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The different roles of the DLR German Space Operations Center in recent Laser Communication Projects

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Abstract

Laser communication is of growing importance for space programs and is utilized in several recent satellite missions, since it offers the advantages of high data rates over long distances. Since 2007, the German Space Operations Center (GSOC) of the German Aerospace Center (DLR) is involved in a number of projects in which laser communication plays a significant role, such as TerraSAR-X, TDP-1, EDRS-A and the upcoming EDRS-C. The role performed by GSOC is different for each of these missions, thus it covers a broad portfolio of operational experience in laser communication.

For TerraSAR-X, a low earth orbit (LEO) satellite, GSOC performs the satellite as well as all payload operations. TerraSAR-X is equipped with a Laser Communication Terminal (LCT) as secondary payload, which is capable of inter-satellite (ISL) as well as space-to-ground links (SGLs). The development of these LCTs is led by the Space Administration of DLR, funded by the Federal Ministry for Economic Affairs and Energy, and performed by TESAT Spacecom GmbH.

In contrast, EDRS-A is a hosted payload on a geostationary (GEO) satellite and the first step in the European Data Relay System, which will soon be supported by a second relay terminal, EDRS-C. The relay system offers LEO satellites more possibilities for high speed data downlinks via laser. It is a commercially used service with quite demanding requirements concerning the availability of this downlink. For EDRS-A, GSOC fulfills the role of the LCT payload control center. For EDRS-C, the task of GSOC is extended to dedicated satellite operations including the LCT payload. To address the demanding requirements, all processes on GSOC side are completely automated.

ESA´s TDP-1 (“Technology Demonstration Payload No.1”) project is the proof-of-concept for EDRS. It is a collaboration between DLR, ESA, and TESAT-Spacecom. The mission involves LCTs installed as secondary payloads on board a variety of LEO and GEO satellites as well as on ground, allowing for ISLs as well as for SGLs. Here, GSOC fulfills the role of the Mission Control Center, which includes collection of orbit and availability data, calculation of feasible link slots, scheduling of customer link requests, and generation of operational products for the LCT payloads of the involved spacecraft. One important aspect of this advanced concept is the connection to multiple control centers or associated facilities (like TECO, INMARSAT, ESOC), which is a necessary prerequisite for successful laser communication between different satellite projects.

This paper gives an overview of the operational concepts of GSOC within the four mentioned projects, with a focus on our involvement in the TDP-1 program.

Keywords: Laser Communication

Acronyms/Abbreviations

German Space Operations Center (GSOC), Laser Communication Terminal (LCT), inter-satellite link (ISL), space-to-ground link (SGL), Technology Demonstration Payload No.1 (TDP-1), European Data Relay Service (EDRS) low earth orbit (LEO) and geostationary (GEO) satellite, Technology Demonstration Payload – ESA Coordination Office (TECO), Devolved Payload Control Center (DPCC), Flight Operations Procedure (FOP).

1. Introduction

When the Mariner 4 space probe reached Mars in 1965, its observational data was transmitted via S-band with a rate of 8.3 bit/s or 33.3 bit/s – depending on weather the low-gain or the high-gain antenna was used [1]. While this was enough for Mariner´s pictures consisting of 200 x 200 pixels, the high-resolution cameras and sensors on board of today`s observation satellites produce by far larger amounts of data. The need of sending these data to earth puts a challenge to present satellite missions and will even increase further in the near future [2]. Although radio frequency systems are still the common transmission method, a lot of effort is put into the new technique of laser communication in space [3].

Compared to radio frequency, optical communication offers several advantages: It provides higher possible transfer rates, it needs less radiant energy even for long distances, and it has a smaller radiation cone and thus a smaller area of reception.

These advantages make laser communication the perfect transmission instrument for the idea of a data relay system, where several LEO satellites downlink

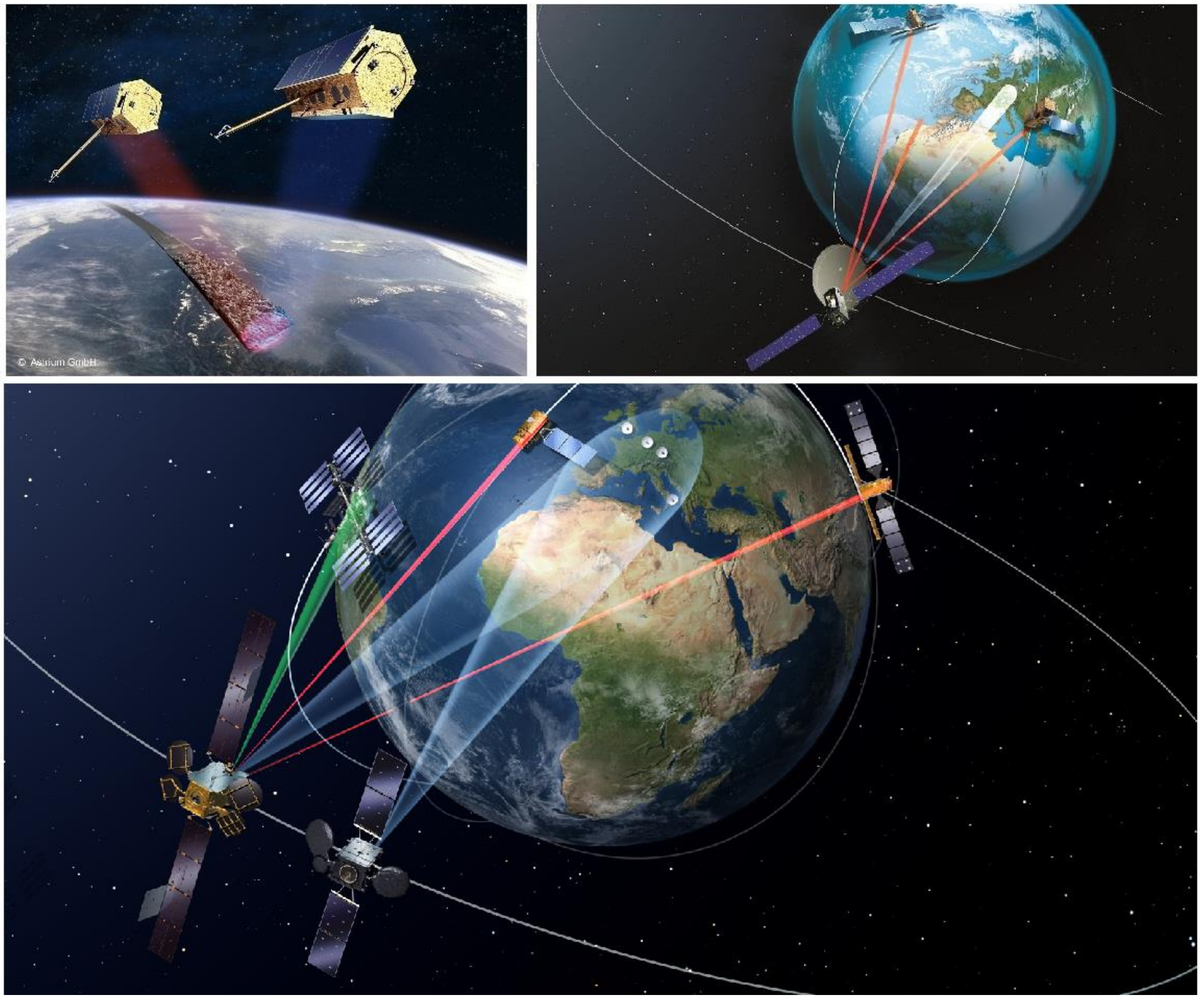

Figure 1: The four missions described in this paper: TerraSAR-X (top left, here with TanDEM-X), TDP-1 (top right), EDRS-A and –C (bottom, here with several LEO customers) (courtesy of Astrium, ESA, and DLR, respectively).

their data to earth via a detour over one or more GEO satellites. This concept increases the orbit coverage dramatically: Basically the half of the orbit is visible from a GEO satellite. Which leads again to two main benefits over the common direct RF link: Longer link duration and the possibility of near-real-time data access. For more information on this, we refer to [4], [5], [6].

Up to today, the German Space Operations Center (GSOC) is involved in several missions that include or even focus on laser communication technology. In each of these missions, GSOC performs different tasks with different operational concepts. This paper gives an overview of the broad spectrum of these challenges. Sorted by launch date, the four projects described in this paper are the LCT on the TerraSAR-X satellite (presented in chapter 2), TDP-1 on the geostationary AlphaSat I-XL (chapter 3), as well as the two relay LCTs of the EDRS project: EDRS-A on board Eutelsat 9B and the satellite EDRS-C to be launched in 2018 (both described in chapter 4). An illustration of all four missions is given in Figure 1. Eventually, we conclude in chapter 5.

2. LCT on TerraSAR-X

TerraSAR-X is a public-private partnership project. The LEO satellite was launched in 2007 and takes high resolution radar images, just as its twin satellite TanDEM-X. Together, they are able to create a digital elevation model of the earth. As a secondary payload, it hosts a Laser Communication Terminal (LCT) of TESAT Spacecom. TerraSAR-X would be a perfect example of a LEO satellite that produces and has to

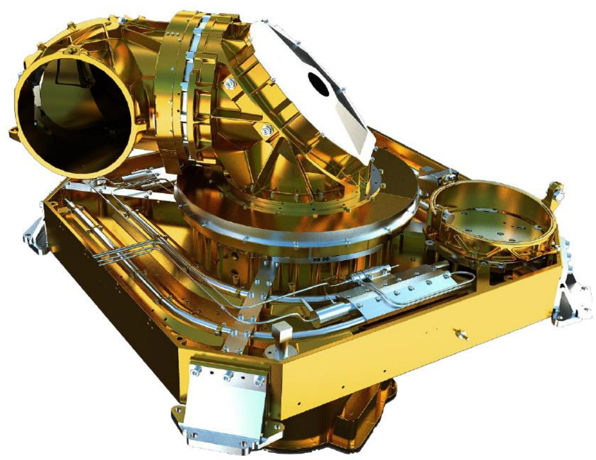

Figure 2: TESAT Laser Communication Terminal as it is used in the TDP-1 project (courtesy of TESAT SpaceCom).

transfer a huge amount of data to the ground. However, its LCT is used for experimental purposes only.

The LCT was used in two different ways:

First, Inter-Satellite-Links (ISLs) were executed together with another LCT on the NFIRE satellite, which was launched in the same year as TerraSAR-X. The first ISL was performed in 2008 over a distance of 8,000 km with a relative speed of 25,000 km/h. In total, more than 500 links were successfully executed until the de-orbiting of NFIRE in 2015.

Second, Space-to-Ground Links (SGLs) were performed towards an optical ground station on Tenerife, Spain. These kind of links face the challenge that their way leads them through the atmosphere, which they have to pass without information loss. During several SGL-campaigns, many tests could be successfully executed.

More information on the results of the LCT experiment on TerraSAR-X can be found in [8]. For more information on the background of the mission, we refer to [7], [11].

In this context, GSOC acts as the S/C Control Center, since it performs the satellite as well as the payload operations entirely. This includes the calculations on Flight Dynamics side, the Mission Planning, and the commanding of the S/C and Payload via a ground station network.

If a laser link on TerraSAR-X is requested, the workflow is as follows: The Flight Dynamics Team, which controls all orbit-related tasks of the satellite, calculates the time frames in which the TerraSAR-X LCT has a free line of sight towards the other satellite or the ground station, respectively. These time windows are also denoted as ‘visibilities’, and are the basic requirement for a possible link. The Flight Operations Team, supported by the Mission Planning staff, is then reviewing if the satellite is free for LCT operations during these time frames. It has to be verified that no on board tasks of the S/C are conflicting with the possible link. In case of a positive result, the Flight Operations Team is preparing and uplinking the respective flight procedures towards the S/C, and informs the other satellite or the ground station, respectively. After the laser link was executed, the results are sent to the scientific customer [7], [11].

Due to the relatively low amount of LCT links and the experimental orientation of the project, no automated planning system was implemented. This fits the requirements perfectly, since it grants a high amount of flexibility. However, for missions that focus on laser communication, like TDP-1 and EDRS-A (see the following chapters 3 and 4), this kind of operations would not be sufficient.

3. TDP-1

TDP-1 is both the name of a Laser Communication Terminal (LCT) payload on board the Alphasat-I-XL satellite as well as the name of the whole project that proves the concept of a geostationary data relay system using laser communication [4]. This project consists of several satellites and ground stations. At first, the center of attention is of course the geostationary Alphasat-I-XL, which launched in 2013 and is a public-private partnership between ESA and UK satellite operator Inmarsat. It receives data from the LEO satellites via optical communication and forwards it immediately to the ground station via Ka-Band. Second, there are the LEO satellites. Currently, four LEOs are participating in the TDP-1 project: Sentinel-1A and -1B, both scanning earth via a synthetic-aperture radar, as well as Sentinel-2A and -2B, which perform data takes in the visible, near infrared, and short wave infrared spectrum. All four satellites are operated by ESOC and are part of EU´s Copernicus Earth observation program. The LCTs on board the LEOs send the data produced by their cameras and sensors to Alphasat. Third, there is a dedicated Ka-Band-Antenna of the German Remote Sensing Data Center (Deutsches Fernerkundungs-Datenzentrum, DFD) in Oberpfaffenhofen, Germany, for the reception of the data. It receives the forwarded data from the geostationary Alphasat and distributes it to the respective users. Last but not least, there is additionally an optical ground station on Tenerife, Spain for experimental optical SGLs. In contrast to the SGLs of TerraSAR-X, we can here also perform links between a *geostationary* and a ground-based LCT. See [4], [5], [9], [10], [11] and references therein for more information about the concept and the background of the TDP-1 project.

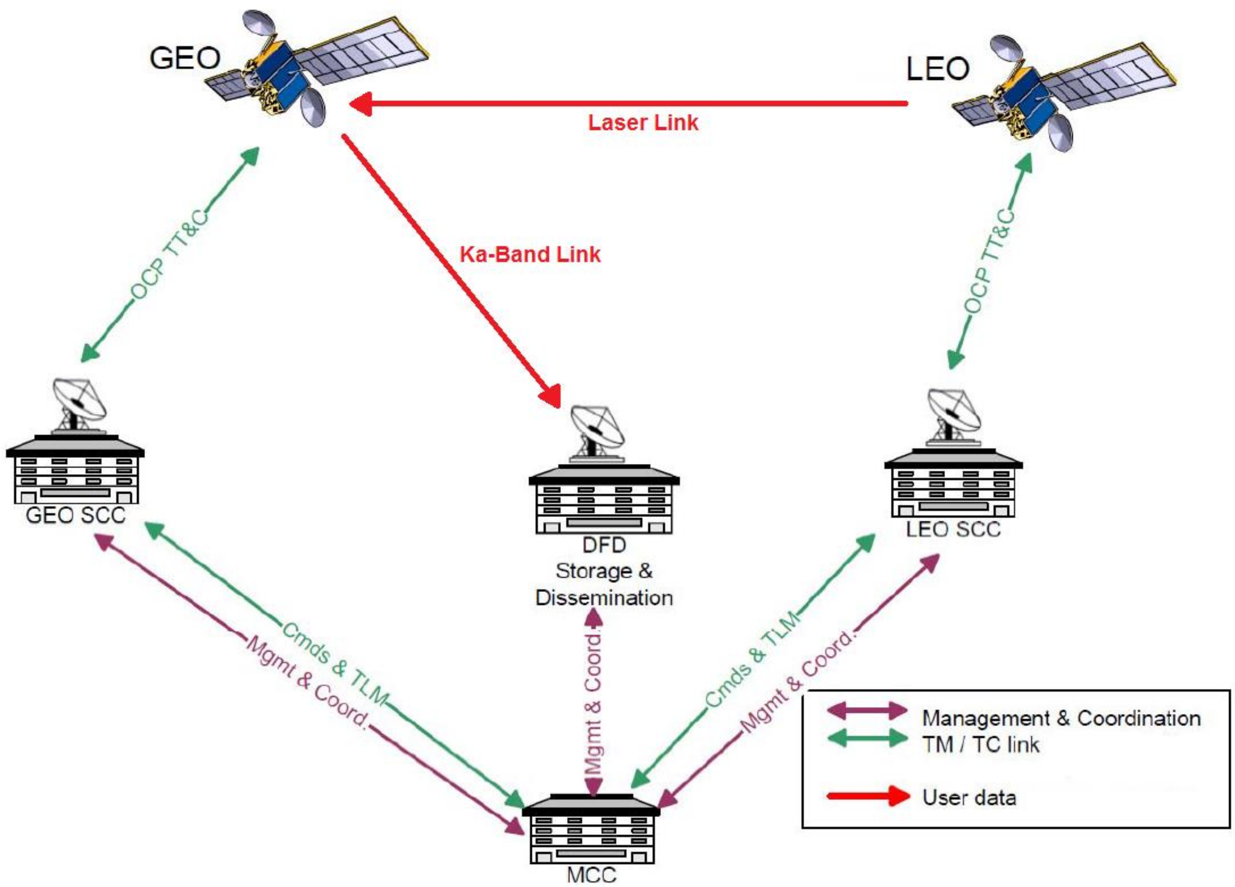

Figure 3: The concept of a relay satellite system with the Mission Control Center as the main coordination office at the bottom. Figure taken from [15] and slightly modified.

As in the previous chapter, all laser communication in the framework of TDP-1 is performed by LCTs manufactured by TESAT Spacecom; see Figure 2 for an illustration. For more background information on the technical aspects of the LCTs, we refer to [8] and [19]. More information about the amount and performance of the TDP-1 links is given in [3], [5], [9], [10], [12].

Behind the participating satellites and ground stations, a certain amount of control centers and coordination offices work together to accomplish a successful collaboration. First, of course, several Spacecraft Control Centers operate the GEO as well as the LEO satellites. Second, due to possibly conflicting payloads on board the Alphasat satellite, there is a specific coordination center called TECO (Technology Demonstration Payload – ESA Coordination Office), that manages the schedule of Alphasat´s payloads [14]. Finally, GSOC performs the important task of the Mission Control Center.

The Mission Control Center is responsible for the laser link planning itself. GSOC developed a dedicated operational concept for this task [4], [11], which is based on the experiences of the TerraSAR-X LCT program. The system is set up to perform these tasks automatically, running 24 h a day and 7 days a week.

The basic idea is similar to the concept described in chapter 2. There is one main difference to TerraSAR-X, though: A lot more LCTs are involved. With the amount of LCTs, the number of possible link combinations grows exponentially. Every step in the planning workflow was therefore found to be much more complex than for just two satellites like TerraSAR-X and NFIRE. This basic environment lead to the decision to implement a system, which performs all these steps automatically. It is designed to run on a weekly basis, that relies on a “planning week”, followed by an “execution week”. During the first week, the schedule for the second week is established. Each Friday, the results of this “planning week” are locked, and the “execution week” starts. In parallel, also a new “planning week” starts to cover the next interval. This weekly approach has the advantage of setting clear periodical due dates to all involved parties and their different product exchanges [4].

As for TerraSAR-X, the calculation of orbits and visibilities provides the time frames for possible laser links. These have to be cross-checked with conflicting activities on the S/C or the ground station ("no-operation times"). The collection of orbit as well as no-operation files from different parties often means different input formats and time frames – a challenge solved by an advanced Flight Dynamics system [13]. The result is a list of link opportunities, the so-called slotlist, which is provided to the customers. The customers can then request links lying inside these slots. The requests are processed and deconflicted by the Mission Planning system. The output is a link list that contains all links planned for the upcoming week. Some additional payload operations for the Alphasat-I-XL LCT are also planned via the GSOC planning system, which are added to the link list at this point. The combination is denoted Sequence of Events, the final output of the workflow. The general overview of the single software modules as well as all transfers and reports are taken care of by the Flight Operations system.

In addition to the basic task of link planning, the GSOC Mission Control Center also generates the commanding products for all participating Satellite Control Centers. For each party, all tasks that are part of the final Sequence of Events are filtered, listed, converted to the desired format, and send to the respective center or station.

Figure 3 illustrates the different interfaces of a Mission Control Center and the other parties in such a relay satellite concept.

4. EDRS-A and EDRS-C

While TDP-1 proved the feasibility of a geostationary relay concept with optical communication between the LEOs and the GEO, the European Data Relay Service (EDRS) is its commercial successor [6], [15], [19], [20]. It is a public-private partnership between ESA and Airbus Defence & Space as prime contractor. DLR is responsible for major parts of the ground network.

The system has already taken its first step with the launch of EDRS-A on Eutelsat 9B in January 2016. The next step will be EDRS-C – this time also the name of the satellite itself –, which is scheduled to launch in 2018 and is based on the very recent smallGEO platform developed by OHB. Both satellites will cover a hemisphere that includes Europe, with a position at 9° E and 31° E, respectively. A third geostationary satellite is under consideration to complement the system with a placement over Asia; this extension of the program is also conducted under the name "GlobeNet".

The first customers of EDRS are the four LEO satellites Sentinel-1A, -1B, -2A, and -2B, that are already participating in the TDP-1 program. The current ground network of EDRS consists of several stations distributed over Europe. For EDRS-A, the stations are located in Paris (France), Weilheim (Germany) and Harwell (United Kingdom).

As for TerraSAR-X and TDP-1, the LCTs installed on EDRS-A are manufactured by TESAT Spacecom. For EDRS, these LCTs allow optical ISLs with data rates up to 1,800 Mbit per second, which is an increase by a factor of 3.5 when compared to conventional X-band downlink rates [16].

GSOC performs two different tasks in this framework: For EDRS-A, it is assigned to fulfil the role of the Devolved Payload Control Center (DPCC). This implies all operations of the LCT as well as the RF payload on board the Eutelsat-9B. For EDRS-C, this role is extended to the operations of the whole satellite, meaning GSOC is here the Satellite Control Center. Figure 4 illustrates this mission concept.

TDP-1 as well as the payload part in EDRS have in common, that the operations on GSOC side – although they cover different tasks – run fully automated [16], [17], [18]. In contrast to TDP-1, the link planning of EDRS is lying outside of GSOC´s responsibility at the Mission Operations Center (MOC) in Ottobrunn, which was established by Airbus Defence and Space. In turn, the automatisation of the processes performed by the DPCC addresses regions with a higher criticality than the link planning on TDP-1 side: Here, the direct commanding itself is concerned, which even includes automated reactions on specific telemetry events – a task that cannot be underestimated. Furthermore, the performance requirements for the availability of the communication service have been set to be very ambitious, which lies in the commercial nature of the program compared to the scientific mandate of TDP-1. Overall, the automatisation of the DPCC is a significant and challenging part of GSOC tasks for EDRS-A and -C. In the following, we will describe the workflows in more detail.

For both EDRS-A and -C, the payload is controlled using an automated operations engine, which is designed to supervise the complete cycle of telecommand uplink and execution, as well as reaction monitoring of telemetry [16]. It is worth noticing, that the reaction time to requests is well below one hour, which is a task that can hardly be handled in a manual operations concept as the one for TerraSAR-X in chapter 2.

The duties of the engine can be grouped two main services: Providing the basic link service, i.e. processing and uploading the link requests from the MOC, as well as the management of payload configuration and

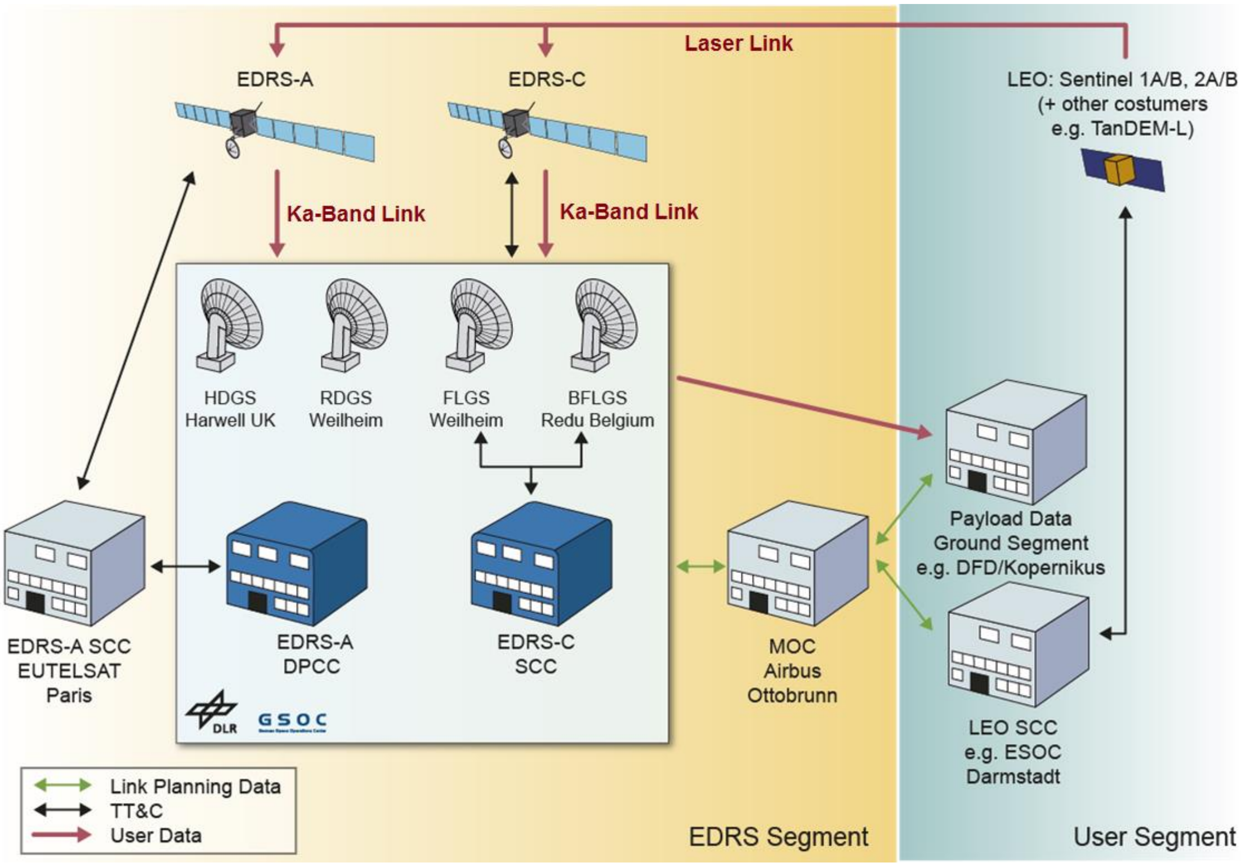

Figure 4: Overview of the EDRS mission concept. The blue box in the center illustrates the two different tasks of GSOC: Devolved Payload Control Center for EDRS-A as well as S/C *and* Payload Control Center for EDRS-C. Figure taken from [17] and slightly modified.

maintenance activities. The latter must of course be scheduled in coordination with the external requests.

To provide the services described above, the automation is focusing on five different tasks: First, the interface between the MOC and the DPCC, which processes and categorizes the different incoming requests, e.g. the differentiation between a high-level link or deletion request. Second is the Link Management System, that manages and schedules configuration and deletion requests [18]. Third focus are payload related maintenance tasks, that are to be planned without requests in a periodic manner, as e.g. time synchronization or the update of orbit parameters. The two previous points make use of the fact, that the Flight Operations Procedures (FOPs) for EDRS-A are deposited in the DPCC system. Both the results of the Link Management System as well as the maintenance tasks are converted into these procedures which are then sent to the S/C, which is the fourth automated task in this list. The fifth task is the reporting. For more information on the technical aspects of the automated engine, see [16], [17], [18].

For the upcoming EDRS-C, the operations at GSOC will extent to the whole satellite. For this reason, the DPCC ground segment was designed to be independent of the particular spacecraft platform. Neglecting minor modifications, it can be used for both satellites. Differences in the platform will be masked through the versatility of GSOC´s core monitoring and control system.

Mission	Tasks of GSOC	Remarks
LCT of TerraSAR-X	Satellite as well as Payload Control Center.	No automated link planning system due to the technological character of this first LCT mission.
TDP-1	Mission Control Center: Planning of the laser links between several different S/C and ground stations, including generation of commanding products for all participating satellites.	Automated link planning system.
EDRS-A	Devolved Payload Control Center of a hosted LCT payload on a GEO satellite.	Automated LCT operations, including short-term reactions to on-board events.
EDRS-C	Satellite as well as Payload Control Center.	Automated LCT operations, including short-term reactions to on-board events.

Table 1: Overview of the different tasks of GSOC in the presented projects.

5. Conclusion

Laser communication has high chances to become one of the key technologies in future satellite missions. Projects like ESA´s EDRS and GlobeNet demonstrate that LCTs are no longer just in development phase, but already the fundamental component of commercial missions. This development offers new possibilities, but in turn creates new requirements for the field of satellite operations. Advanced concepts like automated systems are necessary to overcome these challenges.

Up to today, GSOC is participating in several missions that contain or even focus on laser communication. The various roles that GSOC is assigned to are as different as the missions itself. Table 1 recapitulates and summarizes these tasks for the four projects that were discussed in this paper. During the involvement in the operations of the mentioned projects in the recent years, several new concepts like the automated Mission Control Center for TDP-1 or the automated payload operations for EDRS-A have successfully been established and implemented. It will be interesting to see what new concepts will be needed in the future in the field of optical communication.

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