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Implementation of an Additional Command System, Pathing the Way for New Tasks at Col-CC

A. Schlerf*, D. Sabath*, G. Söllner*, I. Verzola+
* DLR, Oberpfaffenhofen, Germany
\+ LSE Space GmbH, 82234 Wessling, Germany

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Author

A. Schlerf, DLR, Oberpfaffenhofen, Germany, angela.schlerf@dlr.de

Co-Authors

D. Sabath, DLR, Oberpfaffenhofen, Germany, Dieter.Sabath@dlr.de

G. Söllner, DLR, Oberpfaffenhofen, Germany, Gerd.Soellner@dlr.de

I. Verzola, LSE Space GmbH, 82234 Wessling, Germany, ivano.verzola@lsespace.com

ABSTRACT

Thomas Pesquet's “Proxima” mission signifies another high activity period at the Columbus Control Center (Col-CC), which continues with Paolo Nespoli's launch to the ISS in mid-2017. Besides numerous experiments, such as Sarcolab, Airway Monitoring and Everywear, Thomas also performs important maintenance activities, including a CWSA exchange in the Thermal Control System and the Cycle 14.1 software upgrade for the Data Management System. At Col-CC, the preparation for these and other activities has been started a long time before. Our first step was to prepare for the on-board Cycle14.1 software upgrade. In parallel, it was necessary to upgrade our monitoring and command infrastructure due to the planned integration of new racks inside and outside of the Columbus module, as well as a new external payload. Some of these new subsystems and payloads require a completely new command interface, called MPCC.

MPCC stands for Multi-Purpose Computer and Communication, and introduces secure end-to-end communications to Columbus, permitting scientists to directly access payloads from their home base via the Internet. Phase 1.1 of this project began in 2015 and included several demonstrative tests performed by ESA astronaut Andreas Mogensen. Phase 1.2 is currently running and allows several payload users to access and control their experiments via a Ku-band link and the station-wide LAN. Whereas Phase 1 mostly uses existing on-board equipment, Phase 2 - starting in 2018 - will introduce new hardware to the ISS. This will include a new-generation laptop and a new, commercial off-the-shelf LAN switching box deployed in Columbus. In addition, a Ka-band antenna will be attached to the outside of the Columbus module during an Extra-Vehicular Activity in 2019. This will allow data transmission via the new generation of European data relay satellites using the Ka-band frequency. The paper describes our preparation work as well as Col-CC responsibilities during nominal operations, in particular the coordination and control of nominal IP traffic over the Columbus LAN, and monitoring intra- and extravehicular equipment.

Introduction

During the more than nine years of operations of the Columbus module at the ISS, Col-CC has supported 8 long-duration and one short-duration mission with 9 different ESA astronauts. With the Proxima mission of Thomas Pesquet all ESA astronauts of the 2009 class have performed a space mission and provided high valuable results during their stay on the ISS. Based on the long experience of DLR’s German Space Operations Center (GSOC) in manned space operations and the missions to ISS described below, Col-CC is ready to support also the upcoming and future missions like “Vita” with Paolo Nespoli in 2017 and “Horizons” with Alexander Gerst in 2018 with full flexibility and new ideas.

In the Interim Utilization Phase, which was done in parallel to setting up Col-CC ([3] to [5]) for the later Columbus operations, the Eneide Mission in 2005 and the Astrolab mission with Thomas Reiter in 2006 (see [1] and [2]) were successfully supported. Since February 2008, when Col-CC started its Columbus operations (see [6] to [11] and [13] to [15]), all further missions and increments have been prepared and supported successfully. With this experience Col-CC will be able to operate Columbus until at least 2024, assuming that the basic setup will not change (see [12]).

In parallel to the standard operations tasks, the Col-CC Flight Control Team (FCT) is also taking care of expanding the capabilities of Columbus and integrating new hardware and new means for operating payloads and subsystems. The major improvement for the next years is the implementation of the new MPCC hard- and software which will allow to command and monitor new hardware more easily (see below).

European Astronauts on ISS

On 17 November 2016 Thomas Pesquet together with his crewmates Peggy Whitson and Oleg Novitsky was launched to ISS with Soyuz MS-03 (49S). After a long approach of 34 orbits the spacecraft reached ISS on 19 November 2016 and docked successfully. One of the early experiments for each ESA crew member is the MARES Sarcolab experiment for investigations into the effects of microgravity on the human muscular system (see Fig. 1).

Fig. 1: Thomas Pesquet and Sergey Ryzhikov are working with MARES hardware (Photo: NASA)

In December 2016 Thomas Pesquet and Shane Kimborough berthed the HTV-6 vehicle to the International Space Station and in February 2017 a Dragon capsule. The most exiting task on-board ISS were the two EVAs of Thomas Pesquet on 13 January and on 24 March 2017: together with Shane Kimborough he completed an ISS battery replacement and prepared the Pressurized Mating Adapter 3 (PMA-3) for robotic move, respectively (see Fig. 2).

Fig. 2: Thomas Pesquet during his EVA on 13 January 2017 (Photo: NASA)

In January 2017 Thomas exchanged a subsystem in the Columbus thermal control system which removes humidity from the air. The subsystem called CWSA had failed some weeks ago and the redundant subsystem had to be used. To establish again the full redundancy in Columbus, Thomas Pesquet exchanged the hardware by a spare part delivered from ground. After intensive work by the astronaut, supported by the flight control team and experts on ground, the new hardware was tested and provided good results.

Fig. 3: Thomas Pesquet performing Biolab maintenance in Columbus (Photo: NASA)

After more than 9 years in orbit also some payload racks need maintenance to ensure their availability for the next years. One example is the Biolab maintenance Thomas Pesquet performed in May 2017 (see Fig. 3). As for the subsystem maintenance the ESA astronaut is supported by the ground team during the whole activity.

Thomas Pesquet returned to Earth with Soyuz 49 on 02 June 2017 with cosmonaut Oleg Novitsky after working on-board the ISS during Increments 50 and 51. Peggy Whitson stays on-board ISS for another three months returning back with Soyuz 50 beginning of September 2017. The next ESA astronaut Paolo Nespoli was launched in orbit in Soyuz 51 on 28 July together with his crew mates Sergey Ryazanskiy and Randy Bresnik. They docked to ISS on 28 July after 4 orbits.

Columbus Software Upgrade

In the upcoming months and years Columbus will receive several new subsystems like

- Multi-Purpose Computer and Communication (MPCC) Phase 2

external payloads like

- Atmosphere-Space Interaction Monitor (ASIM),
- Atomic Clock Ensemble in Space (ACES)

and new payload racks like

- European Drawer Rack 2 (EDR-2),
- Express Rack 9b (ER 9b).

To prepare the on-board system for the arrival of the new hardware a software upgrade is necessary to allow the on-board system to work correctly with the new subsystems or payloads. Despite the name Cycle 14.1, the amount of the changes on-board Columbus was comparable to the software upgrades done before, i.e. Cycle 11, Cycle 12, Cycle 13 and Cycle 14 (see [6], [7], [10] and [13], respectively). Hence, the preparation of the on-board software upgrade started about a year prior to execution to ensure that all on-board and ground systems are ready and the teams are trained for this demanding task.

On 11 April 2017 the on-board software upgrade took place without problems including the changing of control rooms as done during the transitions before. Due to the virtualization of the servers at Col-CC a login to another server with the new suitable ground software would have been sufficient and the team could have stayed in the main control room K4 even after the on-board software transition. Nevertheless the event was used to move the Col-FCT to the second control room K3 and to perform some maintenance work in K4 until the team changed back to K4 in August 2017.

In parallel to this major upgrade the Col-FCT worked on many other topics like preparation for SOLAR retirement, preparation for the Space Debris Sensor (SDS) as well as on the preparation for MPCC Phase 2 introducing a new secure end-to-end communication system with Columbus.

MPCC

The MPCC (Multi-Purpose Computer and Communication) system provides a new possibility of end-to-end connection via IP. The experimenter and scientists can take advantage of easier access to their payload via standard Internet Protocols and therefore perform science at lower cost and shorter preparation time as it is the case for standard payload operations. With MPCC up to 10 payloads can be operated at the same time from 10 different Principle Investigators (PI) with a maximum combined bandwidth of 50 Mbits per second for downlink and 2 Mbits per second for uplink. Crew interference only is required for the initial installation and setup. During nominal operations MPCC will run autonomously on-board.

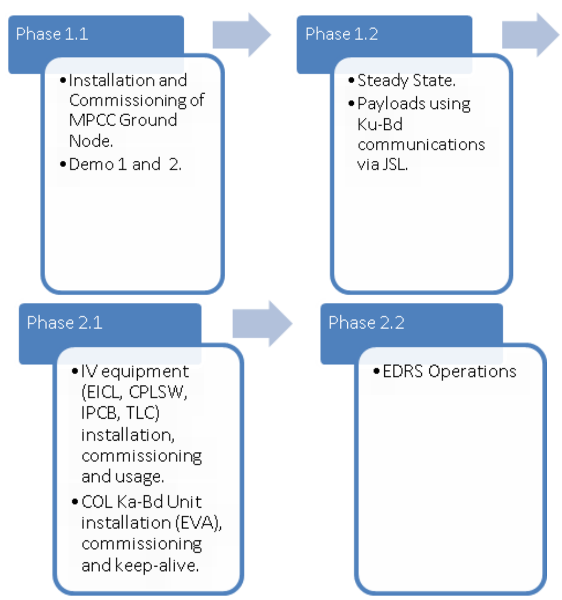

Fig. 4: MPCC Project Phases (Diagram: DLR) (IV: intravehicular; EV: extravehicular)

The MPCC project has been split into two phases and four sub-phases as shown in Fig. 4.

Phase 1 has been started in 2015 and was involving mostly existing hardware on-board and focused on establishing the system, performing several demonstrative activities and introducing the capability of the end-to-end communication for IP-based payloads. Additionally an MPCC Ground Node (MPCC GN) was developed which paved the way for the connection between the user and their payload on board. The MPCC GN is part of the PDC, the Payload Data Center, located at Col-CC.

Fig. 5: Thomas Pesquet with both Astro Pis on board Columbus (Photo: ESA)

Phase 1 is composed of two sub-phases. Phase 1.1 served as a demonstration phase and allowed the preparation and establishment of the ground to on-board connection. During this phase two laptops on board were used to simulate payloads. With this configuration the commissioning could be performed and the system was tested by all means necessary to allow science to be performed. Phase 1.1 was followed by phase 1.2, the so called Steady State phase. In this stage scientists from all over Europe started to exploit this easy connection method to command and control their payload on-board. An example therefor would be the Astro Pi experiment, which has been installed onboard during Tim Peake's Principia mission and also has been run by Thomas during his Proxima mission (Fig. 5). This experiment included two small Raspberry Pi computers (single board computers) that ran science protocols which have been developed by school classes on a competing basis. The entire data exchange with ground has been performed via the MPCC link over the NASA Joint Station LAN (JSL) assets and the Ku-Band connection directly to the user center (see [16]).

Phase 2 will start in 2018 and will also consist of two sub-phases. Here however the splitting has not been performed based on demonstration and steady state concept, but at the start of the operational usage of the new Ka-Band antenna.

Once installed and commissioned on board, MPCC Phase 2 is planned to use two communication paths instead of only one path as during phase 1. On one hand again the well-established NASA Ku-Band IP Service (Ku-IPS) will be used and on the other hand the Columbus Ka-Band inter-satellite link terminal that will be installed on Columbus during phase 2.

Phase 2.1 will be started with the introduction of new equipment inside Columbus, such as a new central laptop that will serve as the heart of the MPCC system on-board as well as a new LAN switch. At later stage additional hardware will be installed in preparation for the next phase. Right at the end of Phase 2.1 and heralding the transition to Phase 2.2, the Columbus Ka-Band antenna will be installed and commissioned. Phase 2.2 will then consist of the nominal operation of the Columbus Ka-Band antenna to allow in addition to the Ku-IPS with NASA assets also an independent communication on Ka-Band via the European Data Relay Satellites (EDRS).

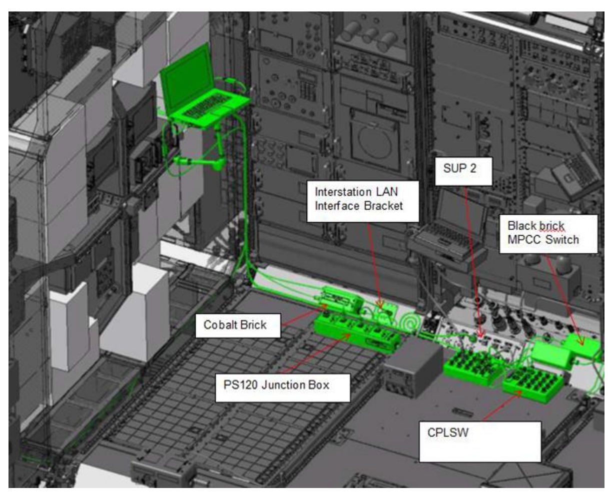

Fig. 6: Columbus View of MPCC equipment (Photo: ESA)

The transition from phase 1.2 to phase 2.1 is currently planned for the first quarter of 2018. The transition itself is foreseen to take no longer than one week, thus the impact to payloads currently running on phase 1 is limited and it can be resumed also on phase 2 as so called ‘legacy payload’.

Fig. 7: The CPLSW based on a 16M Octopus Hirschmann Switch (Photo: ESA/NASA)

In preparation of phase 2 the Col-FCT has to familiarize with several new topics. First of all a new commanding system including a front-end named Zabbix will be introduced. This is an open source monitoring solution that has been tailored to suit the needs of the overall MPCC system (see [17]). In parallel the new Operations data files (ODF) have to be developed, tested and verified. Those procedures need to be in line with the overall ODF standards demanded from NASA side and therefore an adaption of these standards has to be applied also on all the MPCC related operational products. Due to the complex nature of the new system there is a relatively high effort needed from Col-FCT side to prepare all ops products needed for the commissioning and steady-state operations of MPCC phase 2.

As mentioned above with the transition to phase 2, new hardware will be installed in Columbus. In order to be flexible and cost-effective, the new equipment will mostly consist of commercial off the shelf (COTS) items that can easily be replaced and might even be available from the NASA spares pool on-board. The new central MPCC laptop in Columbus, the European IP Communication Laptop (EICL), is a standard HP ZBook that will be configured with uploaded software by the astronauts and via Ku-IPS from ground. NASA has upgraded all laptops on board recently to those new generation models, which have been proven to be very robust and easy to maintain. Also the new Columbus Payload LAN Switch (CPLSW) will be a COTS item, namely a 16M Octopus Hirschmann Switch. It will establish the new Columbus Payload LAN that will be mostly separated from the nominal Columbus Data Management System (DMS). It has 16 ports of which 10 can be used to connect payloads to the payload network. Together with the EICL the CPLSW will provide several services to establish, configure and maintain the end-to-end connection between the payloads and the user. The operating system running these services is based on Ubuntu and thus the entire system runs on a LINUX environment. After booting and in-flight installation of the software, the laptop will be immediately ready in standby mode. In this mode all basic functions of the laptop are available. In order to allow routing of payload IP data however, the laptop needs to be commanded to nominal mode by ground. Upon receiving the ‘go_nominal” command, the EICL automatically starts routing of the payload IP data via the Columbus Payload LAN to groundLater during phase 2.1 also the Taxi-to-LAN Converter (TLC) as well as the IP-Concatenation Box (IPCB) will be installed in Columbus. Those two boxes pave the road for the additional communication path via Ka-Band.

Fig. 8: TLC/IPCB Box Layout (Photo: Airbus)

The TLC allows the connection of Class 1 and 2 payloads to the MPCC System via the Columbus Data Management System (DMS) by converting the data streams from Transparent Asynchronous Transmitter-Reciever Interface (TAXI) data format to standard CCSDS packets. The IPCB on the other hand acts as device between the EICL and the Columbus Ka-Band equipment. It shapes the size of the IP packets, which will be transferred to ground via Ka-Band. Both, the TLC and the IPCB consist of the same hardware and thus also allow a reasonable spare concept. They will receive their power via USB from the EICL. The EICL itself as well as the CPLSW are powered by a Standard Utility Panel (SUP).

To perform the transition to phase 2.2, an extra-vehicular activity will be required to install the new Ka-Band antenna outside of Columbus named ColKa. In parallel to the EVA also several intra-vehicular activities will be performed by Crew in order to connect all needed equipment inside Columbus to the communication chain. This will then be followed by a further commissioning campaign to ensure all functionalities of both ways of communication for the MPCC system, i.e. Ku-Band and Ka-Band link.

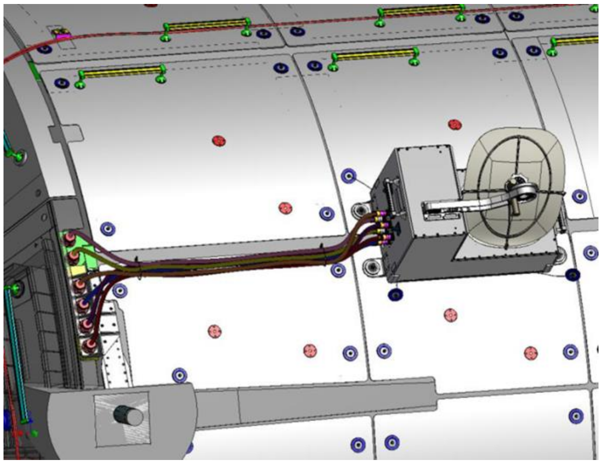

Fig. 9: Ka-Band Antenna on Columbus external hull (Photo: Airbus/ESA)

The communication path for MPCC Phase 2 on board as described in Fig. 10 partially involves also NASA Joint Station LAN (JSL) assets. In order to assure security and integrity of the on-board system, the network has been separated in several so called VLANs (virtual LANs). This allows the communication along desired paths between participating equipment, but also mitigates network congestion and avoids unwanted traffic for safety relevant equipment connected to the station wide LAN, as communication between VLANs is not possible. In Fig. 10 also the different VLAN paths can be identified. The diagram additionally shows the two possible ways of communication with the ground: On the left hand side the Ku-Band path through the JSL and the Ku-Band antenna as well as on the lower right the Ka-Band path, which will be established during Phase 2.2 and will be fully independent from NASA resources. Additionally also the wireless connection of the payloads to the Columbus Payload LAN is under discussion. This could be realized either by the built-in Wireless Access Point (WAP) of the EICL, or via the WAP of the JSL Router in Node 2, the NASA module Columbus is connected to on the starboard side.

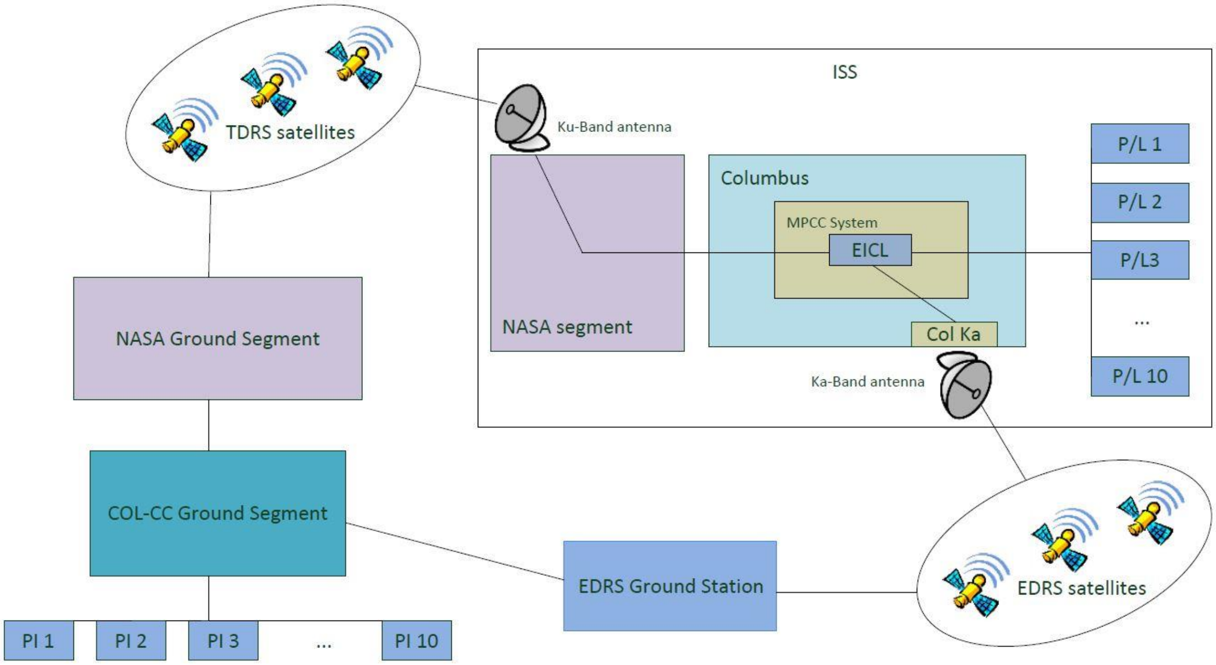

Fig. 10: MPCC Phase 2 overall setup and connections (Diagram: DLR)

On ground the nominal commanding to the MPCC phase 2 system will be performed by the GSOC Ground Controller (GSOC GC) for the MPCC Ground Node and by STRATOS for all MPCC equipment on-board. The STRATOS flight controllers in general are responsible for all 5 subsystems in Columbus, namely power distribution, life support, thermal control, data management and communication (see [14]). Both positions are staffed 24/7 and located at the Columbus Control Center (Col-CC) in Oberpfaffenhofen near Munich. During nominal operations GSOC GC and STRATOS will closely monitor the entire MPCC system and be in touch over several voice loops with the relevant parties: on the one side with the USOCs with the relevant users assigned to them and on the other side with the respective counterparts on NASA side. Both positions will also take care to enable or disable the access of the user to their payload on board, to set the overall and individual bandwidth for the payloads and to monitor the entire system performance. Nominal reconfiguration can be done by STRATOS alone. In case of a malfunction STRATOS on console is able to bring the MPCC system into a stable configuration and will inform the user and counterparts of impacts and/or potential science loss. For further troubleshooting and malfunction handling STRATOS will be supported by a dedicated Activity Specialist from the STRATOS team and – at least for a transition period – by a subsystem engineer from the Columbus Ground Segment with dedicated system matter expertise. The same approach is chosen for installation and commissioning of MPCC phase 2 ,.

Conclusion

The last nine years offered a lot of challenges for the Col-CC Flight Control Team from the technical side as well as from the changing boundary conditions. Col-CC has successfully overcome all critical situations and established an excellently performing team which is ready to tackle the future tasks.

The last year has shown that the support of an ESA astronaut together with big changes on ground like RISE, the Columbus software update, setting up new experiments like MARES/Sarcolab with the Russian colleagues as well as the preparation for MPCC and ColKa can be performed successfully in parallel.

After several successful science runs during MPCC phase 1, the transition first to phase 2.1 and then after installation of the Ka-Band antenna to phase 2.2 will provide the principal investigators and users with even more capabilities and flexibility in performing science. Also the cost efficiency of the MPCC project allows experiments on board not only to be performed by outcome-oriented science centers, but also to become increasingly part of educational institutions all over Europe. Although with up to 10 payloads running in parallel this might impose additional workload to the flight controllers on console, with sufficient training and preparation it will be flawlessly integrated in the nominal operations schedule.

This shows that Col-CC is able to take over some additional tasks to exploit the widespread experience of the highly motivated Col-CC team for increasing the efficiency of the overall ESA ISS exploitation project. This will offer full continuity to the International Partners and in parallel opens the path for a new and more efficient approach for ESA.

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