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LUNA – Considerations For An European Ground Segment for ESA's And DLR's Test Bed For Exploration

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Abstract

The ESA GSP study "LUNA 2015" identified the need for a large-area lunar testbed facility and analogue habitat in Europe:

As a result, the LUNA – European Exploration Laboratory project was initiated by the European Astronaut Centre (EAC). After some reiteration, ESA and DLR in September 2018 agreed on a joint project the LUNA (formerly LUNA 2.0). This increased version is planned as an industrial hall construction on DLR premises at Cologne next to and connected with EAC. Participating parties are ESA-EAC, DLR's Institute of Space Operations and Astronaut Training with its departments German Space Operations Center (GSOC) at Oberpfaffenhofen and the Microgravity User Support Center (MUSC) and the Institute of Aerospace Medicine at Cologne.

While the requirements definition for the construction are being completed, the planning and design for the supporting Ground Segment is on-going. This paper summarizes the considerations for the Ground Segment so far and will explain and elaborate on ideas behind the requirements.

The Ground Segment will consist of the LUNA internal systems, which will serve IT, Voice, Video, Monitoring, Data, and Archive services for international users. The systems must be built in a flexible manner to allow interconnection of user systems, easy integration of additional simulation facilities, as well as functioning as a test bed for future system development e.g. for ESA's EGS-CC M&C system. In addition to on-line systems the LUNA needs to provide off-line systems to enable user data exchanges and collaboration tools with their home bases in parallel to running simulations.

The second part of the Ground Segment will be a European/International network connecting the various relevant facilities allowing easy on-line and off-line access of remote users and user centers. As future exploration missions are likely to be operated decentralized by a network of various control/expert centers, this network will play an important part towards supporting simulation activities and related scenarios. Although the initial network will be established as a bare-bone minimum, it shall be scalable for possible future expansion scenarios. This paper will elaborate on the projected expansion.

The systems shall incorporate current state-of-the-art as well as future technologies but will also make use of experience gained of Columbus and ISS operations from EAC and GSOC, which hosts the Columbus Control Center. Furthermore, it is planned to collaborate whenever feasible and reasonable with existing systems to employ existing knowledge and facilitate knowledge transition from ISS operations to future ESA and DLR missions.

Keywords: LUNA, Analog Facility, FLEXHab**,** Ground Segment, EGS-CC

Acronyms/Abbreviations

Col-CC	Columbus Control Center
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAC	European Astronaut Centre
EGS-CC	European Ground System Common Core
ESA	European Space Agency
FCT	Flight Control Team
GCT	Ground Control Team
GOCR	GSOC Ground Operations Control Room

GSOC	German Space Operations Center
IGS	Interconnection Ground Subnetwork: The ESA ISS wide area network
IMS	Integrated Monitoring and Control System
ISS	International Space Station
LAN	Local Area Network
LCC	Lander Control Center
LUNA	European Exploration Analog Facility
M&C	Monitoring and Control
MUSC	Microgravity User Support Center
MPLS	Multiprotocol Label Switching
NBF	Neutral Buoyancy Facility
SAN	Storage Area Network
TC	Telecommand
TM	Telemetry
USOC	User Support Operations Center
VPN	Virtual private network
WAN	Wide Area Network
WLAN	Wireless Local Area Network

1. Introduction

For the last 20 years the only outpost of human being in space was the International Space Station (ISS) in about 450km altitude above earth. In the meanwhile the ISS is state-of-the-art and human spaceflight is ready to (re-)open the next chapter and move beyond earth to moon (again) and further.

50 years after the Apollo missions the aim is to finally build up a kind of permanent presence out there. These activities will definitely be a common international one supported by different countries and agencies with their different expertise and contributions.

In this context the ESA GSP study "LUNA 2015" [1] identified the need for a large-area lunar testbed facility and analogue habitat in Europe:

"*In view of lunar exploration, which is foreseen to be one of the next steps in human space exploration, lunar analogues are and will continue to be powerful tools to support the development, demonstration and validation of new technologies and operational concepts. Furthermore Lunar Analogues will serve as an environment for astronaut training, Behavioural Health and Performance research as well as providing engaging activities for the public.*

There is in particular a growing interest in artificial lunar analogues, which offer a wider range of simulation capabilities than natural analogues and provide a more controlled, standardized environment facilitating the comparison between different simulation campaigns. Artificial lunar analogues also offer the benefit of reduced preparation overhead and logistics cost, with respect to simulation campaigns in natural analogues."

As a result the LUNA – European Exploration Laboratory project has been initiated with the objective of providing an artificial lunar analogue complex for preparing operations on extra-terrestrial surface(s) and simulation of operations of such activities.

The idea for an LUNA analog facility is already some years old see [1, 2], and there was some kind of iteration. Therefore the current planning was originally named LUNA 2.0, which is also reflected in the original title of this paper. However the project management decided to re-name the facility back to LUNA again as a sign that the stakeholders are willing to realise the facility as defined in this state.

For this IAC congress another paper of the project team will elaborate on potential experiments and user scenarios [3]. This paper will concentrate on the ground segment aspects. It will summarize the ideas for systems to operate the facility and sub-facilities as well as systems to support the users and operational scenarios. This will include a world-wide communications network to grant remote access for users but also to connect other simulation/test facilities with LUNA to build international operation situations.

2. A brief Summary of LUNA and its surrounding set-up

In order to understand the ideas for the Ground Segment discussed in this paper it is essential to understand the general set-up and the involved centers.

2.1 ESA-DLR Partnership

In September 2018 ESA and DLR agreed on a joint project for LUNA. The participating entities of the European Space Agency (ESA) and the Deutsches Zentrum für Luft- und Raumfahrt (DLR) are:

- **European Astronaut Centre (EAC) of ESA**
  ESA's trainings center for astronauts is located on the campus of DLR in Cologne. Originally the entity was built to train the German astronauts for the national German missions. After formation of the European astronaut corps the facility is now operated by an integrated team of ESA, CNES, ASI and DLR experts. EAC is the home base of the ESA astronaut corps. It's the entity that provides medical support to ESA astronauts throughout their career and in particular during ESA astronaut space missions. For the ISS project it provides the training for all ISS astronauts on Columbus operations

and ESA experiment execution on board the ISS.

- **Institute of Space Operations and Astronaut Training of DLR**

  with its departments:

  German Space Operations Center (GSOC)
  located at DLR Oberpfaffenhofen near Munich. The GSOC is the national spacecraft operations center of DLR. Apart from satellite operations the GSOC has operated most of the human spaceflight activities of Western Europe and hosts the Columbus Control Center (Col-CC) for ESA's ISS module Columbus.

  Microgravity User Support Center (MUSC)
  located at the DLR Cologne. The MUSC is a specific user center for experiments in space, in charge of the preparation, execution and evaluation of experiments on board the ISS. Furthermore it hosts the Lander Control Center (LCC) which has extensive expertise in robotic exploration and specializes in the operation of landers.

It is an equally shared collaboration of EAC and DLR-RB. Both partners have profound expertise in human spaceflight and are actively involved in THE current project of international human spaceflight the ISS. In fact it is planned from 2020 that also EAC and GSOC will form an integrated team for European ISS operations with CNES/Cadmos.

Therefore it is natural that the LUNA facility will emphasis on human extra-terrestrial operations.

2.2 The LUNA Facility

The LUNA facility will be physically located on the DLR campus in Cologne between the EAC and DLR's :envihab. The :envihab is the most modern research facility of DLR's Institute for Aerospace Medicine and hosts all ESA astronauts post flight. The MUSC is in close proximity as well.

Fig. 2.1. VR rendering of the current LUNA concept" (credit: P. Turrión San Pedro, A. Drepper, L. Ferra, C. Scott)

The LUNA building is planned as an industrial hall type of building with approximately 20 m x 55 m (. ca. 1.100 sqm) ground area and 10 m height.

The building will host the operational test bed of minimum 750 sqm filled with Regulith, working benches for the experimenters, restrooms, and a technical room.

It is planned to equip the test bed with Gravity off-load (1/6 G), Sun simulation/ Special lighting, Seismic metering, Drill core inserts (heated, cooled, different granularity..), adjustable ramps with Regolith bed for traction/climbing/descend tests, "Geological wall" for instrument tests, and geological rocks as part of the Moon-like landscape, complemented with a lab for technical gases and a dust chamber.

Attached to the LUNA hall the FLEXHab facility is planned. The FLEXHab is the habitation module to simulate modules of a space/lunar station. This module will be used to perform scientific activities as well as it can be used to test station systems and assets.

A more detailed description of LUNA and FLEXHab can be found in [3].

2.3 Planning Status

The joint venture has been settled between ESA and DLR. The requirements document for the building itself has been released. The original date for beginning the construction work envisaged for end of 2019 has to be delayed due to on-going contractual preparation for the actual building.

Consequently there is not the final layout of the building settled yet.

However the phase to define the Ground Segment has been kicked off and started.

3. Ground Segment Prerequisites

This section will summarize fundamental design drivers and boundaries underlying the GS layout and ideas defined afterwards.

3.1 Use existing assets as far as possible

Spaceflight –as any other business- is forced to be effective in terms of costs, manpower, resource utilization, etc.

The triangle EAC-GSOC-MUSC does not only provide a profound team of experts in human spaceflight and exploration, these are three active and running facilities with high available systems and around the clock operating teams. Re-Using the existing systems and teams limits the effort to a big extend in adding more capacity and manpower and allows participating in existing maintenance and operational set-ups.

3.1.1 GSOC/Col-CC and EAC Systems

The GSOC as active space operations control center. Consequently infrastructure, systems, and networks are set-up to be high available and redundant. Up to now we run a common infrastructure and network but still differentiate on system level between GSOC (satellite) systems and Col-CC systems (for ISS). However with permanent system modernisation and new technologies like computer virtualization this differentiation becomes more and more irrelevant and is changed by nature. This is supported by the fact that ESA and DLR agreed to hand over the responsibilities and property rights over all COL-CC assets to GSOC at the beginning of 2020.

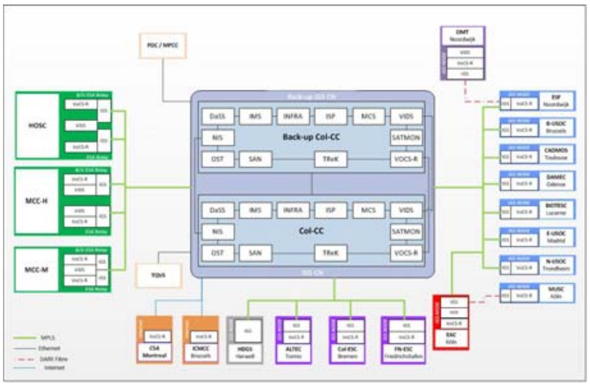

Fig. 3.1. Col-CC Systems Overview

In the case of LUNA we still concentrate on the Col-CC systems as shown in Fig. 3-1. This because these systems are more common in use for LUNA and are already shared and connected to EAC as an ISS-ESA facility. The classical differentiation in terms of service is:

- *Voice*
  Col-CC runs the central ESA voice system for Columbus, which is the same system as NASA is using for all their mission centers (not only human space flight). EAC has a smaller version (Capacity-wise) of this system for training and simulation. Both systems are connected to each other and to NASA systems. Therefore they can serve perfectly as a basis for LUNA connecting already the main centers with a flight-like system. In addition EAC runs a small add-on system with portable keysets for their Neutral Buoyancy Facility (NBF) facility. This system can be extended and used in the LUNA Analog facility. The voice system is probably the first candidate to be exchanged as it is about ten years old. However with the forecasted operations of the ISS until 2030 we are closely bound to NASA and follow up and coordinate with their modernisation plans
- *Video*
  No human space operations without video. Also for video Col-CC runs the main system for Columbus operations and EAC is connected plus has own capabilities using the same technology. The system is state-of-the-art and is frequently maintained/ modernized. The LUNA Analog facility will be connected to this system(s).
- *Data*
  Data routing and processing will be different to ISS-Columbus. But also here we plan for a common approach using modern technologies like EGS-CC. This is discussed further down in this paper.
- *Network*
  LAN
  Due to the high availability requirements GSOC hosts its own high-reliable network infrastructure operated and maintained by an internal network team (NIS) independent from the DLR campus network. The topology is built to fit the needs of a modern control center with network separation from high secure inner system LANs, operational LANs up to DMZs for hosting external systems and managing access from external. This network is currently being modernized. As up-coming phase it is planned to include the MUSC network as a remote facility. The same is done already with the network of the Weilheim Ground Station. Including LUNA/FLEXHab again means adding another remote network facility. This is of course a question of manpower and capacity

but not a complete new set-up.

WAN
The Col-CC runs already an international Wide Area Network (WAN), the Interconnecting Ground Subnetwork (IGS), for all ESA users of the ISS. This network connects already EAC, MUSC, and Col-CC but also some other centers of interest (e.g. ESOC). This network can be used with minimal additional effort. More details are provided in section 5.

- *Computing*
  All computer systems in GSOC are virtualized since quite a while. Whether LUNA systems are set up to run as cloud-like services on the existing GSOC server farm or a dedicated server farm either at MUSC or EAC will be established, is a question of the detailed design and some parameters like data through put. In any case the expertise is there.
- *Archive*
  GSOC and Col-CC have dedicated Storage Area Networks (SAN). To which extend an archive is required will be scope of detailed planning and user requests. The first assumption is that it is not necessary to provide long-term archive of user data. In any case systems are available and would require extensions.
- *Tools*
  It is not quite probable that all existing support tools can be used 1:1 but also here we assume synergy effects. At least existing processes for planning etc. can be used and adopted where required.
- *Collaboration*
  For preparation and remote support existing collaboration environments of EAC and GSOC can be extended and used.

The huge benefits of using these existing systems are quite obvious:

- Cost effectiveness as most systems need 'just' an increase of capacity
- Existing knowledge and experts
- Easy and fast design and implementation and verification
- Existing maintenance structures and processes

In addition we benefit on features we would even not require for LUNA like high availability and some technical features.

3.1.2 Teams

Not only existing systems can be re-used. The LUNA Analog will also benefit from the existing ground infrastructure experts and operations teams. Adding new responsibilities to these teams requires still to ramp up the manpower, but one can definitely benefit from the existing team structure and expertise Furthermore we expect with building an integrated team for Columbus operations from 2020 onwards a possibility to reallocate resources and work more effective without overlaying structures. In addition without being forced to separate Columbus and satellite operations within GSOC any longer we plan to streamline also the internal set-up at GSOC.

- *Subsystem Engineers*

  For the systems and services described above we have at GSOC dedicated engineering teams. Their expertise will help to design the add-ons to the existing systems and we will need only minimal additional manpower to support the LUNA systems. Maintenance processes and procedures exist and can be fully applied. The teams will be combined with the EAC experts where appropriate. The EAC and MUSC experts will take over the local support.

- *Ground Operation Teams*

  EAC has ground controllers supporting EAC operations and Col-CC has a 24/7 on console Ground Control Team (GCT) for Columbus and IGS operations. Both teams will act together. Pure LUNA operations can be supported by either one of these teams using the 24/7 availability of the Columbus GCT for longer experiment runs. The additional operation of the IGS is done by the GCT using existing processes.
  Operator Teams from MUSC will support test bed operation scenarios with their extra-terrestrial operations experience (LUNA-USOC).

- *Planning, System Engineering, etc.*

  We expect to re-use the planning processes existing for Columbus GS operations. We might add tasks to the Col-CC Ground Operations Planner to coordinate and plan the experiments and LUNA usage. System engineering, CM and other functions of GSOC and EAC can also be used if possible.

3.2 Flexible and Phased Approach

It is clear that not all user requirements can be implemented from the beginning. We will start with a kernel implementation of the facility and basic operations. In a staggered approach additional features and functionality will be implemented. This will allow us to keep the budget as well as the implementation time realistic.

A first workshop with potential users [5] showed a wide variety of user scenarios and ideas and we are sure that more will come over time. So it is essential to start with most realistic (also time-wise) user scenarios and stay flexible to incorporate more later when needed. This is one of the basic requirements for the ground segment as well, being flexible, open and adoptable in the future.

However this paper discusses already a certain number of ideas, even those for future phases as these need to be taken into consideration already for the first steps of implementation.

4. LUNA Systems

The Ground Segment can be divided into the following areas:

- LUNA (and FLEXHab) Systems, that means the systems of both facilities itself
- User Systems and Network, that means the systems and services provided for users

The LUNA / FLEXHab system include:

4.1 Environmental Systems

Basic systems of the facility like:

- *Power System*, in both the work bench and the test bed area a very flexible power distribution system is planned to comply with a variety of user needs and locations (test bed)
- *Lighting*, at a later stage a lunar sunrise like angle of incidence system is envisaged
- *Air conditioning* and here in particular temperature and humidity control
- *Access control*, there the system will be attached to an existing system at EAC or GSOC

4.2 User infrastructure

- *Local Network*, this will be an extension of the GSOC hosted network infrastructure (see above). In addition the users will be provided with wireless networks. To communicate with space crafts and rovers it will be necessary to provide further means to support proprietary user hardware. We also assume PUS compatible user hardware.
- *Computing*, as said above the LUNA will not have their own computer hardware as far as it can be avoided. LUNA systems will run as cloud-like services on a server farm of GSOC, MUSC or EAC. This should also include the possibility to host user programs and systems.
- *Data system*, there will be no dedicated data system. More details in a separate section below.
- *Video system*, the test bed will be equipped with a video system with movable cameras to monitor test bed operations. This will be a self-standing system connected to the IGS video systems for ‘broadcasting’.
- *Voice system*, carry-on voice keysets from the EAC system will be used in-side the test bed. The work bench area can be equipped with standard keysets connected either to the EAC or the Col-CC system.
- *Failure Injection*, not really a system, but a functionality of certain assets. It will be interesting to inject failures in network, voice, video, data systems as well as in in the on the “Luna surface” operated hardware. For example a door inside FLEXHab not opening, etc. This still needs some analysis on how to implement.
- *Collaboration Tools*, any experiment team on-site LUNA will be supported by their home base. A certain amount of collaboration tools, like phones, video conferencing, desktop sharing etc. will be necessary. These tools will be provided from the existing infrastructure at EAC, and GSOC/MUSC.

4.3 Remote control

There will be no system control room within the LUNA facility. All systems, which need to be controlled, are required to be remotely controlled from either GSOC Ground Operations Control Room (GOCR) or from a control room at EAC. Future deep space and lunar surface missions will be operated by a collective of mission control centers around the earth (or gateway). Therefore the LUNA system as well shall provide this kind of flexibility and independently of the acting control room.

Fig. 4.1. Ground Operations Control Room (GOCR) at Col-CC, Oberpfaffenhofen

At least at a later stage we foresee common interfaces and have the idea to control the systems with one system, e.g. the European Ground System Common Core (EGS-CC) see section 6.

For the Columbus Ground Segment Col-CC has implemented a hierarchical monitoring and control system called the Integrated Monitoring and Control System (IMS). Each subsystem can be managed via an element manager, which controls its assets via mostly proprietary interfaces but provides a common interface to a central IMS system in the other direction. A similar approach for the LUNA systems might be implemented.

The operating consoles for Columbus at EAC, Col-CC, and MUSC have already a quite common design and layout. In the near future it is planned to increase their communality. With the virtualization of most of the core systems at Col-CC we are now in the position to increase remote client set-up/usage at EAC and MUSC.

5. LUNA Network

Apart from the local services provided within the LUNA and FLEXHab facilities to experimenters it is essential to provide users with remote access.

5.1 The IGS Network

The simplest implementation of a remote access would be of course an access point to the internet. Whereby simple is in this context a very weak word and intentionally the terminology ‘access point’ is used. It is not enough to simply provide a user access to the internet to reach a network at their home base. The access must be secured in both ways, the LUNA network itself must be secured from the outer world and a clear demarcation between user systems and LUNA systems must be done. In parallel the user must be able to access LUNA systems and LUNA provided services. Consequently the access point must be more a gateway to connect to the home base as well as to provide services as well as remote access to/from a home base to the LUNA mission.

Fig. 5.1. The IGS network

For Columbus operations the Interconnection Ground Subnetwork (IGS) is built up and operated by Col-CC. The terminology is historic (and nobody knows who invented that term) but the IGS is a terrestrial based Wide Area Network (WAN). It is a private network running over a public WAN which is provided by a commercial service provider. The network technology is kept up to date and at the moment based on state-of-the art MPLS (Multiprotocol Label Switching) technology. The network itself is secure and essential parts/routes are high available and redundant. All user sites have gateway (IGS nodes) which secure the access to the network. Both the network and the gateways are operated by the Col-CC GCT.

The IGS network does not only provide connectivity among the sites, it primarily provides access to the voice, video and data services/systems of Col-CC. E.g. each site is provided with voice terminals (keysets) connected via the gateway directly to the Col-CC system, high quality video is either streamed ore routed to dedicated video encoders at the gateway(s), M&C systems at the sites and securely connect to the main data routing system at GSOC/Col-cc and so on. The IGS provides also a gateway at Col-CC to the open internet to connect smaller / temporary sites via secure virtual private network (VPN) tunnels.

In summary the IGS network already provides all the services envisaged for LUNA usage in earlier sections of this paper. It is – again - mainly a matter of extending the capabilities, at least mostly.

5.2 Remote Access to LUNA

IGS already connects EAC, MUSC, and GSOC/Col-CC therefore it is clear that this network is used for LUNA system operations. And it was already laid out above what level of flexibility this will bring us and how many synergies we potentially will have.

If we look at the usage and user's perspective of LUNA, a remote access capability is mandatory as well. There might be a lot of use cases where space crafts/ rovers/ assets will be tested in situ and requiring the development team to be on site LUNA. But the majority of simulation scenarios will not – or should not – require the operators being on site. Later missions to moon and beyond will have their operator teams also not co-located but remote either in a station or at a control center on earth. Therefore the general paradigm of LUNA simulations should be:

It should not matter where the control entity for any LUNA simulations is located.

An easy access to LUNA and its services is a must. The IGS network already provides connectivity to at least the main ESA and DLR facilities / sites involved in exploration activities:

- GSOC/Col-CC, DLR Oberpfaffenhofen, Germany
- EAC, ESA Cologne, Germany
- MUSC, DLR Cologne, Germany
- ESOC, ESA Darmstadt, Germany
- ESTEC, ESA Noordwijk, Netherlands
- Cadmos, CNES Toulouse, France

From the LUNA perspective/team it is considered that the gateways at these facilities could be used as hub for each entire site. This means for example that the Col-CC IGS node can be used as central hub for experimenters of all other DLR institutes located at the DLR campus Oberpfaffenhofen.

For those users without access to an IGS gateway, the internet hub at GSOC is used. Depending on the usage profile we might establish additional access points like EAC's access to the ESA network or another access to the internet through EAC.

5.3 Communication Constraints

As said the remote access concept is not a matter of user comfort – to enable a user to stay at his home base while running the simulation. It is part of a realistic operational scenario. But the later operations on moon/gateway/mars/etc. will not use a high available high performant terrestrial network like the IGS. It will utilize a space-to ground or a space to space or a combination of both network types. The communication will have to cope with essential transmission constraints like:

- Link availability
- Contac times and coverage of relay stations (satellites), ground stations/antennas…
- Handover times
- Bandwidth restrictions
- Unreliability and Outages
- Quality of service (Jitter, Packet loss, …)
- Distortions (space weather, earth weather, …)
- Delays (transmission time moon-earth, etc. and/or delays due to data reconstruction on ground)
- …

The IGS as well as the Col-CC systems are optimized to avoid any distortion, any degradation in quality of service or outage times. Interesting enough that even in any regular self-standing or multi party simulation communication or ground system issues are not welcomed or better/worse shall be avoided by all means. The simulations concentrate on on-board issues and execution of on board operations. This is due to the ISS flying in a low earth orbit with high redundant, powerful multiple ways to communicate with ground. Consequently communication loss/problems are part of emergency trainings but never a part of simulation scenarios.

Therefore capabilities to simulate communication constraints need to be implemented especially on network level.

Delayed communication though was already part of some experiments on ISS and becomes more and more a requirement of robotic experiments including the ISS/the astronauts. GSOC is involved in various developments and experiments in the field of delay tolerant network protocols (DTN). Already now, before LUNA, it is planned to implement within the IGS network a central DTN node/capability at Col-CC to support further experiments on the ISS. This will complement other on-going DTN activities at GSOC.

As a side remark/anecdote: a part from some (not many) robotic experiments requiring delays, the day-to-day field of delaying communications is public relations for ISS. In order to provide lip synchronization in interviews with flying astronauts, voice communication has to be delayed due to the different transmission times of voice and video, For this Col-CC has already (and since quite some time) assets.

While realistic communications constraints for space to ground link is essential for conceptual work an un-delayed and less constraint interconnection between work sites will help establishing and maintaining initial sets of ground services. Consequently the network must provide both in parallel: an operational link with realistic communication constrains simulate and another off-line link for system/back office work. In some aspects this is not as simple as for some services delayed and not delayed services must be provided by the one system. For example for voice communications it might be required to provide the operational loops delayed. This potentially with different delays between different entities required (within a rove-gateway-control center scenario). At the same time some back office loops without any delays need to be set-up between the same facilities. Additionally out of scenario operations might be required for safety compliance aspects.

5.4 Network of Centers

Realistically any future exploration activity will be a multinational effort. Like the International Space Station a future Gateway, moon station, exploration activity will include a variety of control centers for operations, payload operations, and engineering. This may include different operations centers for the different components like operating an orbital entity, a station on a surface, transfer between both, transfer between earth and station(s), robotic (surface and station), communication segments, etc..

Consequently a requirement for LUNA will be the ability to support joint multi center simulations including different centers.

Technically the IGS network already provides a significant amount of such scenarios in connecting main European facilities see section 5.1.

Operationally the LUNA consortium/team itmself can provide a variety of contributing services:

- The flight team of the Col-CC can contribute with expertise on operational processes and procedures and finally can provide a station operations team.
- The EAC will handle the astronautically training and support including medical operations.
- :envihab can support with medical and physiological expertise.
- MUSC can provide an entity for payload operations.

For more details refer to [3]. The network as well as the systems must provide the flexibility to realize the different set-ups and combination of centers.

5.5 Network of Simulation Facilities

In addition to the capability to form a network of (operational) centers as described above, the LUNA team has the idea to support a network of (simulating) facilities. Within the LUNA team we will provide and combine different simulation facilities like LUNA, FLEXHab, :envihab, the trainings facilities of EAC, and operational facilities at GSOC and MUSC. Furthermore we have the idea to include, or better provide means to connect other analog facilities to enable a much broader field for multi-segment simulation and development facilities. GSOC/Col-CC works already some projects with other entities like Mamba (a German simulation facility for a surface station) or EDEN-ISS (DLR greenhouse in the Antarctica). For the network of facilities two aspects are of interest:

- Connect different simulating facilities to provide an overall mission scenario.
- Provide services to other simulating facilities (technical as well as operational).

The above mentioned projects for example are interested in both.

Furthermore for both aspects network of centers and facilities the LUNA ground segment will benefit of the IGS and Col-CC systems being already connected to and interacting with the NASA systems for human spaceflight.

6. EGS-CC and Data System(s)

In section 4.3 above it is discussed that it is planned to have a common Monitoring and Control System for the LUNA and FLEXHab systems. This might come at a later stage but it is planned. Also for our own interest as control center we envisage here the use of ESA's new M&C system European Ground System Common Core (EGS-CC). There are other papers and documentation at the IAC or other congresses (like SpaceOps) about the EGS-CC and consequently this paper will not elaborate further than to mention that the EGS.CC is a new and modern M&C system, which is currently under development. Major players in the development are now ESOC and GSOC. Consequently it is more than reasonable to use this system for LUNA. Furthermore for obsolescence reasons it is planned by ESA, DLR, and Airbus to exchange the existing M&C system for the Columbus module with EGS-CC.

The LUNA and FLEXHab facilities will not only act as a user of EGS-CC but also (and maybe more important at the beginning) as a test bed for test and verification of the EGS-CC development and adaptation activities for Columbus.

Data system and/or Monitoring and Control systems for the (LUNA) user assets is a much more complex story. It is assumed that a majority of assets will come with proprietary M&C systems and the network will support this. But in parallel a valid assumption can be that the EGS-CC might/can act as a new at least European wide standard/usage. If this comes true, it will be reasonable that for the sake of interoperability exploration assets might use this system as well. Nevertheless the ground segment will be prepared to provide EGS-CC system(s) as a service to users if it is requested. At least for FLEXHab as a station test facility we will put a special emphasis on using EGS-CC.

7. Conclusion

Although the LUNA and FLEXHab facilities are still in the planning phase it is the time now to start with the design of the ground segment.

This paper tried to summarize the important assumptions as well as paradigms for a future ground segment for simulation of exploration activities. Some of these assumptions might become not true and some of the paradigms might change and new might come. Therefore it is imperative to plan for a staggered and phased implementation flexible enough to cope with future extensions as well as changes.

In order to have a realistic, fast, and affordable ground segment implementation it is more than reasonable for ESA and DLR to make re-use of systems as well as of teams already existing for human space flight/Columbus. The paper clearly shows that the capabilities of the Col-CC ground systems provide a solid basis for the requirements envisaged for a LUNA/FLEXHab ground segment. Especially the international and interoperable character of these systems and of the IGS forms a profound basis of future usage scenarios. Furthermore both projects can profit from each other, LUNA/FLEXHab from existing systems and services, Columbus GS from modernization and synergies to make the Columbus GS ready for Columbus 2030+.

All in all the design of this ground segment is a very exciting project and forms (hopefully) the/a baseline for future European exploration activities.

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