The German Responsive Aperture Network Development (GRAND) – Accelerating Space starts on the ground

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Abstract

GSOC, the German Space Operations Center of the German Aerospace Agency (DLR), provides ground segments to all types of space missions, from human exploration to scientific observation, whether near Earth or in deep space. This process takes typically between months and a few years until the ground segment is fully ready for the mission.

Over the last years, the pressure grew to accelerate the deployment of ground segments, particularly for small satellites and in general for LEO missions. Newer missions also require more flexibility in terms of telecommunication technologies. Behind these requirements we find often "New Space" actors, who seek for rapid deployment of their products. As an example, some Cubesat manufacturers propose to purchase satellites on their website almost in the same way as if you were purchasing your new car or your new backpack.

DLR created the Responsive Space Cluster Competence Center (RSC³) to research how to accelerate space missions deployment. The two main objectives of RSC³ are to develop required responsive space technologies and to realize technology demonstration in this field. Work has already been done, for example, in the area of a remotely deployable compact control center (V3C – Verlegefähiges Compact Control Center). V3C is a fast, secure and decentralized control center for your satellite and provides a mean to operate your spacecraft in field conditions.

GRAND, the German Responsive Aperture Network Development, aims to answer to the new challenges from the perspective of the ground stations networks and will focus at first on small satellites missions in LEO orbits. This document presents the main questions of GRAND and the strategy adopted to lower the deployment of ground stations to days. Available technologies in telecommunications, secure communications and networks, activity scheduling will be evaluated as well as regulatory aspects and of course the typical requirements coming from such missions. In the end, GRAND will propose an autonomous, resilient, scalable, sustainable and durable solution for supporting Responsive Space and provide a faster way to activate your space assets.

Keywords:
DLR, Responsive Space, ground station, telecommunications, operations

1 GROUND STATIONS NETWORKS AND NEW SPACE ERA

1.1 Preparing the aperture network [1]

Preparing a network of apertures – or ground station network – for a satellite mission consists of several steps with many levels of complexity. Below is an overview of the typical steps taken:

1. **Mission Requirements Analysis:**

Here we are looking for mission requirements imposed at ground stations, for example frequency bands, data transmission rates, and communication protocols required for satellite operations.

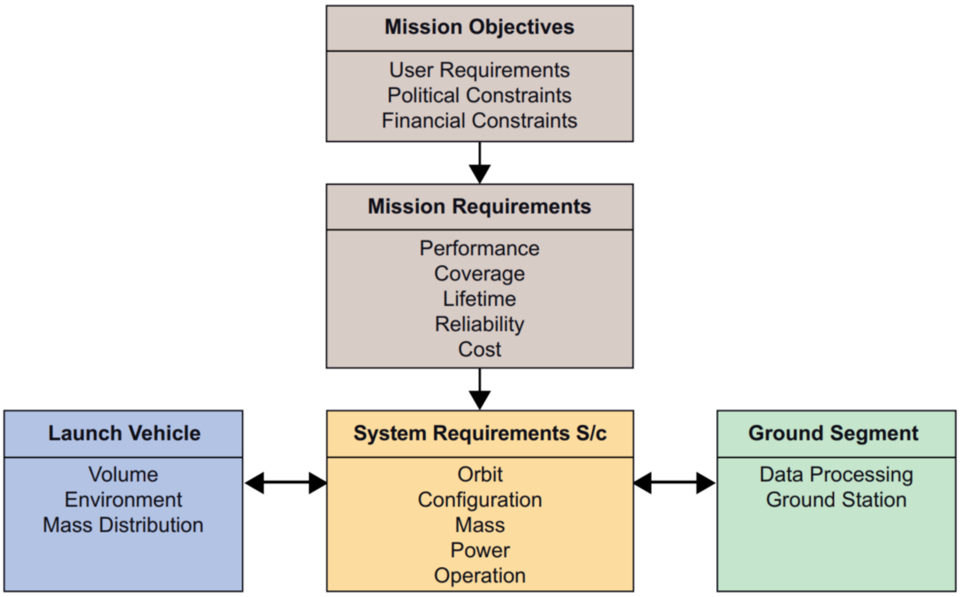

Fig. 1 Objectives and requirements of a space mission ([1] page 20)

2. **Site Selection:**

The locations for the ground stations must then be identified based on geographic accessibility, orbital constraints, and environmental conditions (e.g., low risk for RFI – radio interferences). Fig. 2 shows the DLR ground station network as an example for sites

3. **Infrastructure Development:**

A ground station requires various infrastructure in place before even considering to track satellites. Besides antenna systems, we consider here communication equipment, power supply, network connectivity.

4. **Regulatory Compliance:**

The ground stations require approvals and/or licenses to operate ground stations, for example ground station transmit licenses, ITU satellite frequency allocations, or approval from other missions already operating in the region in case of potential interference.

5. **Integration, test and validation:**

Each ground station is integrated within the ground station network. A series of tests validates compatibility, functionality, and reliability under different operating conditions.

6. **Data exchange:**

A connectivity needs to be established between ground stations and mission control centers in order to exchange safely telemetry and telecommands.

7. **Operations and Maintenance:**

For this task, we need among others protocols, tools for scheduling satellite passes and for monitoring and controlling the station, contingency procedures and schedules for preventive maintenance.

Fig. 2 Example of ground station network, the DLR "myGSN" (in orange the DLR RF ground stations, in red the upcoming DLR optical ground station, in yellow the DLR NOC [2])

1.2 Challenges with the New Space era

The emergence of New Space driven among others by increased private sector brings its own set of expectations. Let us focus on the main challenges for ground station networks:

1. **Rapid Deployment:**

New Space missions come often with tight schedules. This limited time affects the space segment as well as ground stations. In addition, experience showed that both Old Space or New Space spacecraft missions start considering ground stations late, which leads to an even higher time constraint.

2. **Cost Constraints:**

Budgets of New Space actors are also particularly limited, which in return fosters an efficient and sometimes innovative use of resources along with creative solutions.

3. **Flexibility and Scalability:**

New Space companies look for a flexible ground station network that can adapt to changing mission requirements and scale up or down as needed.

4. **Operational Efficiency:**

Should a New Space mission build ground stations, these stations are expected to be operated with the aim to maximize satellite mission performance and minimize downtime. Optimizing ground station operations require efficient concepts of operations and tools for scheduling satellite passes, data processing, system maintenance, and much more.

5. **Collaboration and Interoperability:**

While Old Space missions are often a collaboration between few partners, New Space missions are often collaborations with multiple partners, including government agencies, international organizations, and other private sector entities. It can then become complex to ensure interoperability and seamless communication between ground stations operated by different entities.

Beside the cost control aspect, these challenges described above can be summarized with the key expression: **responsive space**.

1.3 A responsive aperture network?

It becomes evident that many preparatory steps of the aperture network described in chapter 1.1 are contradicting with the challenges of the New Space era listed in chapter 1.2.
Cost constraints regularly push missions to rely on already existing multimission assets and to create either collaborations and/or business relations with ground services providers. The satellite ground stations considered are then already fixed geographically, which opposes to flexibility that New Space might require. Almost all ground services providers use different scheduling, monitoring and control protocols, thus requiring additional development of tools due to the lack of interoperability. And if the newer missions still consider creating new ground stations, the required infrastructure and administrative tasks will surely block a rapid deployment, unless you install your ground station at an existing site. But then again you are bound to a fixed location.
In addition to these issues, regulations and licensing processes for spacecrafts and ground stations are complex and slow and do not fit with rapid deployment nor with scalability.
And the rapid increase of new satellites in space illustrated in Fig. 3 combined with limited launch capabilities create a high demand for ground services which challenge the operational efficiency.

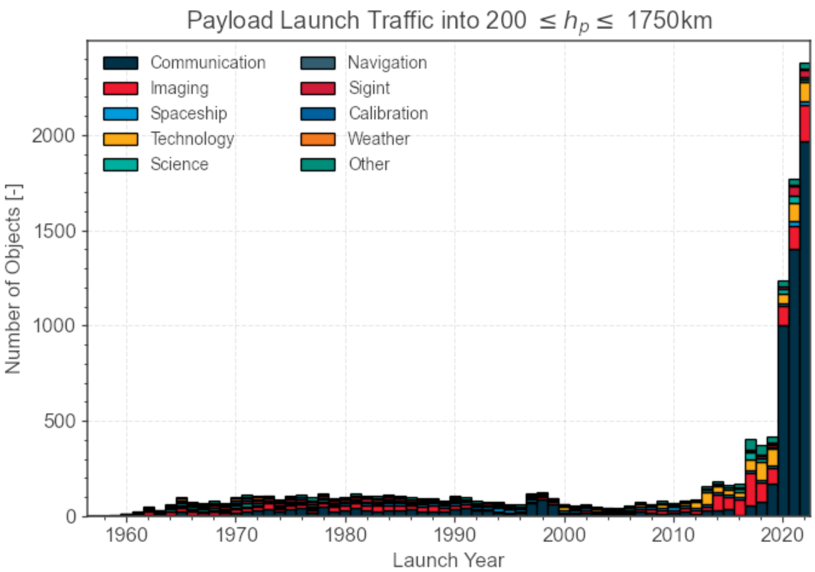

Fig. 3 Evolution of number of satellite launches into LEO per year [3]

In the end, designing responsive aperture networks for New Space missions appears to be highly complex.

GRAND, the German Responsive Aperture Network Development is a new project with this precise aim to study and improve responsiveness of the ground stations networks, driven by the challenges of New Space established before. We will detail in the next chapters what are the main questions of GRAND. We will then explain the strategy used in this project to answer to these questions. Afterwards we will present the expected results through the lifetime of this project.
We will keep in mind that GRAND will focus on:

- LEO (Low Earth Orbit) missions
- Supporting cubesats and smallsats
- Reducing the activation time of the ground station network to few days

2 GRAND START

In the following we will enumerate the main objectives of GRAND and develop the current strategies we plan to adopt for the responsive aperture network.

2.1 Concept for a responsive aperture network

GRAND is primarily intended to ensure that RSC³ (Responsive Space Cluster Competence Center) missions can be carried out. Like every other space mission, this requires a ground segment consisting of a Mission Operations Segment and a Payload Data Segment. Both segments require an aperture network to quickly support the satellites with TT&C (Telemetry, Tracking & Commanding) and payload data reception. Consequently, after analyzing previous research works and potential implementations (e.g. [4]), we will start with defining a concept for this ground station network. To create this concept, we plan to consider several aspects in project GRAND.

2.1.1 What kind of apertures does the mission need?

The above simple question is actually containing wide spectrum of aspects of antenna technology. Not only do we want to identify which type of carrier a mission might need (RF, optical, …). It is also vital to understand which locations are possible and if existing resources can be used or if new apertures need to be created.

Here we plan to do a review of representative smallsat missions in order to understand the common types of wavelengths used, the typical technical capabilities for telecommunication, and the typical orbits (within LEO).

Keeping in mind rapid deployment, flexibility and scalability established in chapter 1.2, we will perform a market analysis on existing apertures with a focus on rather smaller antennas and transportability. Examples of small apertures are shown in Fig. 4.

Fig. 4 Examples of apertures (Courtesy SeaTel, Atlas)

2.1.2 How do I quickly integrate apertures into my ground station network?

Imagining that we have answered to the first question and that we know the apertures needed including their location, the next step is of course to integrate these ground stations into the existing network. Rapid deployment and interoperability may play an important role for this question. Thus, we will evaluate existing standards and good practices related to the integration of ground stations and we will identify the most suitable ones for responsive aperture networks. As results, we will define clear interfaces between apertures and mission control centers. Of course, protocols such as SLE (Space Link Extension), DTN (Bundle Protocol) or USLP (Unified Space data Link Protocol) will be investigated for the purposes of GRAND.

2.1.3 How do I quickly activate apertures for my mission?

The apertures being now theoretically integrated, ground stations would now be activated for new missions. Activation processes shall be identified and described in order to support flexibility and operational efficiency. Concepts of operations are needed here and will be one of the main results for

GRAND. The licensing process of ground stations will also be investigated since this is currently one of the biggest time consumers (a licensing process lasts at least several months).

2.1.4 How do I quickly plan the aperture network?

With our activated aperture, a proper resource/pass planning is required which maximizes the operational efficiency, both for the mission and for the ground station network. We will evaluate here the upcoming scheduling standard defined by CCSDS [5] [6] and existing implementations.
An example of implementation has been developed at DLR under the acronym GSSNG – Ground Station Scheduling Next Generation [7] which will be compared to other planning solutions.

2.2 Development, Deployment and Demonstration – the 3D

The next step towards a responsive aperture network will be the development of the concept defined previously. The network and its components shall seek for:

- Autonomy – through research on autonomous ground station systems
- Resilience – through research into secure and redundant architectures
- Scalability – through research into scalable ground station systems, installation concepts (keyword: transportable) and standardized interfaces
- Sustainability – through research into reusable communication solutions
- Durability – through research into new communication technologies with potential for scalability

Once developed, a strategy is necessary to deploy and connect the apertures with the network. The following criteria are examined for this strategy:

- Location of the apertures
- Transportation
- Storage
- Licenses for ground stations and satellites
- Connection of apertures

The project foresees that an operational validation will take place. Specifically, 2 main demonstration points are required:

- The installation and activation of the ground station network
- The operation of a satellite under real conditions

For the second point, it means that a test mission will be operationally supported by this responsive aperture network (consisting of at least 2, ideally 3 representative ground stations). For this, at least one satellite will be required, most likely in the form of a cubesat.

Only with these 2 validated main points can the overall concept and, above all, its rapid response be proven. This is the prerequisite for being able to activate this concept correctly and under real conditions in the future.

2.3 Research & development of technologies

Part of GRAND will be to research telecommunication technologies and to investigate further responsive space initiatives. In the end we want to identify in an early phase which synergies can be reached and how these can advance GRAND and responsive space
Here are a few examples for synergies and new telecommunication technologies:

- V3C (Deployable Compact Control Center) [8]
- Phased arrays (especially for their scalability)
- Optical communication and automation (e.g. [9])
- REACTS (Responsive European Architecture for Space - [10])

3 EXPECTED RESULTS

At this time of the project, results are being defined and still not fully shaped. Here are some of the main results which we expect to produce during our progress within the project GRAND. Of course, this is a non-exhaustive list and the ones described below might still vary a bit.

3.1 Aperture analysis

One of the first main activities in GRAND will of course be the analysis of existing technologies, in our case of available apertures. While for a long period of time, the RF dishes were the most common satellite communication instruments, the last decade has seen the democratization of other technologies like phased array antennas or optical ground stations. The existing and future aperture types will be analyzed, as already mentioned in chapter 2.1.1, with a special focus on capabilities for a responsive network like transportability and will be compared to the list of expected typical mission profiles GRAND shall support.

3.2 Concepts of deployment and operations

The concept document will contain the key information to GRAND and provide the reader with an assembly and user guide. It will describe how to maintain the aperture network in a ready-to-activate state, which is the cornerstone for this project. It will then depict how to deploy and/or activate apertures, whether owned or contracted, on-site or remote (assembly guide). And it will detail how to operate the network for various satellite mission scenarios (user guide).
Of course, such conceptual document will need to be revised regularly due to new publications and progress ongoing in this field. Evolutions of technologies in telecommunication, new deployment variants, new apertures and aperture providers will also support revisions. And we shall not forget the progress made on concept of operations for optical ground station as this concept is currently being investigated by several actors of the optical communication branch.

3.3 List of recommended standards

In order to operate a ground station network, clear interfaces are a must and need to be agreed on between all actors of the network. Existing standards, recommendations and what we can call de facto standards, namely non-standard interfaces which are already being used by a large number of users, will be investigated for their suitability to responsive aperture networks. Interfaces to be considered are among others scheduling, monitoring data, and data exchange (real-time and offline), thus answering to the questions of chapters 2.1.2 and 2.1.4.

3.4 GRAND demonstrator

Probably the most important result of GRAND will be a representative aperture network. The extent of the actual deployment will depend on available funds. Ideally the network will consist of 3 or more apertures with different setups. The important setups should respond to the criteria established in chapter 2.2. Here are some of the considered setups:

- DLR aperture vs external (belonging to a service provider)
- Aperture in Germany vs outside Germany
- Transportable aperture vs fixed location
- Typical RF aperture (reflector antenna) vs new technology (e.g. laser communication or phased array)

A good example for a demonstrator would have the following setup:

1. DLR aperture, transportable phased array, deployed in Germany
2. Aperture from a typical satellite communication provider (e.g. KSAT, SSC, …), laser terminal, fixed location outside Germany
3. Aperture from a cloud services provider (e.g. AWS, …), typical RF dish, fixed location outside Germany.

In fact, any combination will remain interesting as long as it can validate our concept with a satellite mission.

4 CONCLUSION

Overall, preparing an aperture network for a new mission requires careful planning, coordination and technical expertise to ensure the successful operations and the mission's objectives. This complex task requires a certain amount of resources but New Space missions rarely have access to these. Here we described the German strategy to tackle the depicted challenge. We detailed the results which will be produced within GRAND, namely technology studies and concepts of deployment and operations. And we established the need for a validation of our network with a representative network consisting of a set of at least 3 apertures. In the end, GRAND will provide solutions and demonstrate how to increase the timeliness of ground station network deployment and activation. Results and solutions will be presented during the upcoming years. Furthermore, GRAND is paving the way towards a full-size network of responsive apertures. In addition, concepts of operations for optical ground stations are under investigation and will surely bring new perspectives on how to operate apertures in general, which will benefit particularly to responsive space.

5 ABBREVIATIONS

DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)
GSOC	German Space Operations Center
ITU	International Telecommunications Union
LEO	Low Earth Orbit
NOC	Network Operations Center
RF	Radio Frequency
RFI	Radio Frequency Interference
RSC³	Responsive Space Cluster Competence Center
SLE	Space Link Extension
TT&C	Telemetry Tracking & Command
USLP	Unified Space data Link Protocol
V3C	Transportable Compact Control Center (Verlegefähiges Compact Control Center)

6 ENTITIES INVOLVED IN GRAND

6.1 DLR

The German Aerospace Center (DLR) serves as Germany's main institution for research and development in aerospace, energy, transportation, and security. Founded in 1969, DLR plays a key role in advancing scientific knowledge and technological innovation in various fields. When it comes to space exploration, DLR stands at the forefront of international collaboration, undertaking missions to explore celestial bodies like Mars, conduct Earth observation, and develop satellite technologies. These endeavors not only expand our understanding of the universe but also contribute to applications such as environmental monitoring and disaster management. Concurrently, DLR dedicates substantial resources to addressing security challenges through research and development initiatives. This encompasses cybersecurity, critical infrastructure protection, disaster management, and defense technologies. By leveraging its multidisciplinary expertise, DLR develops innovative solutions to enhance security and resilience across different sectors.

6.2 RSC³

Within DLR, the Responsive Space Cluster Competence Center (RSC³) is a specialized initiative focused on advancing responsive space operations. This concept emphasizes the rapid deployment and adaptability of space assets to meet evolving needs and unforeseen challenges. The RSC³ fosters interdisciplinary collaboration, research, and development efforts to develop cutting-edge technologies and methodologies for responsive space missions. These include advancements in propulsion systems, autonomous navigation, on-orbit servicing, and mission planning. By promoting innovation and collaboration, the RSC³ aims to enhance the agility and flexibility of space missions, paving the way for more efficient and effective operations in space.

6.3 GSOC

Another crucial component of DLR's space operations is the German Space Operations Center (GSOC). Located in Oberpfaffenhofen near Munich, GSOC serves as the operational hub for managing and overseeing satellite missions. It provides support for a diverse range of missions, including Earth observation, communication, navigation, and scientific research. GSOC's responsibilities encompass mission planning, orbit determination, payload management, and real-time monitoring of spacecraft operations. Examples of satellite missions supported by GSOC include Copernicus' Earth observation missions, the Galileo navigation system, TerraSAR-X radar imaging, and communication satellites. Through its operational expertise and state-of-the-art facilities, GSOC ensures the success and reliability of satellite missions, contributing to scientific research, economic development, and societal well-being.

These examples underscore the crucial role that GSOC plays in managing satellite missions and enabling a wide range of applications, from environmental monitoring to navigation services and telecommunications. As technology continues to evolve, GSOC remains at the forefront of space operations, supporting missions that benefit humanity and advance our understanding of the cosmos.

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