Towards a Modular and Flexible New Ground System

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At GSOC, we start developing a concept for a modular and flexible ground system. Applying a service oriented architecture and using standardized interfaces, such a system will help to support upcoming missions of all kinds, especially in the context of the increasing amount of small satellites. Such a system will offer complete new ways to organize space operations in form of distributed operations. Also dedicated setups for special mission phases will become much easier as the system is designed to be dynamically deployed or changed. Providing the opportunity to access the system not only from within the control center allows using the experts wherever they are located and reduces the need to double such resources.

I. Introduction

Spaceflight is changing, and with it spacecraft operations does. The number of launched spacecrafts is significantly increasing; space-crafts are getting smaller and cheaper. While we were used to have one large satellite for a special purpose, nowadays there are formations and fleets of similar or equal satellites. Small groups of students at universities build experimental cube-sats and find rather economical possibilities to launch them. Start-Up companies use satellites on a trial-and-error basis with short lifetimes. Dysfunctional objects deorbit and they are replaced rapidly by the next generation.

All these developments have a strong impact to the ground system used for such missions. With the more easy and low-priced possibilities to bring an instrument into orbit, the ground system to control such an instrument is demanded to be inexpensive as well. Furthermore, the rapid developments and shortened production- and launch-cycles require much more flexible ways to set up and configure the ground segments. In addition, with satellites being operated by smaller teams, groups or companies, it is essential for them to have direct access to their space-segment out of these groups – that is they will not establish an additional dedicated ground operations team. Consequently operations will no longer be necessarily confined to one single dedicated control-centers such as ours at Oberpfaffenhofen.

However, even if all those boundary conditions do change, the tasks to be fulfilled to successfully operate a space mission stay the same. Orbit and attitude still need to be controlled. Activities on board still need to be planned and initiated. Ground stations still need to be connected to the mission control instance, contacts still need to be scheduled, and space-links still need to be established. Telemetry data still needs to be received and analyzed. And last not least, payload data still need to be received, processed and delivered.

At the Germans Space Operation Center (GSOC) we are convinced to have the proper tools to carry out all such tasks. Developed throughout a heritage of 50 years from its founding and with more than 70 missions – from all areas of space-flight – operated at GSOC, we have a rich portfolio of expertize, experience and tools. Now it is up to us, to make this treasure available to customers in an environment rapidly changing as outlined above.

II. Determining the Goals

Being aware of the ongoing and upcoming changes described above, the future requirements were collected in two ways. First, the business-unit development group of our institution made a survey with GSOC customers, representing the various kinds of satellite operators. Second, the personnel in charge at GSOC to carry out satellite operations was asked to provide some kind of wish-list, how their daily work could be improved.

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A. Customer Survey

The customer survey was targeted to various kinds of satellite operators. The span reached from a large German satellite manufacturer to scientific institutions such as universities and DLR internal and external institutes. The main focus was to find out, how the collaboration between satellite operators and control centers like GSOC could be improved.

Beside the general demand for cheap and quick solutions, especially in the context of small satellites like cube-sats, three aspects were found to be welcomed by our partners:

1. A more flexible way to access the satellite by the owner, especially the satellite's payload.
2. A better separation between payload- and bus-operations, allowing to control the payload without the need to also take care on the daily routine bus operations.
3. A possibility to have a rudimentary ground system ready right away to start testing.

Technically, these demands require a more flexible way to setup the ground segment. In the best case, the ground segment shall not be build up starting from scratch based on the final and rather detailed mission description, but it already exists in some basic default configuration, can be deployed as such and later on tailored to fit the mission specifics. That includes that those mission specific configurations can be applied and altered by the users.

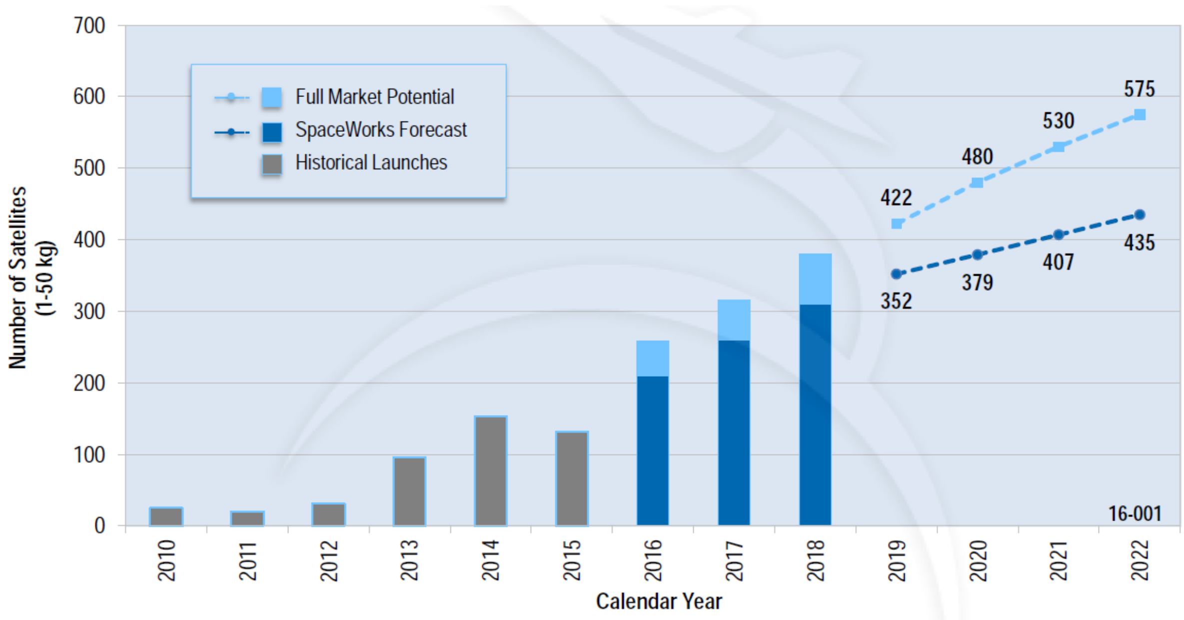

Fig. 1 Forecast of satellite launches in the class of 1-50 kg [1].

B. Internal Inputs from GSOC

In parallel to the customer survey, it was discussed internally at GSOC, in which way the current setup of infrastructure, customer relation and so on should be altered to improve for routine operations. The result could be summarized to two requests:

1. More flexibility in the access of the systems in terms of network restrictions as well as physical location (control-room, office or even remote).
2. Improved synergies due to the common use of shared resources and data, especially a common way to access data in the same format.

Although coming from a completely different perspective, the technical way to meet these requests is similar to the result from the customer survey. In fact, the more flexible access to the systems as wished by the customers was not prevented by the structural design of the systems but just impossible due to the setup of the network.

C. Key-features of a future ground segment

From the requirements worked out above, the principal features of a future ground segment can be deduced.

First of all, it has to be modular to provide the requested flexibility. In order to allow exchanging particular building blocks, the interfaces between the modules have to be standardized. Furthermore the architecture of the system has to be service oriented. That way the customer can select the functionality needed and configure and put together the required services to tailor the whole system according to her needs. The systems providing the services have to be easily deployable for each customer.

From a network point of view, it has to be possible to get access to all the systems running for a given mission from outside GSOC that is through the internet. Thus, instead of an onion-style layering to protect the operational core from the outside, the network has to be structured into separated areas for each costumer or project. Such areas have to be set-up dynamically with minimum effort and the services can be easily deployed into them.

III. From Hosted to Holistic

As the first studies were led by our business-unit development group, the focus was put to the perspective of our customers. Following the most important request of those, the main aspect of the development of the new ground system was, to empower the satellite owner to communicate to their space-segment through a system located at GSOC, while physically being at their home institutions. This idea created the name of the project at that early stage: Hosted Control Center.

The combination with the inputs of GSOC personnel shifted the focus quite a bit. First of all, we came to the conclusion that the principles and technical novelties of HCC were very well suited to be used for missions entirely operated by GSOC as well. That made the name “hosted” unsuitable. Furthermore, from following discussions we learned that the phrase “hosted” was often understood in a way, that GSOC would only provide infrastructure to host a ground-segment may built out of sub-systems provided by our customers. But this was a direction we never had in mind. In fact, it is not our goal to provide an open cloud platform with a bit higher reliability of availability.

Bringing both aspects together, we realized that we had inadequately separated between operations and the systems in use. So we stepped back and took the whole picture in view again: The various necessary sub-systems with all their interactions, together with the operations crew working on those systems – be it centralized or distributed. That led us to the decision to rename our project: “Holistic Control Center”.

A. Envisioned Use-Cases

The Holistic Control Center is not developed to fulfill the dedicated needs of a special mission. Therefore we do not have a detailed requirements-document to work against. Instead, we have ideas how to perform space operations in a novel, innovative way. Then we analyzed the technical limitations we have right now, preventing us from realizing our ideas, and we identified new technical concepts to overcome this barrier. In the following we will present and discuss these ideas in terms of use-cases.

1. Using common data bases

Looking to the typical ground-segment of a contemporary mission, one finds the same data stored at several places. Most often the reason for the duplication of the data is a different context of the data access. This can be different in time (e.g. mission preparation versus routine operations), different in scope (e.g. fast access to the last data only versus long term analysis of the full dataset), or as well different users (e.g. purchaser versus contractor). On top of those reasons, sometimes data-bases just have to be doubled to provide the same data to different systems in different formats; and data duplication appears to be much more pragmatic and quicker than exchanging the data interface of one of the systems.

A prominent example is the mission database. It is developed at first by the satellite manufacturer and later on also used by the satellite operator to validate and execute the flight procedures. At the moment, it is quite common that the checkout system in use by the manufacturer requires the mission database in a different format then the flight operating system. Converting the database from one system to the other – including the verification, that both representations in fact are equal – is a substantial effort.

The reasonable alternative, usage of a single common database instance for both parties, requires two main aspects of HCC: standardized access to the data for all users, and the possibility to access the same database (wherever it is finally located) from the manufactures side as well as from the mission control center.

2. Experimental space-missions run by universities

As pointed out earlier, it is nowadays not unusual for a university to construct its own small satellite by students. An example is the project Flying Laptop by the University of Stuttgart [2], or the project UWE, an acronym for "University of Würzburg's Experimental Satellite," with a serial of so far 4 cube-sats [3]. Although it is usually the goal of such projects to study all aspects of space-flight and space operations, they are most often glad, to have a professional and mature ground system available as backup.

In that sense, GSOC did collaborate with the project Flying Laptop and provided support with the s-band antennas at GSOC's ground station at Weilheim. With the well-established SLE-standard for exchange of online telemetry- and telecommand-data, it was easy for both sides to set up the interfaces and include GSOC and Weilheim ground-station into the mission's ground-network. Beside ground stations, cooperation alike could be set up for other aspects of a mission. For example, orbit determination and flight dynamics could be used to cross-check on calculations performed at the universities.

Again, this use-case highlights several aspects of HCC: First of all the modularity of the system, precondition to build up a distributed system. Furthermore this use-case requires that an instance of HCC can be set up in a fast and easy way, providing basic functionality without an excessive overhead of installation and configuration. Otherwise it would be impossible to supply services to universities within their budgets.

3. Distributed Operations

A similar use-case to the above is to distribute different levels of operations to different partners. Given, there is a way to access and operate the systems running at GSOC from outside GSOC it becomes possible to perform satellite operations at GSOC and somewhere else, depending on the state of the mission. One case could be to use the multi-mission resources at GSOC – for example existing 24/7-shift operators – to monitor automated routine operation. In case of anomalies those shift operators would signal the experts and the satellite subsystem engineers to perform failure analysis based on all available data. The other way around is possible as well; permanent routine operations to be performed somewhere else using access to the systems run at GSOC and including DLR experts only in case of contingencies.

Which way is suitable depends strongly on the missions profile. But both variants bear the advantage that resources existing inside and outside GSOC can be combined and brought to action when needed.

4. Backup Control Center

A typical requirement present in the early phase of designing a mission is a backup control center in case the main control center is not available due to catastrophic events. However, this requirement usually is an expensive one, since it most often results in additional cost for a second infrastructure. Or instead, if existing infrastructure is foreseen for this task, the effort to implement the particular mission needs onto this infrastructure is most often quite expensive. Thus such a backup control center is quite often removed for budget needs.

The situation would change if one had an easy and inexpensive way to use existing ground infrastructure for at least basic mission support. HCC can support this: It shall be possible to use standard systems off the shelf with minimum effort for configuration and deployment.

5. Test-Campaigns

During the mission preparation phase, one needs to have test and training campaigns. So far, such tests are most often performed on the operational system to avoid the need to build up a dedicated test system in parallel. In turn, all the operational infrastructure is needed to perform those tests. For example, tests are run in the control rooms that have to be booked and paid for.

An alternative would be a way, to move – or even clone – a whole system with all its configurations from the operational segment to somewhere else for testing. For instance, for such a test campaign we could declare some meeting room to be the test control room, if we were able to switch all network plugs from the usual domain into this project's HCC network segment. In fact, this is in line with the concept of HCC to easily deploy a configured HCC instance into a dynamically created network segment.

In that way, not only the technical systems at GSOC are services that can be used by HCC customers, also the hardware infrastructure at GSOC – rooms, consoles and so on – can be seen as services provided by HCC.

B. Standardized Satellite Operations

Redefining a satellite mission ground segment in a service oriented, modular way requires a large amount of abstraction of the various tasks. This abstraction is not necessarily limited to ground operations. Also the tasks performed by the space segment can – to a given degree – abstracted. Obviously this is true for the satellite bus to a much larger extension than for the payload. But specifically these standard bus operations can be part of a standard installation of an HCC instance. That way, already right after the installation, the HCC instance would be a working ground system out of the box – with limited functionality, but in line with the requirements formulated by our customers during the survey.

IV. Work Packages and Affected Systems

As already indicated by the name "Holistic Control Center," the creation of a ground system in line with the principles outlined above will not only affect the technical implementations of the subsystems and the underlying network. As we have seen in the discussed use-cases, also the infrastructure at GSOC becomes a part of HCC. Therefore also formerly static concepts like access-control and security concepts need to be adapted to cope with the flexibility introduced by HCC. Reflecting this, we have a preliminary work package breakdown with topics and areas of work to be addressed.

1. Centralized Data Bus

In order to connect the various systems and service providers, we need a centralized data exchange. Such a bus-system also allows to control connections across network boundaries in terms of proxy-applications.

2. External Interface to the World Wide Web

Opening the control center for the access from outside requires a state of the art gateway to the WWW. On the other hand, GSOC is part of an established ground network with many other agencies and space business partners. Those connections rely on the fact, that there is a dedicated and separated OPS-LAN at both ends. For the plan opening up GSOC to access via the WWW, concepts have to be established how to bring this in line with the contractual guaranteed level of security.

3. Network

As pointed out already, the fixed network structure currently set up at GSOC is no longer suitable for the HCC project. We need to explore the possibilities provided by technologies such as "Software Defined Network" (SDN) to dynamically create the necessary network segments for HCC customers, while keeping up the security standards required by space missions.

4. User-management

Opening up the systems run with HCC to configuration from customers outside requires a completely new way to do the user-management. On the other hand, there are still DLR employees working as system specialists for several HCC customers. Thus we have to find ways to give those people easy access to multiple HCC-projects, while particular projects are also allowed to manage their own users by themselves.

5. Adapting the Sub-Systems

All the existing sub-systems like flight operating system, mission planning, flight dynamics, ground stations and so on will need to adapt to the concept of HCC in several ways. First, the data interfaces have to be exchanged to connect to the centralized data bus. Second, the configuration and deployment of the systems have to be changed in a way to fit into the service oriented architecture of HCC. With those adaptions it will become possible to easily re-use the existing components internally for every new mission.

6. Documentation

A significant part of the workload for setting up the ground segment for a space mission is to provide the ground segment documentation. Evolving the ground segment into a service oriented architecture, it will be possible to create the documentation the same way the services are selected and put together.

7. Pricing and Accounting

With the possibility to distribute the ground system as well as operations between GSOC and external partners, especially when customers operate system run at GSOC from outside, we need to find new ways to charge customers for our work. The fixed prices we were used to work with so far have to be understood as prices for certain, well-defined packages; or they will have to be replaced by pricing models based on what has been actually done in a given period of time. That may include amounts of processed data, usage of IT resources and others.

8. Contract definition and controlling

Closely connected to the pricing and accounting are legal and contractual issues. But not only has the changed accounting being reflected in the contracts. Because of customers may perform satellite operations directly, we need new ways to regulate liabilities. Similar issues arise when systems at GSOC work with databases and services maintained outside GSOC; DLR has to be freed from liability in cases where external databases become corrupted or inaccessible.

9. Security concepts

Finally, as pointed out already, the concept of HCC can be extended from IT systems to the hardware infrastructure at GSOC. That will require having systems like access control as dynamically as the other parts of HCC.

At the moment we are far from having answers for all the questions arising from the above list. We started working out roadmaps and estimating timelines. For now, we have prioritized the first three work packages – centralized data bus, interface to the WWW, and network. Those three are the basis for all further developments within HCC, so we try to get those three tasks done first. But we have in mind already that if we succeed working out appropriate solutions for those, it just will be the beginning.

V. First Prototyping

As described in the previous section, we started with the prototyping for three technical work packages. And out of those three, the centralized data bus is the most important. Again, already at this early stage we need to have in mind that this bus will have to comply with rather complex requirements in terms of network, security and others, but our first step is to get something running as a prototype locally.

As HCC is not like a typical satellite mission, we have chosen not to do the project planning strictly based on ECSS but apply methods of agile project management instead. This reflects the fact that our goals for HCC are rather defined as user-stories and possibilities than as a set of hard and detailed requirements. The agile project management also allows us to quickly start prototyping with techniques we are not yet fully familiar with. Especially in the context of the web-technologies, we have to realize that the institutional space-business is in large parts kind of archaic compared to modern IT solutions, though some up-to-date islands exist. Nevertheless, we start to incorporate technologies developed for Google, Facebook and others into the framework of space-flight. Following the agile concept of “fast failure” we try out those technologies for our applications and figure out, what to use best.

A. Central Data-Bus

Another first for us is the close collaboration on deep technical level of all departments of our institute. With time, rather distinct fields of responsibilities have developed and those been distributed to the departments “mission operation”, “flight dynamics” and “communication and ground stations.” With the ansatz of HCC to re-design the complete ground segment as a service oriented architecture, the centralized data bus will be a complete new way to interconnect all the systems of the various departments. Reflecting this, the project team to create a prototype for this bus system consists of members of all of the named departments. Here again the principles of agile project management are helpful to bring this heterogeneous group together.

The technical details of this prototyping are presented in a separate paper by Stefan Gärtner [4].

B. Installation and Configuration

One of the main requirements of HCC to any system is, it has to be easily deployed to a new instance for another customer. In terms of installation we work with docker containers to do the deployment. This also opens up new ways to control the configuration of the system as each container defines an individual unit that can be referenced. For example, TCP/IP-connections between containers can be specified that way without configuring IP-addresses externally.

Concerning configuration, one can distinguish in general between two kinds of configurable parameters. One set reflects the mission specific settings defined by the customer, the other internal configurations to put things together within one HCC instance. The first set in general should be kept under the responsibility of the mission's owner. He is supposed to specify whatever is needed to describe its mission. Our goal is to find an automated way to translate this mission description into configurations for the services. That way, we will always have a congruent set of configurations for all services and mal-configurations are not under our responsibility.

For the other set of configurable parameters it is vice versa. Those are completely under our control for every mission and hence transparent for the customer. To give an example: Naming of machines, hosts or containers must not affect a customer in any way. He will get a specified access point for data-exchange, for adding, removing or reconfiguring services, but the internals of the installation of the services remain hidden. That is may be a change for customers and even for ourselves, but it will reveal the benefits of the service oriented architecture.

An intuitive illustration of this is depicted in Fig. 2.

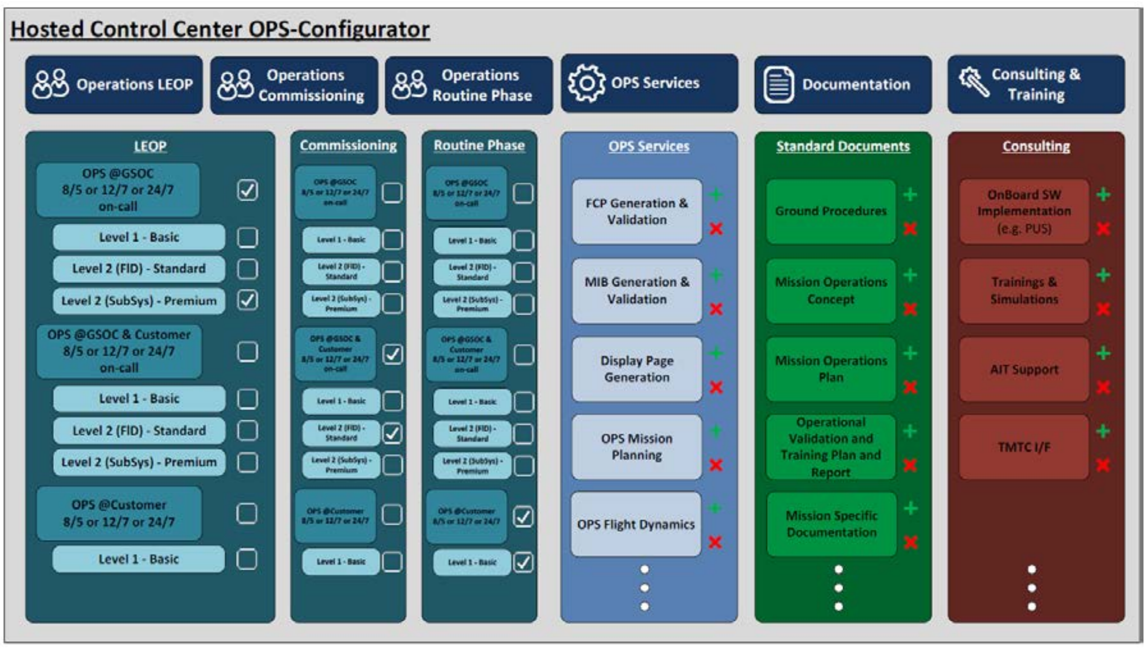

Fig. 2 Sketch for a customer frontend to select and configure HCC services.

VI. Using Standards

One of the paradigms of HCC is the use of standards. It is essential for the goal of modularity to provide interfaces that are well established and in use by external partners. For space-flight the standards in use are the recommendations by the Consultative Committee for Space Data Systems (CCSDS). In case customer require for some reason the use of their own proprietary data formats, we will use the standards as far as possible and just convert to the dedicated formats at the interfaces to the connected customers.

Unfortunately, just saying "we use CCSDS" is not a well-defined set of standards. Within CCSDS there are several areas and not all standards smoothly fit together. Our first approach to use a single protocol for data exchange on the centralized bus is the standard MO/MAL (mission operation, message abstraction layer) [5]. This standard foresees to be extended through the space-link on board of the satellite. As appealing it is, to unify ground-and space to one single system operated in a single, standardized way, this concept collides with other protocols already established. For example, there is another CCSDS group, Cross Support Services, that establishes a standard for service management in the context of ground station operations [6]. Of course the ideas and even most of the techniques to provide a standardized way to define, configure, invoke and monitor services are the same, yet the standards differ and are (at least at the moment) not compatible.

Those problems we find reproduced within our HCC working group, since of course people used to be responsible for ground station networks are used to CSS/SM while others, focused on satellite command systems, favor MO/MAL.

VII. Conclusion

At GSOC, we undertake an initiative to build up a new, modular, flexible and standardized ground segment for satellite operations. We have analyzed the needs industrial players as well as research organizations will have in future and found those demands well in line with improvements suggested by our personnel out of their long experience in mission support.

The key to build up such a system is a service oriented architecture that allows a satellite operator to put together her ground segment to her particular needs. This also allows to combine services offered by GSOC with services implemented somewhere else. A further benefit is the possibility to more flexibly distribute operations between traditional 24/7 shift crews at a control center and appropriate persons somewhere else.

We are aware that building up such a system will affect not only the technical implementations of mission operating systems and the underlying IT infrastructure: the full benefit of this concept will only reveal if it is consequently applied through all fields including all levels, from the pure hardware of a control center building up to the contractual and legal issues.

We have started to implement prototypes for the first steps: a common centralized bus system, new ways to dynamically organize our IT infrastructure, especially the network, and the possibility to access internally run systems from outside GSOC via internet. These first steps are promising and we continue our journey towards a modular and flexible new ground system.

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