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Laser Communication in Space: The TDP-1 Mission Control Center and its current operational experience

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TDP-1 is a quasi-operational technology demonstration payload, designed to prove the concept of data transfer between low-orbit observation satellites and earth via a geostationary relay satellite in between the communication chain. This detour allows to significantly increase transferable data volume at reduced latency time, and is performed with the help of Laser Communication Terminals (LCTs) on board the low-orbit as well as the geostationary satellite, from which the data is immediately downlinked via Ka-Band. In this framework, TDP-1 is the successful precursor mission for the forthcoming European Data Relay Satellite System (EDRS).

A dedicated operational concept has been developed by DLR GSOC as TDP1 Mission Control Center. The concept is based on heritage programs TerraSAR-X and NFIRE and includes all necessary tasks and steps like calculation of feasible link slots based on satellite orbit and availability data, scheduling of customer link requests, and generation of operational products for the involved spacecrafts to execute the links.

This paper gives an overview of the current Mission Control Center System Design of the TDP-1 program and its operational experiences.

Nomenclature

DFD = German Remote Sensing Data Center (Deutsches Fernerkundungs-Datenzentrum)
EDRS = European Data Relay Satellite System
GEO = Geostationary (satellite)
GSOC = German Space Operations Center
LEO = Low Earth Orbit (satellite)
LCT = Laser Communication Terminal
MCC = Mission Control Center
SCC = Spacecraft Control Center
TDP-1 = Technology Demonstration Payload No.1
TECO = Technology Demonstration Payload – ESA Coordination Office

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I. Introduction

TODAY`S earth observation satellite missions produce tons of interesting scientific, military and commercial data. However, these missions always face the challenge of how to send these amounts of information back to earth. The quantity and duration of ground station contacts and thus the downlink capacity is limited. In addition, for some missions it might be of utmost interest to obtain data in near realtime, i.e. the time between the on-board data generation and the on-ground data recording needs to be minimized – an issue that, until today, depends on the location of the data take and the location of the next ground station contact. Only if these two match in a fortunate way, the waiting time can be small. The urgency of these problems will even increase with further satellite missions[1]. A solution to both the problem of the data amount as well as the problem of data delay is given by the idea of a relay satellite system[2,3,4]. In turn, such a relay system is perfectly suited for the usage of laser communication[4,5]. This technology allows for high data rates over long distances while only needing low radiated power. Both parts – the concept of a data relay satellite as well as the usage of the laser technology – are combined in the TDP-1 program ("Technology Demonstration Payload No.1").

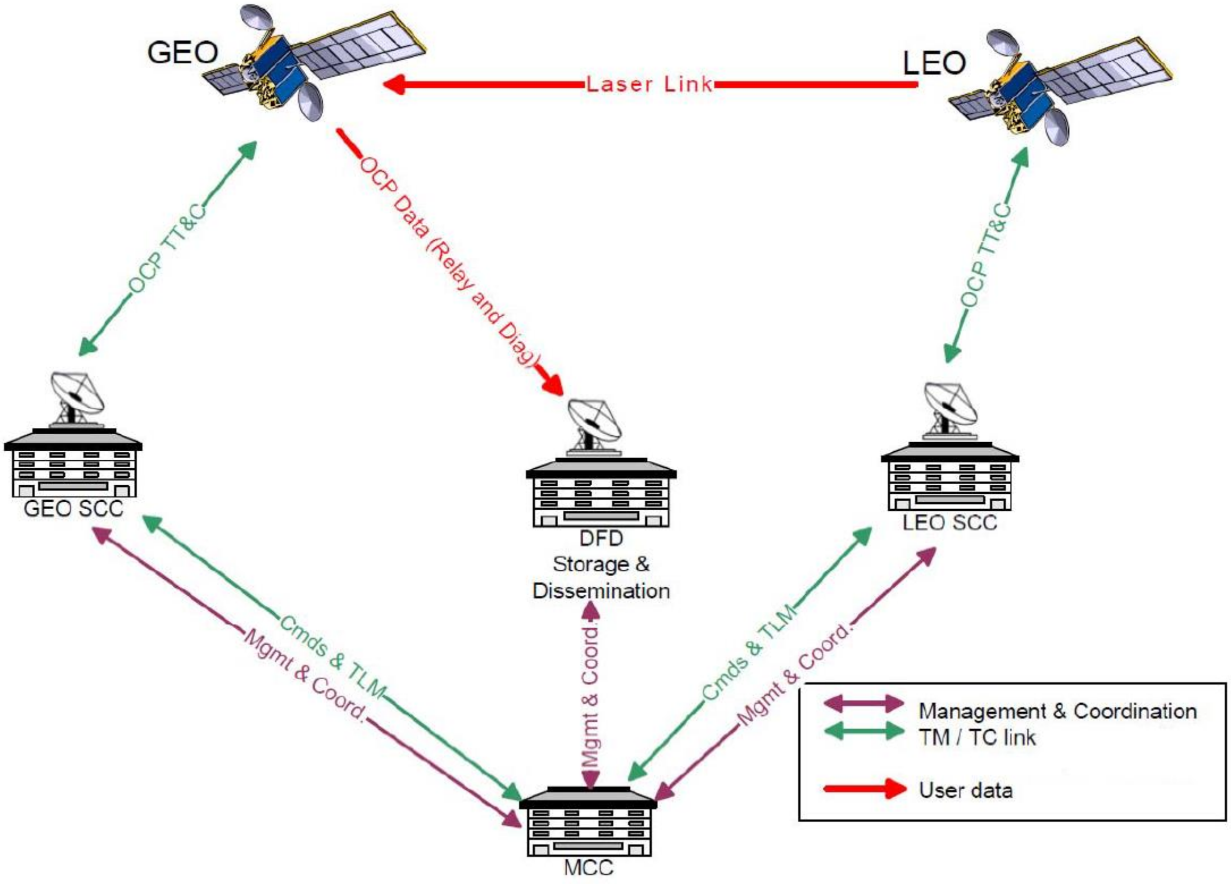

Figure 1. The concept of of a relay satellite system (Graphic taken from Ref. 2).

TDP-1 is both the name of a Laser Communication Terminal (LCT) payload on board the Alphasat-I-XL satellite, that had its launch on July 25, 2013, as well as the name of the whole project that proves the concept of a geostationary data relay system using laser communication. Therefore, it can be seen as the precursor mission of European Data Relay Satellite System (EDRS). While EDRS is a commercial mission, TDP1 is a quasi-operational payload with the scope to demonstrate and validate operational scenarios for commercial missions, as well as serving for scientific and experimental tasks.

This paper follows former publications[6,7] about GSOC ground system designs of laser communication missions with and without data relay systems, and gives an insight into the current situation of the TDP-1 ground system concept. We will briefly discuss the underlying idea of data relay systems as well as the used laser communication technology in section II. Section III will then give a short presentation of the involved parties of the TDP-1 project, thus also giving a good overview of the project itself. The main focus of this paper, the current concept, tasks, and the operational experiences of the TDP-1 Mission Control Center (MCC) will be presented in section IV. Eventually, we conclude in section V.

II. Background

A. Data Relay Systems

The idea behind a data relay system is somewhat comparable with a (very high) radio tower, providing a free line-of-sight and thus a possible radio signal connection for a quite huge area on ground – e.g. a whole city. In space, a similar task can be performed by a geostationary communication satellite (GEO): observation satellites (LEOs), usually orbiting earth in a low altitude, can route their data to the ground station network over one or more GEO relay satellites. Between the LEO and the GEO satellites a free line-of-sight persists for nearly the half of each orbit[4]. Between the relay satellite and the ground station, there is always a free line-of-sight, of course. Thus one is no longer bounded to the restricted coverage and short duration of a usual ground station contact.

However, from an operational point of view, the task of performing such a detour data transfer is more complex and thus more challenging[2,3]. Figure 1 illustrates the different management (purple), telemetry and commanding (green), and data flows (red) necessary for such a communication via relay satellite. A specific Mission Control Center (MCC) is needed to coordinate the different participating ground stations. In the framework of TDP-1, this MCC tasks are carried out by DLR GSOC and are described in more detail in section IV.

B. Laser Communication

The concept of a data relay system is in general not bound to a specific kind of communication method. However, laser communication technology is particularily applicable: It is capable of transferring information over long distances with high data rates, low radiated power, and a small area of signal reception. In addition, it is also tap-proof. Obviously, high precision is a key to high performance.

The laser communication in the framework of TDP-1 is performed by Laser Communication Terminals (LCTs) manufactured by TESAT Spacecom; see Fig. 2 for an illustration. These terminals use the Binary Phase Key Shifting (BPKS) to modulate the information which is supposed to be sent, into a transmittable pattern. To establish the optical link, both involved LCTs need to coarsely target each other. This is done by performing a spatial as well as a frequential acquisition. For the former, one of the two LCTs conducts a spiral search pattern until hits on the other LCT are detected. After these initial procedures, the data transmission can start. The LCTs used for TDP-1 are capable of transferring up to 1.8 Gbit per second[4,5].

A former generation of these LCTs was already part of the TerraSAR-X as well as NFIRE missions, and could collect valuable information about satellite-to-satellite links[8]. However, in contrast to TDP-1, these were LEO-LEO-links only, while in the current framework these links only take place between GEO and LEO satellites (here we talk about satellite-to-satellite links only – see the section below for experimental satellite-to-ground links). For TDP-1, LCTs are installed on board each of the three satellites participating the project – see section III for more details on satellites and stations.

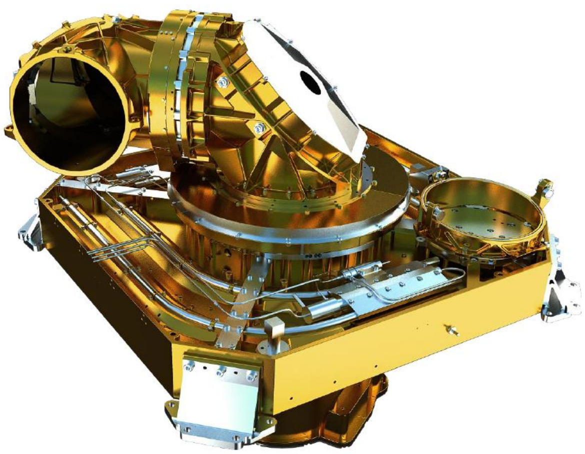

Figure 2. TESAT Spacecom Laser Communication Terminal (courtesy of TESAT Spacecom)

As already briefly mentioned above, LCTs can also be used for a direct space-to-ground communication. Here, the atmosphere puts additional challenges to the execution of the laser links. Space-to-ground communication was done e.g. during the TerraSAR-X as well as the NFIRE satellite missions[9], and is also performed in the framework of TDP-1 between the Alphasat satellite and an mobile optical ground station on Tenerife.

For a more detailed discussion of the technical aspects of the LCTs as well as its operational experiences, we refer to Refs. 5, 10.

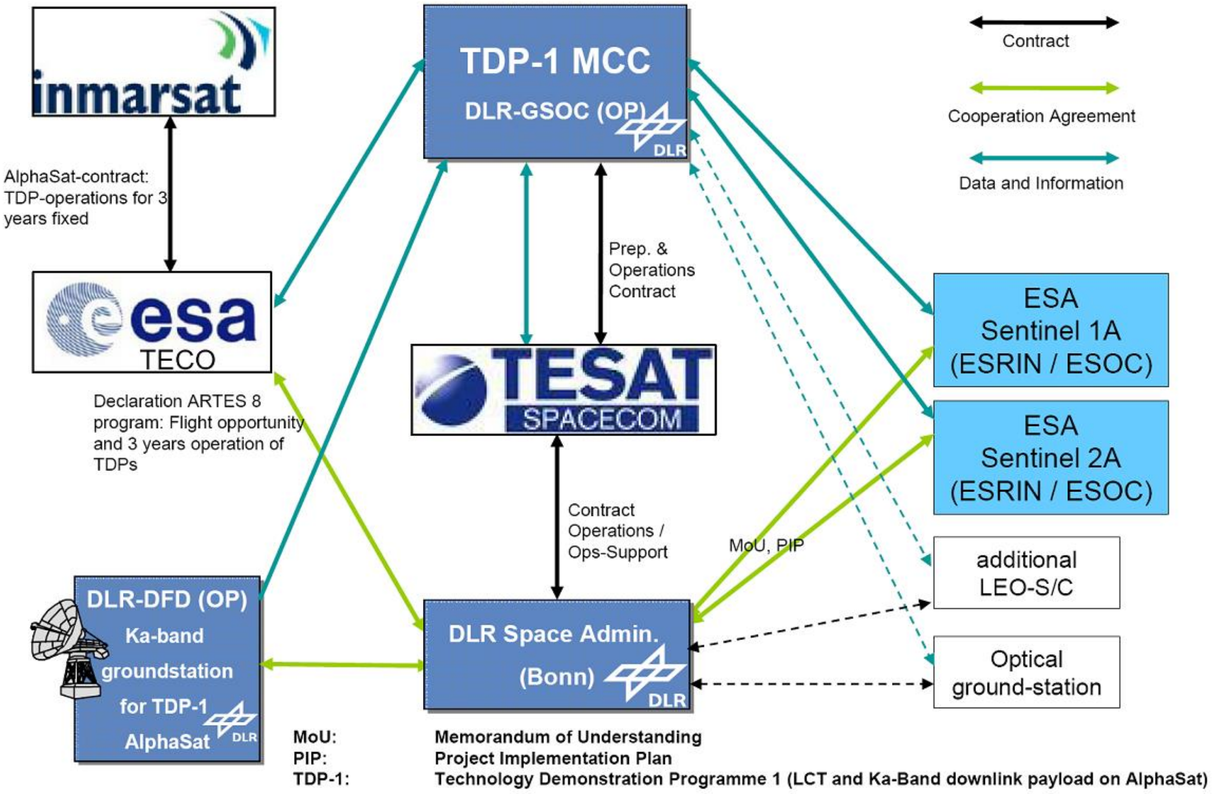

Figure 3. The organisational structure of TDP-1. Graphic taken from Ref. 4.

III. The involved parties of the TDP-1 relay system

The TDP-1 project involves several parties that manage, control, or coordinate different spacecrafts, ground stations and control centers. Concerning the technical part of laser links itself, the following satellites and ground stations are directly involved:

- A geostationary data relay system: For TDP-1 this task is executed by the Alphasat-I-XL satellite. Launched in 2013, the geostationary Alphasat, Europe's largest telecommunications satellite, is a Public Private Partnership between ESA and UK satellite operator Inmarsat. Data of the LEO satellites is linked to this GEO satellite by using the LCT, and immediately forwarded to the ground station via Ka-Band.
- LEO observation satellites: In the framework of TDP-1, this role is performed by the two satellites Sentinel-1a and Sentinel-2a, launched on April 3, 2014 and June 23, 2015, respectively. Both satellites are operated by ESOC and are part of EU´s Copernicus Earth observation program. A LCT on board both satellites sends the data to the Alphasat via laser communication.
- A ground station for the reception of the data: A Ka-Band-Antenna of the German Remote Sensing Data Center (Deutsches Fernerkundungs-Datenzentrum, DFD) in Oberpfaffenhofen, Germany, receives the forwarded data from the geostationary Alphasat. From here, the data can be forwarded to the respective users.
- An optical ground station: The TDP-1 program also involves a mobile ground station with an adaptive optics on Tenerife, Spain, for experimental optical space-to-ground links. These links put additional challenges to laser links, since hereby the laser traverses the atmosphere. By performing these experimental links, one gathers important information about this kind of communication method (see Ref. 9 for more details about space-to-ground links).

Behind these obviously involved spacecrafts and ground stations, several control centers and coordination offices have to work together for a successful execution of laser communication. For TDP-1, these are:

- Spacecraft Control Centers for both the GEO as well as the LEO satellites. As pointed out above, these roles are fulfilled by INMARSAT and ESOC, respectively.
- An Alphasat payload coordination office: Due to several possibly conflicting payloads on board the Alphasat satellite, there is a specific coordination center called TECO (Technology Demonstration Payload – ESA Coordination Office). It manages the scheduling of the payloads and prevents these kind of problems on the Alphasat.
- A Mission Control Center (MCC), which is responsible for the laser link planning itself and the generation of operational products for the different Spacecraft Control Centers above. The activities of the MCC – operated by DLR GSOC – will be subject of the forthcoming chapter.

The organisational structure of these involved parties is illustrated in Fig. 3.

IV. The TDP-1 Mission Control Center

A dedicated operational concept has been developed by DLR GSOC as TDP1 Mission Control Center[6,7]. The concept is based on the heritage programs TerraSAR-X and NFIRE and includes all necessary tasks and steps like calculation of feasible link slots based on satellite orbit and availability data, scheduling of customer link requests, and generation of operational products for the involved spacecrafts to execute the links. The system is set up to perform these tasks automatically, thus it runs 24 h a day and 7 days a week.

The planning system is designed to be a weekly planning: During the “planning week”, link requests can be placed into and taken back from the system. A preliminary feedback of the current status is produced to inform about successfully planned but also about possibly rejected requests. Each Friday, the results of this “planning week” are locked, and the “execution week” starts. Now, the respective products for all planned links are generated and the links are performed. This weekly approach has the advantage of setting clear periodical due dates to all involved parties and their different product exchanges. In the following, we will have a closer look on the necessary steps of the planning and its implementation in the GSOC MCC. An illustration of the steps can be found in Fig. 4.

The first step in the whole planning process of a laser link, is to find out in which time intervals the links could actually be established. The obvious prerequisites for this is a) that the two participating LCTs (that could mean LCTs on two satellites, but in general it might also be one laser terminal in space and one on ground) have a free line-of-sight to each other, and b) that both LCTs can be operated during that time. The first requirement is primarily defined by the orbit of the LEO, but also by the spacecraft attitude, since the LCT might not be allowed to point towards other exposed parts of the satellite. This visibility calculation is executed by the Flight Dynamics Department of GSOC for all possible laser connections based on the orbit information of the participating satellites[11]. Here, effects like sun blinding are also taken into acount. This task corresponds to the box “Visibility Calculation” in Fig. 4. The second requirement just means, that the involved spacecrafts do not perfom e.g. any kind of maneuver or payload activities, which might prohibit a parallel operation of the LCT. These no-operation times are collected in advance for each spacecraft and organised by the Flight Operations System of the MCC (see “NOps Builder” in Fig. 4). The information of these two limiting factors is combined in a so-called “Slot List” for each LCT pair and sent to the external partners (“SlotLister” in Fig. 4). These partners then have an overview on when and which kind of laser links (i.e. between which satellites) were possible, and can choose the desired link times by inserting a link request into the MCC system.

The next step is placing the incoming link requests into the free slots. The GSOC MCC offers capabilities to take into consideration possible additional constraints like required pre- and post-link activities, limits for the amount of communication per time interval due to thermal reasons, etc. The constraints are implemented in the MCC Mission Planning System, where the refined scheduling takes place (see box “Mission Planning System” in Fig. 4). The so-called resulting “Link List” is then distributed again to the external partners for information purposes, but also sent back to the Flight Operations System of the MCC for further processing.

In the last step of the laser link planning process, the operational products for the planned links are generated. As mentioned above, this happens in the moment the “planning week” becomes the “execution week”, and for some products even later, i.e. shortly before the link. All necessary commanding products for the participating satellites are generated (Fig. 4: “Procedure Paramizer”). A necessary input for the parameters of these products is an update of the orbit information (Fig. 4: “Chebyshev Generator”). In contrast to the propageted long-term orbits from above, these are calculated on the basis of up-to-date input from each satellite. For more detailed information about these calculations, we refer to Ref. 11. The final products are eventually sent to the corresponding Satellites Control Centers. Additionally, the Ka-Band Ground Station is informed about the link (Fig. 4: “RPS Converter”).

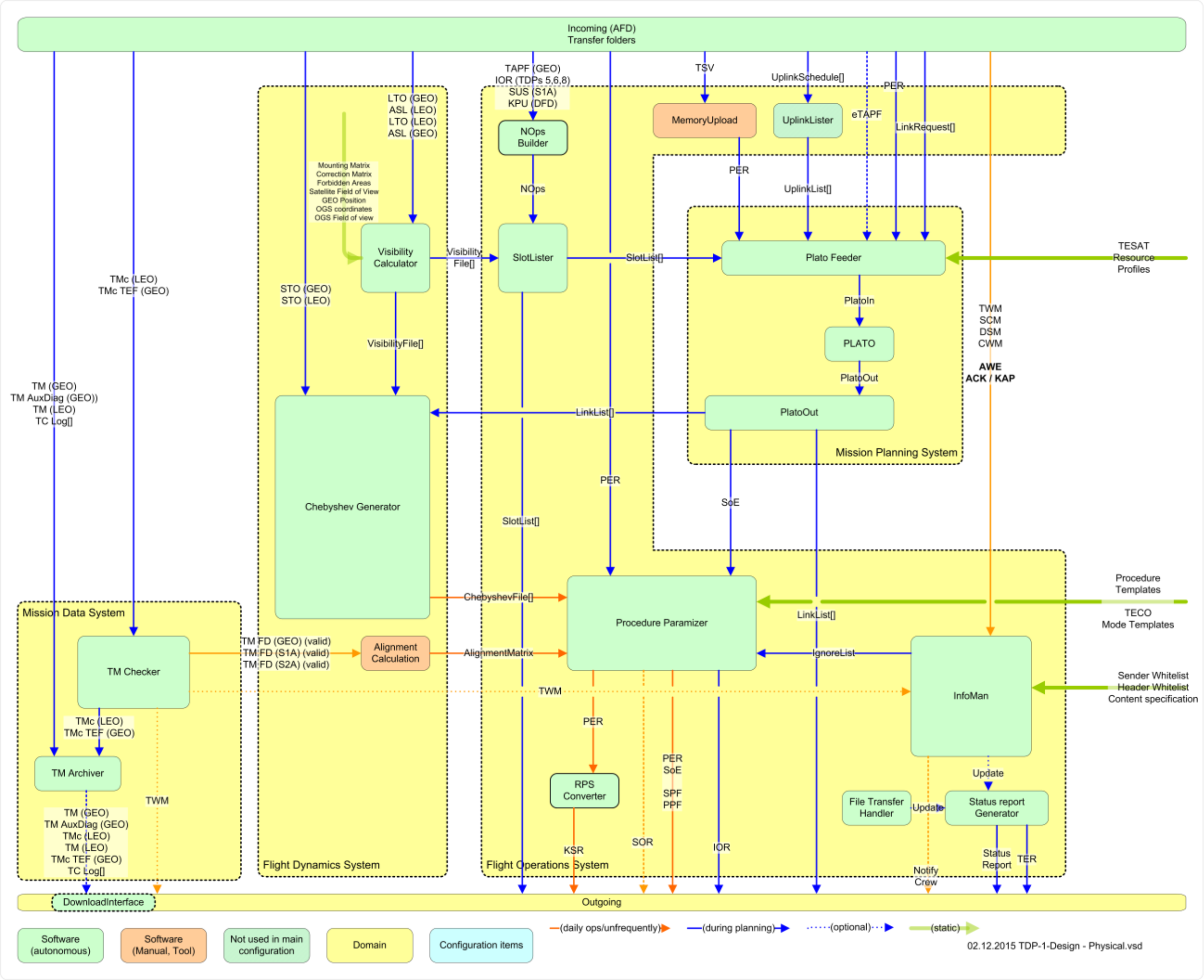

Figure 4. The physical layout of the TDP-1 MCC design

In addition to these planning steps, the MCC collects and archives the telemetry of all participating Terminals. The telemetry is automatically checked on several defined limits, and a status report is generated to inform about the outcome of the performed link(s).

Until 2015, the MCC successfully planned and generated the operational products for more than 150 links between Sentinel-1a and Alphasat. In total, this lead to 84.044 seconds of communication. When assuming the highest possible data rate of 1.8 Gbit per second, this corresponds to 18.5 Terabyte of data. The first successful link between Sentinel-2a and Alphasat took place on September 17, 2015. During the rest of the year, more than 50 links were successfully prepared by the TDP-1 MCC. Since then, the numbers for both satellite links are increasing nearly every day. In addition to that, four space-to-ground link campaigns were performed between the Alphasat and the optical ground station on Tenerife in 2015 alone.

V. Conclusion

The TDP-1 project successfully proofs the concept of a data relay satellite system using laser communication technology. An important role in the complex process of this new kind of data transmission is played by the GSOC Mission Control Center. Here, all necessary information for requested links is gathered and processed, and the link planning is performed. The resulting operational products are generated and distributed to all participating ground stations. Nearly three years of extremely successful operation in orbit pave the way for upcoming commercial missions like EDRS.

Acknowledgments

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References

[1] Toyoshima, M., “Trends in satellite communications and the role of optical free-space communications”, Journal of Optical Networking Vol. 4, Issue 6, pp. 300-311 (2005)

[2] Wallrapp, F., Ballweg, R., Gataullin, Yunir, “The European Data Relay System (EDRS): Operational Challenges”, 62nd International Astronautical Congress, Cape Town, SA (2011)

[3] Troendle, D., Rochow, C., Martin-Pimentel, P, Heine, F., Meyer, R., Lutzer, M., Benzi, E., Sivac, P., Krassenburg, M., Shurmer, I., “Optical LEO-GEO Data Relay: The In-Orbit Experience”, AIAA SPACE 2015 Conference and Exposition, (2015-4496)

[4] Martin-Pimentel, P., Rochow, C., Gregory, M., Heine, F., Kaempfner, H., Troendle, D., Sterr, U., Kuhlmann, S., Ballweg, R., Lutzer, M., Philipp-May, S., Guetlich, B., Meyer, R., “Laser Com in space, the operational concept”, AIAA SpaceOps Conference, Pasadena, CA (2014-1839)

[5] Zech, H., Heine, F., Troendle, D., Seel, S., Motzigemba, M., Meyer, R., Philipp-May, S., “LCT for EDRS: LEO to GEO Optical communications at 1,8Gbps between Alphasat and Sentinel 1a”, Proc. SPIE 9647, Unmanned/Unattended Sensors and Sensor Networks XI; and Advanced Free-Space Optical Communication Techniques and Applications, 96470J (2015)

[6] Ballweg, R., Wallrapp, F., “EDRS Operations at GSOC- relevant heritage and new developments”, AIAA SpaceOps Conference, Stockholm, SW (2012-1275210)

[7] Ballweg, R., Kuhlmann, S., Rossmanith, G., Hobsch, M., “TDP1 Ground System Design”, AIAA SpaceOps Conference, Pasadena, CA (2014-1626)

[8] Kuhlmann, S., “Operation of TerraSAR LCT and Implications for Future Projects (NFIRE to TSX, TDP1, EDRS)” SpaceOps Workshop 2013, Laurel, MD, USA, June (2013)

[9] Gregory, M., Troendle, D., Muehlnikela, G., Heine, F., Meyer, R., Lutzer, M. Czichy, R., “3 Years Coherent Space to Ground Links: performance results and outlook for the optical ground station equipped with adaptive optics”, Proceedings of SPIE - The International Society for Optical Engineering, 8610:04 (2013)

[10] Gregory, M., Heine, F., Kaempfner, H., Meyer, R., Fields, R., Lunde, C., “Tesat Laser Communication Terminal Performance Results on 5.6 Gbit coherent Inter Satellite and Satellite to Ground Links”, ICSO International Converence on Space Optics, (2010)

[11] Schlepp, B., Kahle, R., Saleppico, J., Kuhlmann, S. und Sterr, U. “Laser Communication with Alphasat - FD Challenges and First Flight Results” 24th International Symposium on Space Flight Dynamics (ISSFD), Laurel, MD, USA (2014)