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Manuscript MPCC and KU-IPS, new ways to control the next generation of COLUMBUS Payloads - GROUND SEGMENT aspects

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Abstract

The ISS (and the Columbus module as integral part of it) was originally designed to use the classical space to ground communications approach. This “legacy" system consists of CCSDS based telecommand (TC) and telemetry (TM) packets routed via a complex chain of a hierarchical TC/TM server architecture.

The implementation of the European Multi-Purpose Communications Computer (MPCC), using the NASA KU-IPS (Internet Protocol Service), allows much easier and straight forward IP-based communications. An end-to-end IP-based link from the ground user to the Columbus payload LAN, including via wireless access points on-board, allows a new category of simpler, more commercial payloads, and opens the research capabilities to an entirely new group of payload users.

While a corresponding paper (Implementation of an Additional Command System, Pathing the Way for New Tasks at Col-CC) describes the changes to the on-board systems and operations for ESA's Columbus module, this paper discusses the required additions in the ESA ground system architecture, the changes in the paradigm in ground operations, and examines potential chances and problems associated with both.

The MPCC/KU-IPS is an additional path to the legacy system and requires the development of alternative operational procedures and handling parallel to the established operational processes. The main idea behind the implementation of KU-IPS and MPCC was to allow new users a simplified and direct access to their payloads on board Columbus.

The direct IP- communications path and, even more, the direct Internet access of User Home Bases (UHB)/Investigators, define additional tasks and responsibilities for ground positions. As the UHB may no longer be "hidden" behind the established User Operations Center (USOC), the ground controller is required to act more in direct payload and payload user support. The additional support will also be required as the ground controller now faces a larger community who are not as highly trained in operations procedures as the current personnel at the USOCs. The final phase 2 of ESA's MPCC/KU-IPS implementation is the planned integration of an own Ka-Band terminal on Columbus. This builds a completely new direct communication path with, again, even more tasks and responsibilities for the ground controllers.

Keywords: Multi-Purpose Communications Computer (MPCC), KU-IPS, Ground Operations, GSOC GC

Acronyms/Abbreviations

APID	Application Identifier
C&C	Command and Control
CCSDS	Consultative Committee for Space Data Systems
Col-CC	Columbus Control Center
CoFR	Confirmation of Flight Readiness
CPLSW	Columbus Payload LAN Switch
DaSS	Data Services Subsystem
DMS	Data Management System
EICL	European IP Communication Laptop
ESA	European Space Agency
GCT	Ground Control Team
FN	Flight Node
GN	Ground Node
GSOC	German Space Operations Center
HOSC	Huntsville Operations Support Center
HRM	High Rate Multiplexer
IGS	Interconnection Ground Subnetwork: The ESA ISS wide area network
ISS	International Space Station
JOIP	Joint Operations Interface Procedure
JSL	Joint Station LAN

KU-IPS	KU-band Internet Protocol Service
LAN	Local Area Network
M&C	Monitoring and Control
MCC-H	Mission Control Center Houston
MCC-M	Mission Control Center Moscow
MDB	Mission Database
MDM	Multiplexer/Demultiplexer
MPCC	Multi-Purpose Communications Computer
OS	Operating System
PDC	Payload Data Center
UHB	User Home Bases
TC	Telecommand
TM	Telemetry
TReK	Telescience Resource Kit
USB	Universal Serial Bus
USOC	User Support Operations Center
USOS	United States On-board Segment
VDPU	Video & Data Processing Unit

1. Introduction

The International Space Station (ISS) is a quite huge research facility / laboratory flying in Low Earth Orbit.

You may sum up the main differences of the ISS towards other space-borne research facilities (such as satellites) as:

- A manned laboratory
- A laboratory operated by multinational agencies.
  In actuality it is a collection of laboratory segments from multiple agencies/countries
- A laboratory with frequently changing probes, experiments and/or research facilities.

While the first is obviously the main design driver for the station, this paper will concentrate on the variable laboratory aspect and its implications for data exchange between ground and station.

The ISS is comprised of modules from different nations, operated by the different agencies' control centers. Although Russia and Japan have already their own data link with the station (and ESA is planning to have one) it is still one interconnected station. As such main functions must be controlled via one facility – the main ISS Mission Control Center Houston (MCC-H). Essential system health and status telemetry as well as commands from all modules are routed in a centralized manner through MCC-H using a common TM/TC format and routing.

Changing experiments implies also changing experimenters/users. ESA respected that from the beginning with a de-centralized operations concept, with multiple User Support Operations Centers (USOC) in various contributing countries. But here as well a centralized control instance – in this case the Columbus Control Center (Col-CC) – is required to organize and oversee the different activities for ESA and to coordinate those with MCC-H. TM/TC is standardized with the same format and routing as described above for system health and status TM and TC.

This already shows one dilemma of the variable experiment assets and flexible research versus the need for a controlled and safe environment, the latter of which dictates a centralized organization. This is especially true, given the limited communication access to the station.

The ISS community has the strong desire to increase utilization and decrease preparation work and time. Therefore new ways to access payloads in an easier and faster manner are heavily demanded, at the moment cumulating in the KU-IPS.

2. The 'old' legacy path

2.1 General Setup

The original implementation of the TM & TC path follows the very conservative set-up of uplink/downlink of standardized TC and TM packets via centrally controlled assets. The TC and TM packets adhere to CCSDS standards as well as the protocol. Commanding is routed via the MCC-H central command server and uplinked to the on-board MDM, for distribution to the modules and their systems. The return path is basically the same in reverse: from modules' systems/payloads to the MDM, down to Houston for distribution back to the partners.

Note that for the sake of simplicity in this section the description concentrates on the systems relevant for command and telemetry routing and leave systems like sat modems etc. out, as these are not relevant here.

Some partners can use their own up- and downlink assets as well, but for essential system commanding and data the MCC-H path is used to enable MCC-H to take over in case of emergency (with Mission Control Center Moscow (MCC-M) as back-up with similar systems).

2.2 Even more complicated for ESA Payloads

ESA’s decentralized USOC approach creates even two more layers (USOCs and Col-CC) as shown in Fig 2.1.

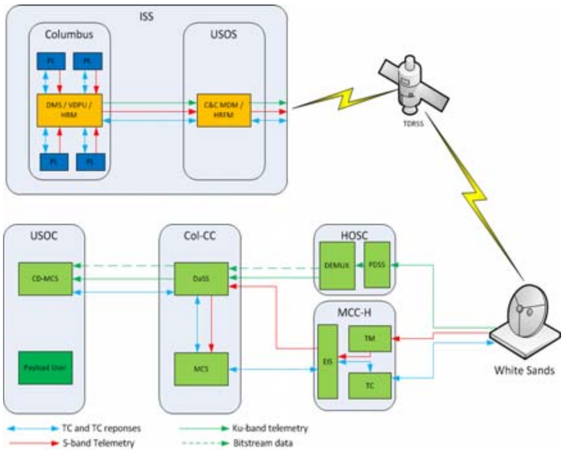

Fig. 2.1. Legacy path end-to-end

a) *USOC:*
An experimenter at a USOC issues a command usually using the monitoring and control system CD-MCS, provided as customer furbished equipment by ESA. Within the CD-MCS payload database the CCSDS command packet(s) are generated and sent to Col-CC.

b) *Col-CC*
At Col-CC the commands are received at the Data Services Subsystem (DaSS) and forwarded to the central MCS at Col-CC. There the command is put into the Columbus command stack. On priority (System over payload) and FiFo basis it is routed to MCC-H.

c) *MCC-H*
At MCC-H the commands are received at the External Interface Server (EIS) and forwarded to the central command server for uplink to the station, again on priority basis.

d) *Station*
Commands arrive on station in the USOS C&C MDM, and are distributed to their destination, in our case, the Columbus module.

e) *Columbus*
Commands are received in the Columbus DMS, unpacked and sent to the payload.

The commanding from a) to b) and from b) to c) requires that the USOC be enabled for commanding in the Col-CC MCS, a task performed by the GSOC GCT.

The Payload telemetry is differentiated into TM packets or HighRate bit stream. Both types are transported in CCSDS packet format but via different systems.

a) *Columbus*
TM packets are routed via the DMS, high-rate via the VDPU, both routed to the Columbus HRM, and forwarded to the USOS.

b) *Station*
Received in the USOS the Columbus stream is multiplexed with other modules’ data and assigned an APID in the station MDM / HRFM for downlink.

c) *HOSC*
Unlike the system data, which is routed via MCC-H, payload data is routed to Hunstville Operations Support Center (HOSC), which is NASA’s payload center for the ISS. HOSC unpacks the Columbus APID and routes this to the ESA Gateway.

d) *Col-CC*
Received in the ESA Gateway, the stream is demultiplexed into the original TM packets and bitstream data and forwarded via the DaSS to Col-CC for distribution back to the USOCs.

e) *USOC*
Received in the USOC, the data is processed in the CD-MCS according the payload database.

2.2 Disadvantages of the legacy system

As said before this centralized routing approach allows a central organization of station usage and dataflow. However it has significant disadvantages:

- It is a long path through several different systems. The chain has proven to be very reliable, but however in case of problems it takes time and often quite an amount of troubleshooting to find the root cause.
- Intensive coordination between the USOC <-> Col-CC <-> HOSC/MCC-H is required.
- The packetizing creates bandwidth overhead.
- The usage of the provided CD-MCS is not a must, as the DaSS provides APIs to connect other M&C systems. However, if using CD-MCS, the data definitions need to be put in the MCS mission database. Each Payload database at the USOCs is a subset of this MDB.
- Even if CD-MCS is not used the packet definition must be configured in the DaSS.

- Users require a complete operator training for the CD-MCS and have to understand and deal with all regulations, constraints and procedures.

3. The ‘new’ MPCC / KU-IPS

3.1 KU-IPS an alternative way for up/downlink data by NASA

The above described legacy path is obviously very heavy and requires a lot of time to implement and test the communications path for payloads. Users want to do research and do not want to spend a lot of time for transfer protocols and such. Therefore NASA was looking for a different much easier approach and implemented the KU-IPS, the KU-band Internet Protocol Service. As the name says this service provides IP connectivity directly to the Joint Station LAN (JSL) so that users can access and control their payloads using standard IP protocols and programs.

Technically the user-system is connected to the KU-IPS interface at HOSC, which provides the up/downlink via KU-band services and connects up to the JSL on board. This path is transparent for a user, who does see a direct secure path to his/her payload.

For this HOSC provides the software suite Telescience Resource Kit (TReK), which allows the remote access to the KU-IPS. It includes a small M&C application as well.

Normally the TReK software would be installed at each user site, which would them be responsible for its maintenance, updates (often once per Increment), and confirmation of flight readiness (CoFR). Access is secured by individual HOSC accounts with two-factor authentication using RSA tokens.

3.2 ESA is using NASA KU-IPS via MPCC

As NASA’s payload user center it is HOSC’s task to support the US users. It is, however, not feasible for them to take care of European users in terms of Trek deployment, user access administration, and IP configuration for payloads. Therefore ESA has developed the Multipurpose Communications Computer (MPCC).

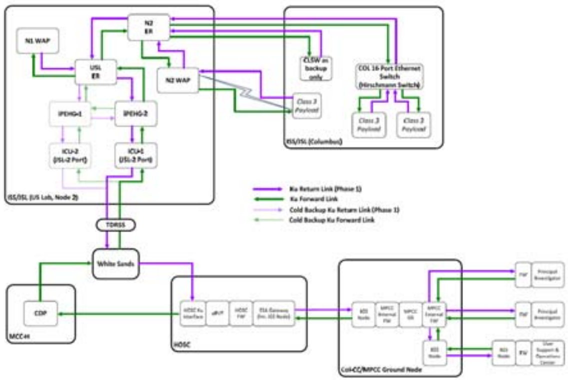

Fig. 3.1. MPCC-setup Phase 1 from [1]

The overall set-up is shown in figure 3.1. The MPCC acts as the gateway for European users to the KU-IPS service. It provides one single interface between HOSC and ESA users so that HOSC needs to deal only with one ‘ESA user’. The TreK software necessary to connect to KU-IPS is integrated in the MPCC and does not need to be deployed to the users. The user access the MPCC remotely via standard browsers.

3.2.1 Technical set-up

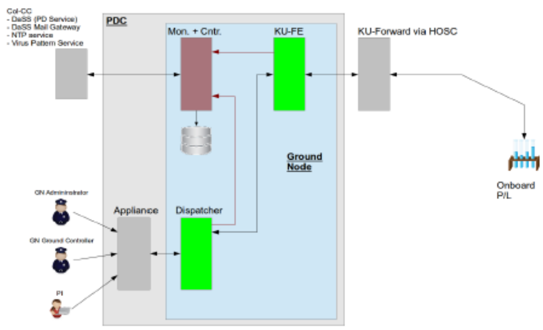

Fig. 3.2. MPCC-Ground Node from [2]

The MPCC Ground Node is a set of virtual machines installed in the Payload Data Center (PDC) at Col-CC. The PDC itself is set of centralised servers providing virtual machines for USOCs to host their M&C applications, etc. Consequently the PDC was deemed the best home for the MPCC (apart from the fact that both was developed by Airbus D&S)

The Ground Node consists of the following main components:

- *The Dispatcher*
  provides the mapping and control of incoming IP connections (from the users) with the on-board payload IP adresses.
- *The KU-FE (Front-end)*
  The KU-FE provides the interface to the KU-IPS forward link service provided by HOSC. It runs the Trek software to receive the Proxy-IP-Addresses for each on-board payload.
- *Mon+Con (Monitoring and Control)*
  runs system and monitoring services for MPCC and provides the DaSS interface for data exchange with Col-CC systems.

Additionally, three types of users have been envisioned for MPCC Phase 1:

- The PI (Principle [or Payload] Investigator)
- The GN Controller/Operator
- The GN Administrator

Their responsibilities are discussed in Section 5.1.

3.2.2 Benefits of the MPCC-GN

The MPCC Ground Node has following advantages:

- Easy IP-based access to payloads for ESA users
- Standard software (i.e. Internet Browser) required at User sites only
- One centralized TReK installation
- Ease of administration by HOSC
- Col-CC Ground Operations personnel can provide European User support
- Only one operational interface between HOSC and ESA/Col-CC
- One known interface for ESA users, namely Col-CC
- Access to HOSC systems by the existing Col-CC Ground Controller accounts
- Access to MPCC by European users via existing accounts

3.2.3 Additions in the ESA Ground Segment architecture

Already the installation of the PDC two years ago made significant changes to the ESA Ground Segment set-up necessary. With the PDC the computation assets (M&C software, etc.) were moved away from the local USOCs to the central virtual environment at Col-CC. This limited the hardware requirements at the USOCs, and changed the data routing as well as the bandwidth and virtual channel/path allocation over the ESA owned wide area network (IGS) connecting all the user centers within Europe. The operator at the USOC no longer uses own hardware in the USOC for these functions but remotely logs in to the virtual clients in the PDC at Col-CC.

In this regard the integration of the MPCC within the PDC was a logical step und made use of the centralized virtual environment with the remote access of the users. The centralized maintenance of this new subsystem is also given within the PDC.

Originally it was planned to route the MPCC traffic within the existing OPS data virtual channel of the IGS, but already the first experiences showed that the bandwidth management is tricky, that interferences with the regular OPS data traffic can happen, and that troubleshooting of MPCC bandwidth issues was next to impossible. Consequently a dedicated virtual channel for MPCC traffic was configured between Col-CC and HOSC, and between Col-CC and each USOC.

As already mentioned the access to the MPCC for standard users, as well as Ground Node operators and MPCC administrators, follows the standard mechanism of the PDC, namely via remote login from a dedicated workstation, with a dedicated user Login and two factor authentication by an ESA e-token.

Initially, the administration and the Ground Node operator function were to be performed remotely by Airbus DS personnel in Bremen, Germany. After the decision by ESA to hand these responsibilities over to Col-CC, it became apparent that this way of accessing these MPCC functions from within Col-CC is not optimal.

From the network perspective the PDC is placed in a demilitarized zone, separated from the Col-CC Ops LAN, for secure access from external (to Col-CC). This is done because the PDC is intended for external users and not for the Col-CC. Adopting this architecture and the underlying security mechanism (e-tokens) for access from Col-CC was consequently deemed undesirable for the following reasons:

- Impracticality of installing the required dedicated access workstations on all consoles (especially in light of the Col-CC's recent virtualization of all Ops clients)
- Convoluted network routing required to move the workstation "out" of the Col-CC in order to access the PDC/MPCC as an "external" site

- Col-CC operators use a smartcard login for two-factor authentication rather an USB-e-token

These factors have led to the development of a special software and proxy based implementation to enable access to the MPCC from any standard Ops LAN workstation in the Col-CC control rooms (see Figure 3.3). This also allows us to keep our flexibility in usage of prime and back-up control rooms and back user rooms.

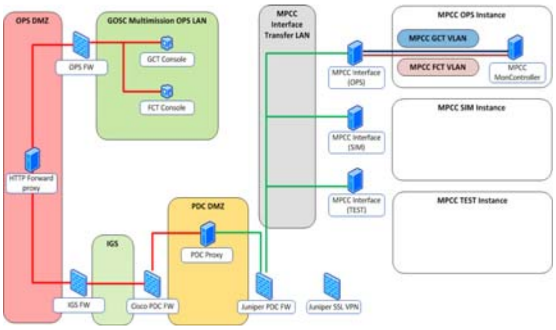

Fig. 3.3. Proxy Access to MPCC GN [5]

With this implementation, the MPCC Ground Node is accessible via SSL VPN into the PDC environment and provides Ground and Flight Operator services via HTTP, SSH, Filetransfer and noMachine NX. Access is required from GSOC OPS LAN where the usage of VPN is not permitted. An apache server on the boundary of the PDC is used authentication, authorization and redirection so specific services. While HTTP services are provided via reverse-proxy, SSH is provided via Anyterm, a web-based Terminal client. File transfer is implemented with a custom HTML Dropbox, and access to the NX is implemented through Apache Guacamole, a web-based VNC and RDP client. This enables simple web browsers on the clients' side to connect to MPCC services. In addition, no changes have to be made on MPCC. The described setup uses existing authentication mechanisms and complies with established security requirements by both GSOC/Col-CC and ESA.

3.3. Testing and Simulation Assets

The MPCC Ground Node software was developed by Airbus in their Test Lab at the Engineering Support Center (ESC) at Bremen, Germany. Initial testing with HOSC was done from the ESC via the IGS.

At the end of the development the MPCC GN was integrated into the PDC at Col-CC as virtual machine and handed over to operations. This happened quite seamlessly as the initial experiment runs were done with small ESA robotic experiments without any danger of damage.

However it turned out very early that another Test node was required for preparation and test activities for future payloads. In parallel the development of MPCC phase 2.1 was started (see section 6) at the ESC at Bremen.

As the MPCC GN is software running in a virtual environment it is quite easy to clone the virtual machine and create another instance. Thanks to the set-up of remote connectivity to the GN operator workstation at Col-CC instead of dedicated machines, it also required an overseeable effort to generate variable remote connectivity. Consequently it is now possible from each Ground Operations Control room or from our Col-CC PDC reference facility to connect to any of the MPCC GN instances.

Of course these instances require dedicated interfaces (IP-connections) to the KU-IPS at HOSC.

At the moment there are four MPCC Ground Nodes configured and in use:

- Operational Ground Node at Col-CC
- Test Ground Node at Col-CC

  For preparation, testing and simulations for upcoming payloads. As future payloads are already tested with phase 2.1, this node is barely used.

- Development Node at ESC in Bremen

  Currently Test and development for the enhanced MPCC phase 2.1

- Phase 2.1 Test Ground Node at Col-CC

  For already preparation and simulation runs with future payloads on phase 2.1

As soon as phase 2.1 is qualified for operations and become active, the phase 2.1 node will be used for operations and the test node will be migrated to phase 2.1 test. The operational phase 1 node will stay for a short time as fall-back and then be de-installed (or used as phase 2.2 test node).

4. Internet access to the station

4.1 Internet access to OPS LAN

The original approach of the ESA Ground Segment was that dedicated European user and operation sites, USOCs, are connected by a private wide area network (technically running over a public WAN provided by a service provider). Users and experimenters who want to access the station need to come to those sites and use there the dedicated assets to do so. One alternative to physically coming to a USOC, is that the USOC provides an interface to allow external sites, so called User Home Bases (UHBs) to remotely connect to the USOC and run via the USOC assets to their experiments on board. In this case the USOC is responsible to provide the interfaces and systems.

One of the ideas of the PDC was to quasi virtualize the dedicated USOC assets within the centralized PDC environment. By doing this, the possibility is given to connect UHBs directly with the PDC and provide them a virtual environment to use. Therefore the design of the PDC foresees a gateway to the public internet with a secure access mechanism (the Appliance).

With the legacy M&C systems the usage was still quite limited as CD-MCS and DaSS require dedicated user configurations. And also on-board the experiments are hosted in the legacy-controlled racks. In fact the internet access, while possible, was never really used.

With MPCC providing IP-based access the scenario is changing. Especially on the payload side the need to use the legacy controlled facilities goes away. The first portable experiments have already been executed. The internet gateway is not yet in use but some smaller payloads are already planned. Especially for the commercial payload approach it might become important.

4.2 OPS Support Tools via Internet

Up to now we concentrated on the TM&TC transmission and the ops data. But for doing operations additional tools and assets are required. Usually within the IGS world these are either centrally provided services by Col-CC or accessible via the IGS network directly. For the new internet users gateways have to be provided.

4.2.1 Video

On-board video provided by the payload itself is part of the telemetry/operational data. This is then part of the MPCC provided data.

But station video from internal or external cameras is available by the central Col-CC video system via and over the IGS network. For some experiments, especially those which need interaction with, or monitoring of, astronaut activities, this video is required.

As part of the renewal of the video system at Col-CC (driven by obsolescence), new requirements were introduced to provide a gateway for streaming video to the internet.

4.2.2 Voice

One of the most important services throughout the ISS operations is the voice intercommunication between all sites and the station. More than 1000 voice loops are configured in total at all international partner sites.

Each control center has its own voice system, which interconnects with the other control centers. At ESA there is one central voice system located at Col-CC. Each European facility is equipped with a certain number of remote voice keyset terminals connected to this central voice system.

For external users there is the possibility to dial-in via black phone and get connected to a single voice loop. This works well for Public Relation or very special support to one activity. However for execution of an experiment, especially with astronaut interaction, this is not sufficient at all.

With some experiments we delivered remote keysets to external sites and connected them through the internet to our system. But this takes considerable effort and is only reasonable for long duration experiments.

At the moment ESA is only planning for small and self-standing experiments to be executed from UHBs directly, and considers no need for voice communication for these. However we are convinced that this will be required very soon, not only for the execution, but also for training and preparation beforehand. Therefore a solution must be found, e.g. a web-based voice conferencing system connected to the Col-CC system, like the one GSOC is currently developing for satellite operations.

4.2.2 Ops Support Tools

There is a plethora of mostly web-based applications for preparation, planning, and documentation, for example planning tools, console logs, procedure repositories, trouble ticket systems, etc. Many tools are provided by NASA for all International Partners. Additionally ESA-internal tools (mostly) are provided by Col-CC for all ESA users. All these tools are accessible via a dedicated OPS Support virtual channel/LAN on the IGS.

Since some years a gateway, the so called BigIP, provides access via the internet. The access is controlled via ESA e-Tokens.

However some tweaks are definitely required for a bigger external user community using MPCC. Up to now only USOCs, who have access anyway to all tools via the IGS, have used MPCC. So only the time, or better yet, non-USOC user operations, will tell what has to be changed here.

5. Changes in the paradigm of Ground Operations

This paper concentrates on the ground segment aspects of MPCC and therefore as well exclusively on the ground segment operations. On-board/flight segment operations are discussed in a corresponding paper [3].

MPCC is a new system in the Ground Segment with new resources and a new interface to on-board. However we did not reinvent any wheel but try to incorporate this system as far as possible in the existing processes.

5.1 New responsibilities of Ground Control Teams

For the preparation and planning of ground segment resources the same processes and procedures apply for MPCC runs as for activities with legacy path. Only MPCC as system and the resources had to be integrated in the planning function.

As mentioned in Section 3.2.1, three types of "users" have been defined for MPCC Phase 1:

- The PI (Principle [or Payload] Investigator)
- The GN Controller/Operator
- The GN Administrator

5.1.1 Principal (or Payload) Investigator

The tasks of the PI center around the monitoring and control of the payload, including up- and downlink of files and data.

As previously mentioned, the PI accesses the MPCC from a dedicated workstation via the PDC firewall and Appliance. User sites are supplied with PDC Tokens, which are validated by the Appliance when the user site connects. The Appliance can be configured to allow a User to connect via the existing IGS infrastructure, via the Internet, or via either. A User may not initiate multiple connections.

5.1.2 GN Controller/Operator

The on-console Ground Control Team (GCT) at Col-CC is responsible of monitoring and controlling all systems running at Col-CC as well as the IGS network during operations in real-time. The MPCC is therefore one more system to observe. It was very reasonable that the GCT does not only the health and status monitoring but take over the Ground Node Operator function.

Before an experiment run it is the GCT's task to set-up all ground resources, voice, video, data connections for/to the user.

Additional tasks for the GSOC GCT as MPCC GN Controller are summarized as follows:

- Enablement of PI connections
- Configuration of Uplink bandwidth
- Establishment of the ground link to the HOSC HPEG application and enablement of the Payload IP path
- Monitoring of up- and downlink bandwidth received in the GN
- Level 1 troubleshooting of connection and bandwidth issues

These new tasks have led to the creation of a new ESA JOIP, in which the step-by-step coordination with the Columbus Flight Control Team and the User is detailed, including the verification of connections with the user and HOSC up to the payload.

Since the MPCC/KU-IPS is an alternative path to the station, and the Ground Node Operator is configuring and switching this path, the GCT is here much more involved in the payload operations as for the legacy path. This begins with the dedicated bandwidth planning for up- and downlink up to the IP-link configuration with the user.

Towards the NASA the interfaces remain the same because the MPCC Ground Node is the single interface from ESA to HOSC and the end user is transparent to HOSC. Here the GCT acts basically as the ESA user.

Two GSOC Ground Controllers have been trained to a level of expert knowledge in the MPCC Ground Node, and are responsible for training and certifying the GCT in its operation, and for the development of routine and troubleshooting procedures.

5.1.3 GN Administrator

The Ground Node Administrator is a Linux certified network engineer responsible for all required operating system (OS) and network configurations of the Ground Nodes. Additionally the GN Admin is responsible for OS and software upgrades, as necessary. Since these tasks are already performed for the PDC for the legacy systems, the responsible team has been tasked with the same responsibilities for the MPCC.

5.2 A new level of user

Although we have said above that there are – up to now – no dramatic changes, we await big differences with the future external users/UHBs.

The main idea is allow users to run their experiments from their home base anywhere and not to be forced to come to a USOC. Just as important, one goal is to avoid the burden of long training and familiarization with the legacy system and operations, and instead use the standard IP protocols that most everybody is familiar with.

The draw back will be that "untrained" users will be involved in operations. Up to now a user is usually a member of an USOC and:

- Is trained in the on-board Columbus Systems
- Is trained in on-board payload operations, especially for the rack in which the payload is hosted
- Is trained in the Ground Segment Systems
- Has an operations training in the planning and preparation processes, operational procedures, voice protocol, …
- Is on-console at a USOC in an operational environment
- Is part of an integrated team in an operational team

All this is not necessary for a MPCC UHB. The GCT will have to support such users more intensively and in a different way than for trained users.

- It can't be relied on that the existing preparation and planning processes and procedures will be applicable. A more individual and more time intensive support must be given.
- The GCT must guide the user through the execution. We assume that as Ground Node operator the GCT will have more burden there as the Flight Control Team.
- The GCT must monitor the activities of the user much more intensively during execution to be able to intervene if necessary.
- The GCT will have to answer a lot more questions.
- The GCT will have to perform much more unplanned changes in real time because of unknown or unprepared service requests.

It is assumed that a new fast and basic user training for such users needs to be developed and given.

5.3 Commercial Users

One idea behind the development of the MPCC is the commercialization of the ISS utilization in Europe.

In addition to the research facilities funded by the ESA and the national agencies it is the idea to have research from commercial funded companies and institutes. These – so the idea behind – do not be involved in the agency owned legacy systems, but can access their experiments via the standard IP-based MPCC. More about this development is written in a complementary paper for this congress [4].

For the GCT at Col-CC this will be even an additional change to interface with commercial centers in addition to the institutional sites as these commercial centers may not be used to the agency space operations.

6. Further enhancements of MPCC

The MPCC set-up described in this paper and implement at the moment is just the initial first phase of MPCC implementation in Europe. It serves as the first testing phase using US assets on board. Two more steps or enhancements are planned.

6.1 MPCC Phase 2.1 with Columbus Payload LAN

6.1.1 Technical Set-up

In the so-called MPCC phase 1 ESA is using the KU-IPS from HOSC to get access to the Joint Station LAN and the ESA experiments are connected with the JSL.

The next phase is a modification on-board to utilize for ESA payloads a Columbus owned network/LAN. For this, network equipment (switch, WAN-routers, etc.) has to be brought on-board the Columbus module.

The routing of payload commands and data inside Columbus is done software-based via the European IP Communication Laptop (EICL). The EICL is commanded and controlled via the MPCC Ground Node, however in this case by the Columbus Flight Control Team (FCT) members. The GCT remains responsible for configuration and control of the MPCC ground elements.

The equipment is already on-board and the activation is already planned. At the moment the MPCC Ground Node software is under test.

For the test on ground there are already two MPCC ground nodes for development and testing installed in the PDC, allowing parallel Phase 2 testing while operating experiments with the MPCC phase 1 Ground Node.

6.1.2 Changes in operations

For Ground operations no big changes are involved. The coordination and preparation differs a bit but still within the confines of existing procedures and processes.

The biggest change associated with MPCC Phase 2 will be the involvement of the Columbus FCT in the operations, namely the configuration of the on-board network for new payloads and the routine operations of the EICL.

Similar to the separation of GN Operator and GN Administrator tasks, the Flight Node (FN, i.e. EICL) tasks have been separated into Operator and Administrator tasks. They will be briefly outlined here, but not discussed in depth.

6.1.2.1 FN Operator

In MPCC Phase 2.1, the FN Operator is responsible for:

- Enablement of IP path from EICL to Payload
- Configuration of downlink bandwidth
- monitoring of up- and downlink bandwidth in the EICL
- Troubleshooting the on-board segment

The Columbus FCT STRATOS position will assume these duties. Training and certification will be performed in a similar manner to the GCT.

6.1.2.2 FN Administrator

In MPCC Phase 2.1, the FN Administrator is responsible for:

- OS and software upgrades on the EICL
- Network configuration of the EICL and Columbus Payload LAN Switch (CPLSW)

Since such tasks are typically in the domain of certified Linux and network engineers, discussion are currently underway regarding how the FCT shall support them, if at all. One option that would seem to make sense would be for the GN Administrators to also assume the task of FN Administrative tasks.

6.2 MPCC Phase 2.2 Col-Ka

6.2.1 Technical Set-up

As final implementation phase it is planned to get an ESA owned KA-band terminal on the station. This antenna shall be installed at the Columbus module.

The KA-band downlink is planned via the European Data Relay Satellite System (EDRS) to the EDRS ground station at Harwell (UK). From there the data is routed to Col-CC MPCC GN.

The design foresees that the EICL then decides based on planning files and the availability of the KA-band link via EDRS if data is downlinked via the European KA-band link or via the KU-IPS from NASA.

All components (ground and space) are currently in implementation and testing on ground is planned for end of this year.

The new IGS site at Harwell is in installation. The interface to the Mission Operations Center of EDRS for planning and preparations is under development.

6.2.2 Changes in operations

This will have some dramatic changes for the Col-CC operations as relay satellite planning and scheduling has to be done. Here the GSOC flight dynamic team will be involved. The benefit at Col-CC is that it is co-located at the DLR's German Space Operation Center (GSOC) where the EDRS Ground Operations are located.

In which extend the operations of the Col-CC GCT is affected is not yet clearly defined.

7. Conclusions

The ISS is not only a collection of international laboratories for space research; it is a test bed on its own for future exploration. Various technologies and techniques can be tested and demonstrated or exercised for usage for future manned as well as unmanned exploration missions.

Consequently it is the best place to test new communication methods like the KU-IPS. Standard IP-protocols might not be the method to be used for deep space exploration missions, but could change the operations of payloads on satellites in near earth orbit.

One permanent criticism about the ISS utilization is the complicated and long lead time to get an experiment flying on-board. All participating stakeholders request to decrease preparation time and increase utilization at all. KU-IPS and MPCC is in this respect a step in the right direction. It allows an easier and more standard communication with payloads. However there are some drawbacks in operating in a complex and multi-user operational environment.

But it definitely allows a new user group to do research on the ISS. But this user group as non-space-operations-experienced introduces new challenges for the control centers for supporting preparation and operations of these new users.

The big space operations centers have all initiatives or project groups for investigating what future control centers shall look like. This includes research on future utilization cases and user groups.

Both the communication changes to IP-based comms as well as the operator/user paradigm changes fit perfect that area/direction.

GSOC binds these activities for the future under the umbrella of the so called Hosted Compact Control Center (HCC). Although the Col-CC does not participate in the HCC activities, this might be of benefit to both Col-CC and GSOC.

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References

[1] OPS-CON-1OPS-996-GSOC, *MPCC Phase 1.2 Concept of Operations* issue1.0

[2] ESO-IT-MA-0052*, MPCC (Phase 1) Ground Node Console Handbook,* issue1.0

[3] A. Schlerf, D. Sabath, G. Soellner, I. Verzola, *Implementation of an Additional Command System, Pathing the Way for New Tasks at Col-CC*, 68th International Astronautical Congress 2017

[4] Kai Burmeister, Christoph Massau, *Commercial payloads and the ticketing process - fast and direct access to ISS using MPCC and KU-IPS by standardized services-,* 68th International Astronautical Congress 2017

[5] Lukas Orlowski, *MPCC Technical Note,* GSOC 2017