay focused on the HAP at all times. These two roles may become obsolete once enough experience in controlling the HAP has been collected during flight trials.

5.2. Structure

The GS-Ops comprises five operator stations, additional devices for information reception and forwarding, and an external safety pilot station. The devices are interconnected in a local network. The structure is shown in Fig. 7.

5.2.1. Operator Stations for Flight Guidance

The operator stations are the work area for the operators. Each station is equipped with a computer and at least two screens. On the computers, the control software is running to visualise the system information of the HAP. The stations for the control of the HAP all use the same version of the software U-Fly, developed inhouse at the DLR Institute of Flight guidance [4], customised for managing HAPs. Though, it provides different interfaces for the operator roles. Additionally, it enables the remote pilot to command the aircraft. Therefore, a joystick and pedals can be used for direct control, or the HAP can be controlled by multiple autopilot modes including waypoint flights with the flight management system. The software supports the operators with tools and auxiliary information for flight path planing [5]. For increased situational awareness in low flight altitudes, the remote pilot receives a video feed. This enables more accurate maneuvering during manual flight.

For increased safety during the operations, the operator stations and the critical network devices are connected to an uninterruptable power supply to ensure the control of the HAP during power failures. In case the GS-Ops does not receive position updates of the HAP over the C2 data link, the position can be tracked using the equipped ADS-B receiver.

5.2.2. Interfaces

The GS-Ops is equipped with multiple interfaces for receiving and sending commands and status information of the HAP. A short overview of these communication interfaces is summarised hereinafter.

The aircraft control server in the GS-Com publishes the data coming from the HAP. The devices of the GS-Ops are subscribed to this stream and they receive associated messages via the ethernet connection. Furthermore, the GS-Ops is able to forward this data stream via a wide area network connection to other surveillance stations.

In addition, the GS-Ops is used as a relay station for the safety pilot station. Therefore, a Wireless Local Area Network (WLAN) is used to transmit information to the safety pilot tablet. The commands, sent by the remote control of the safety pilot, are received by an Radio Control (RC) receiver, translated into the data link format, and forwarded.

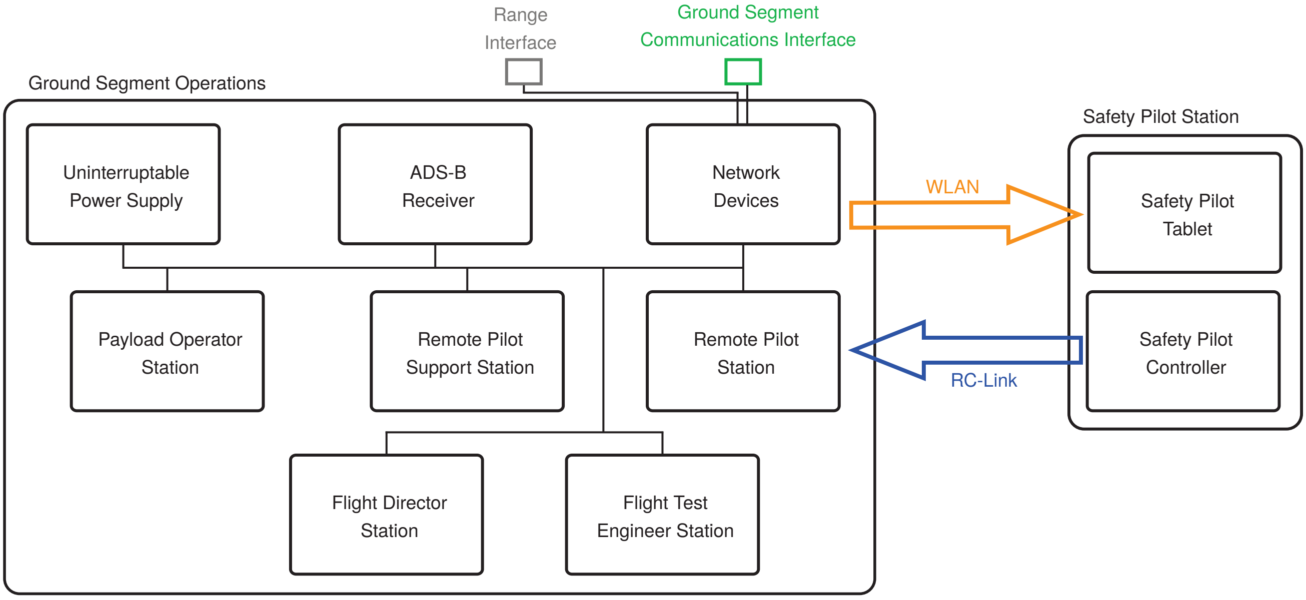

FIG 7. Ground Segment Operations (GS-Ops) components and data interfaces. System data is received by the GS-Com interface (green input) and distributed by the network devices to the operator stations. Furthermore ADS-B data is distributed in the network. Additionally, forwarding to the safety pilot station occurs via WLAN (orange arrow). Control-commands of the safety pilot station are received via an RC-link (blue arrow) and forwarded to the communications interface.

The first flight of the HAP will be performed on dedicated test ranges to increase safety. Such ranges often possess tracking equipment which functions as additional information sources. Additionally, test ranges often demand status information of vehicles operating in their area. To process the data communication with a test range, a dedicated server for the transformation of out- and in-going data is included.

5.2.3. Safety Pilot Station

The safety pilot utilises a common remote control used for small UAV to control the HAP. The radio signals are received in the GS-Ops and forwarded to the HAP by the command channel. The safety pilot support is equipped with a tablet computer. On this, a simplified version of the user interface used in the GS-Ops visualises the system status of the HAP and marks critical values and limits.

6. CONCLUSION

In this paper, the concept of a GS for an EO HAP was presented. As described in Section 1, the restrictions and requirements on communication hardware show many similarities comparing HAP operations to Small-Satellites and UAVs operations. Therefore, it was decided to make use of COTS hardware and proven operation concepts in the HAP GS.
The GS is split into two main areas, the communications (GS-Com) and the operations (GS-Ops) area. The communications area, described in Section 4, is responsible for maintaining the data links and the necessary communication equipment on ground. Consequently, the operations area, described in Section 5, is responsible for monitoring and controlling the overall mission and mainly to operate the aircraft. This GS design is capable of high reliable command and control of the aircraft as well as the reception of high throughput payload data on the ground.
In the next phase of the project, it is planned to procure and assemble all the identified necessary hardware and software. First ground tests and later flight tests with the on-board communication hardware are planned. After these successful tests, the GS will be used for the first real test flight with the DLR HAP.

Contact address:

daniel.sander@dlr.de

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