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TDP1 Ground System Design

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This paper illustrates the historical development of the TDP-1 ground segment, the system as implemented and operational experience, as well as an outlook to future programs.

Aim of the project TDP-1 – Technology Demonstration Payload No.1 - is the demonstration of a data relay service, using an optical High Data Rate Inter-Satellite Link (ISL) between a Laser Communication Terminal (LCT) flown on a low earth orbiting satellite (LEO-LCT) and a second LCT (GEO-LCT) placed on the geostationary communication satellite AlphaSat (of INMARSAT) . The LCT planning system consists of one geostationary satellite (GEO) and up to five low orbiting satellites (LEO) which are also referred to as customers. The main task of GEO within this system is to serve as service provider for the LEOs and one optional optical ground station (OGS). The service consists of an optical data link between the Laser Communication Terminals (LCT) of the satellites (inter-satellite-link,ISL) and a link from a satellite to a ground station (space-to-ground-link, SGL).

DLR's Operations Center (GSOC) role in the TDP-1 program includes design, development and integration of ground infrastructure and operations of the satellites and ground stations.

GSOC already gained experience operating Laser Terminals in test scenarios on the TerraSAR spacecraft. This knowledge was be used to develop the TDP-1 operations concept. One major task is the planning of the laser connections and the required coordination between all parties. This paper will illustrate the development from the first activities at GSOC in connection with laser data transfer through the design of the TDP-1 system to an outlook at the EDRS operations concept.

I. Introduction

TDP1 is a German research and development program, designed to proof the concept of a relay satellite system using an optical data transfer system for the satellite to satellite (Inter-Satellite-Link, ISL) connection. The downlink of the relay data will be performed using a Ka-Band RF downlink. This mission is commonly considered the precursor to the EDRS (European Data Relay System) constellation.

DLR's German Space Operations Center (GSOC) was tasked with devolving and implementing the ground system and providing an end-to-end data relay service from a pick-up point on the originating spacecraft to delivery of the data to the end user on ground.

This paper will present the overall concept of the program, the ground system designed and implemented at GSOC and the first operational experiences.

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The major tasks were: design of a fully automated planning system, design of an automated command and control system, development a multi-party operations concept and activation and proof of the overall concept.

The overall system comprises of the optical terminal hosted on a geostationary spacecraft. In the case of TDP1 this satellite is not operated by GSOC, but Inmarsat which brings an additional player into the game, the ground system at GSOC, a dedicated antenna for the relayed data, an optical ground system and any combination of low- flying terminals.

According to the statement of work the system should be capable of handling six optical terminals, one of which is aboard the relay spacecraft, one is an optical ground terminal and the other ones are aboard low-lying object (satellites or aircraft). 22 optical links should be planned per day between any combination of two optical terminals.

The operational phase started after activation of the instrument on the geostationary spacecraft with calibration of the terminal, using the optical ground station. Second objective is verifying and improving operational interfaces with the operator of the host satellite.

Since there will be a gap between the activation of the LCT on Alphasat and the first low flying customer the development of the ground system is split in two parts, the first stage will enable us to support the test with the relay satellite and allow us then to include lessons learned into the completion of the system to perform the operations with the target constellation of 6 terminals.

The first two customers will be the satellites Sentinel 1A and 2A of the European Space Agency ESA. GSOC will interface with different entities of ESA at different stages of the program and exchange different products. The paper will describe the different interfaces, products and explain the challenges at the individual stages of the development.

II. Data Relay Concept[1]

A schematic showing the concept of a geostationary data relay for earth observation data can be seen in Figure 1.

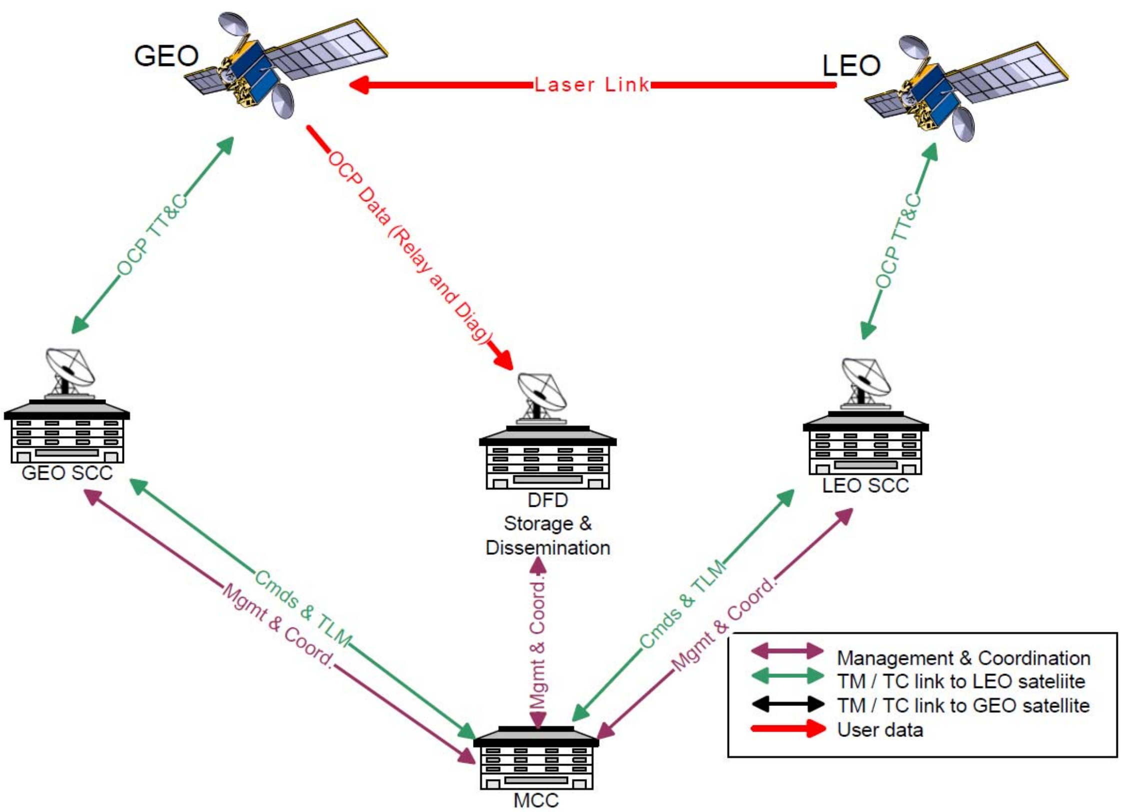

Fig 1: Concept of TDP1 GEO relay system

Components:

The components of the system are described in the following sections.

Low-Earth-Orbiting satellite (LEO)

The LEO is typically an earth observation satellite carrying one or more instruments that generate user data that have to be transferred to ground. In the conventional approach the data is transmitted to ground through ground stations for example in X-band (not shown in Fig. 1). In the case of a relay satellite the LEO transfers the data to the GEO satellite (link in red). Consequently the LEO has to be equipped with a high-data rate LEO to GEO communication device. In order to be able to transfer large amounts of data, at least two technologies might be used:

1. Optical Communication with a Laser Terminal (“Laser Communication Terminal”, LCT).

2. Radio-Frequency Communication in Ka-Band.

Note: for the sake of clarity, only one LEO is shown. In fact, various LEOs may use the relay satellite either in parallel or one after the other depending on the technical implementation.

LEO Satellite Control center (LEO SCC)

The LEO satellite control center operates the LEO satellite. It is responsible for housekeeping and payload operations. Among these tasks is the correct pointing and activation of the LEO to GEO communication device. For a correct pointing of the communication device towards the GEO the GEO orbit has to be known to the LEO SCC.

Geostationary Relay satellite (GEO)

The GEO receives the user data from the LEO satellite and relays it to ground. For this purpose it needs a receiver, which is compatible with the terminal of the LEO. Therefore the same technologies come into consideration, namely LCT or Ka-band. As for the LEO, these devices are usually steerable and have to be pointed towards the LEO, depending on the used technology.

To complete the relay function, the GEO needs a high data rate terminal to send the data to ground. The technology that can be used for this purpose is not dependent on the LEO to GEO link. To receive a comparable data rate Ka-band is used. TDP1 has one dedicated receive station, but the space to ground beam for a geostationary satellites may cover a very large portion of the earth which enables various ground stations spread over large distances to receive the data in parallel. This is planned for the EDRS system.

GEO Satellite Control center (GEO SCC)

The GEO satellite control center operates the GEO satellite. It is responsible for housekeeping and payload operations. Among these tasks is the correct pointing and activation of the receiver. In order to correctly point the receiver to the direction of the LEO, the LEO orbit has to be known to the GEO SCC.

DFD (German Center Remote Sensing Data)

DFD provides the ground station that receives and stores the data transmitted by TDP1's Ka-Band antenna.

Mission Control Center (MCC)

The TDP1 MCC is the core component in the system. It interfaces with all other components and coordinates them. Its main purpose is to receive all the link requests from the different users and generate a link session timeline taking all known constraints into account. In addition it monitors and controls all involved infrastructure. Depending on the request of the customer the MCC can extend its service to include all preparations for a data transfer, including preparation of procedures and generation of associated command files.

III. LCT operations development at GSOC

A. Operations TerraSAR X

GSOC became involved in LCT operations for the first time with the program TerraSAR-X, which hosted a Laser Communication Terminal as a secondary Payload. A second LCT is flying onboard the US satellite NIFIRE which is operated by the company Orbital Sciences Corporation (Orbital). NFIRE was launched in April of 2007 with TerraSAR following in June of the same year. GSOC is the operator of the TerraSAR-X and also commanding the LCT. The TerraSAR LCT is designed for two types of contacts, a satellite to ground link and Inter-Satellite-Links. As the objective in this case is test and evaluation of LCT operations the responsibilities are divided between GSOC as the satellite operator and the LCT manufacturer TESAT. The first LCT tests on TerraSAR were Space-to-Ground links (SGL) performed with ground terminals located on DLR property in Oberpfaffenhofen near Munich and on the island of Tenerife. The first Inter-satellite Links were exercised starting January of 2007.

Essential to all LCT operations is the planning cycle which is an iterative process. Starting out with the different orbit information one party, in case of TerraSAR-NFIRE Inter-Satellite-Links (ISLs), Orbital, calculates the link options and makes a pre-selection with available links. GSOC then coordinates of the final link selection and publishes the deconflicted links to all parties. The two control centers for TerraSAR and NFIRE then prepare

individually their respective LCT operations with input from the instrument manufacturer TESAT (in form of command input files) and their flight dynamics departments which are Chebychev coefficients for the LCT pointing. GSOC then produces the detailed sequence of events (SOE) and provides it to Tesat. After the links, GSOC and Orbital make a quick determination of the success of the operations and provide all the corresponding data to TESAT for evaluation. Results then flow into the input for the next links.
Occasionally other partners like the DLR Institute of Communication and Navigation (IKN) request the opportunity to perform Space–to-Ground-Links (SGLs) using their own optical ground stations. In that case those partners provide their objectives to TESAT for them to generate the LCT configuration files and GSOC again publishes the SOE and performs the operations.

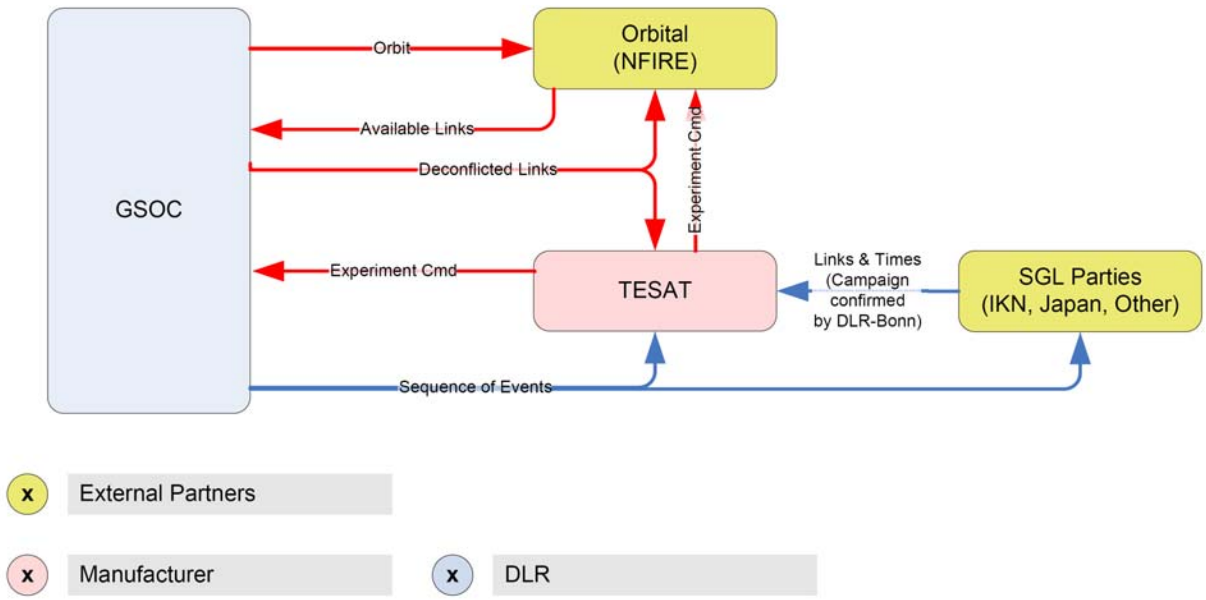

Fig 2: TerraSAR LCT operations concept

B. TDP1 System Design[2]

The next step in the evolution is the project TDP-1. TDP-1 is an experimental mission giving the proof of concept of a relay for earth observation data from LEO spacecraft via a GEO satellite using LASER as a transfer media. It is considered a precursor mission to the European Data Relay System (EDRS) project.

GSOC's objective in the program is to establish a control center for LCT relay operations providing end-to-end service of data transfer from a LEO spacecraft via a relay satellite to the final data user. That means in theory a handover of the data at the originating source, i.e. the LEO satellite and delivery to a dedicated ground station or end user. In practical terms GSOC will be capable to execute all data transfer functions, including the operations of all participating Laser terminals and RF equipment.

The TDP-1 payload hosted on a geostationary satellite consists of a laser communication terminal, mainly for the inter-satellite-link to a low earth orbiting spacecraft and a Ka-Band payload for the data downlink from the geostationary satellite. GSOC started preparatory design for the TDP-1 project in late 2011. The laser terminal can also be pointed to an optical ground station, a functionality that will be used during the commissioning phase for calibration purposes. The launch of the geostationary relay satellite Alphasat was on July 27, 2013. Sentinel 1a as the first LEO customers followed on April 3, 2014.

The participating agencies it TDP-1 are the German Aerospace Center DLR as the contracting entity or customer, with its institutes GSOC and DFD, INMARSAT hosting the GEO payload, TESAT as the LCT manufacturer and the European Space Agency as the first LEO customers.

The concept of operations for GSOC is that GSOC collects the orbital information of all participating spacecraft and possibly the ground contact information of the LEO satellites. It then performs visibility calculations and publishes visibility reports for periods of one week and collects link requests. On a specific day GSOC forwards the final link selection to the TDP coordination office (TECO) at INMARSAT and receives feedback the next morning. Then GSOC prepares the command information for all participating laser terminals. The downlink from the ALPHASAT is received via Ka-Band at DLR's DFD Institute and the data is distributed from there. GSOC receives a report about the success of the link and LCT diagnostic data for Tesat for evaluation of the LCT performance.

The LCT terminal onboard ALPHASAT is also capable of contacting optical ground stations. This feature will be used for testing and calibration during the commissioning phase, when no LEO satellite is available. The first ISLs are planned for the first quarter of 2014.

The information being exchanged between the GSOC and the partners are:

LEO SCCs to GSOC: Orbit information, link requests, possible constraints, TLM
GSOC to LEO SCCs: Link possibilities, SOEs, LCT command inputs
INM/TECO to GSOC: Orbit information, deconflicted links, TLM, command logs
GSOC to INM/TECO: link list, SOE, command inputs, telemetry requests
Tesat to GSOC: link requests, command inputs
GSOC to Tesat: SOE, status reports, TLM, command logs

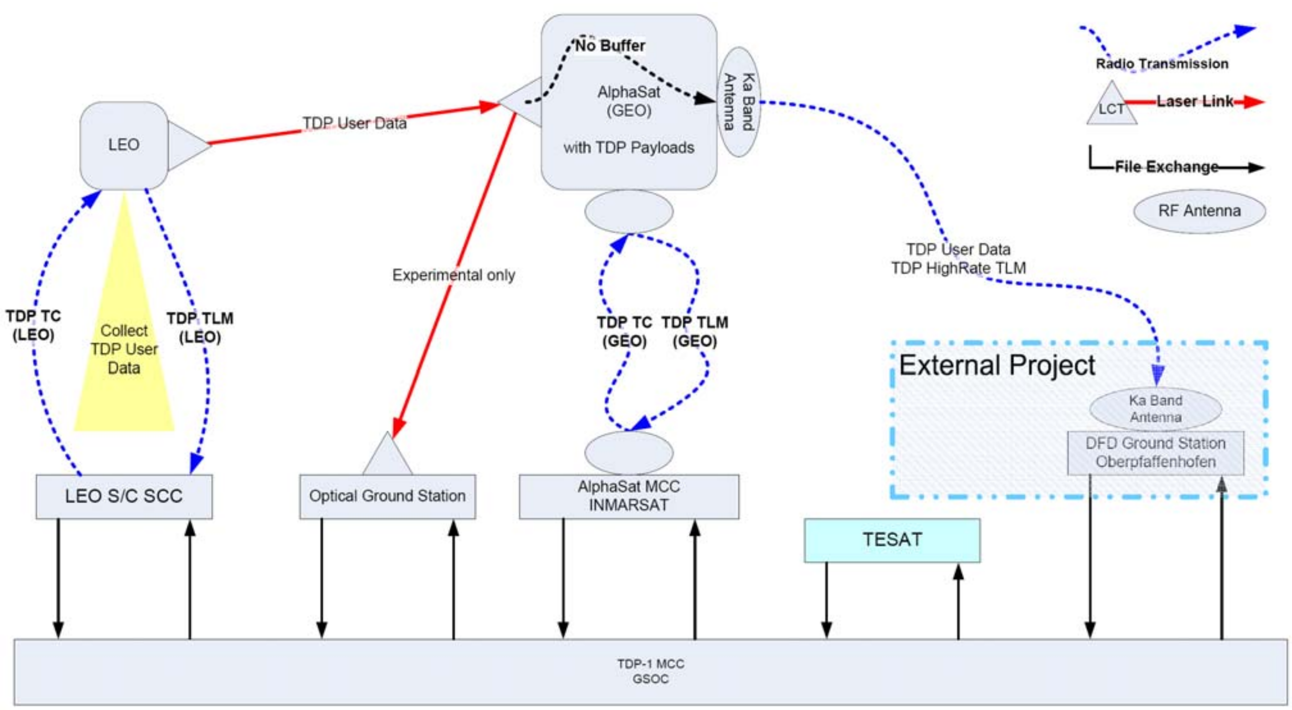

Fig 3: TDP-1 Project

C. GSOC In House System Design

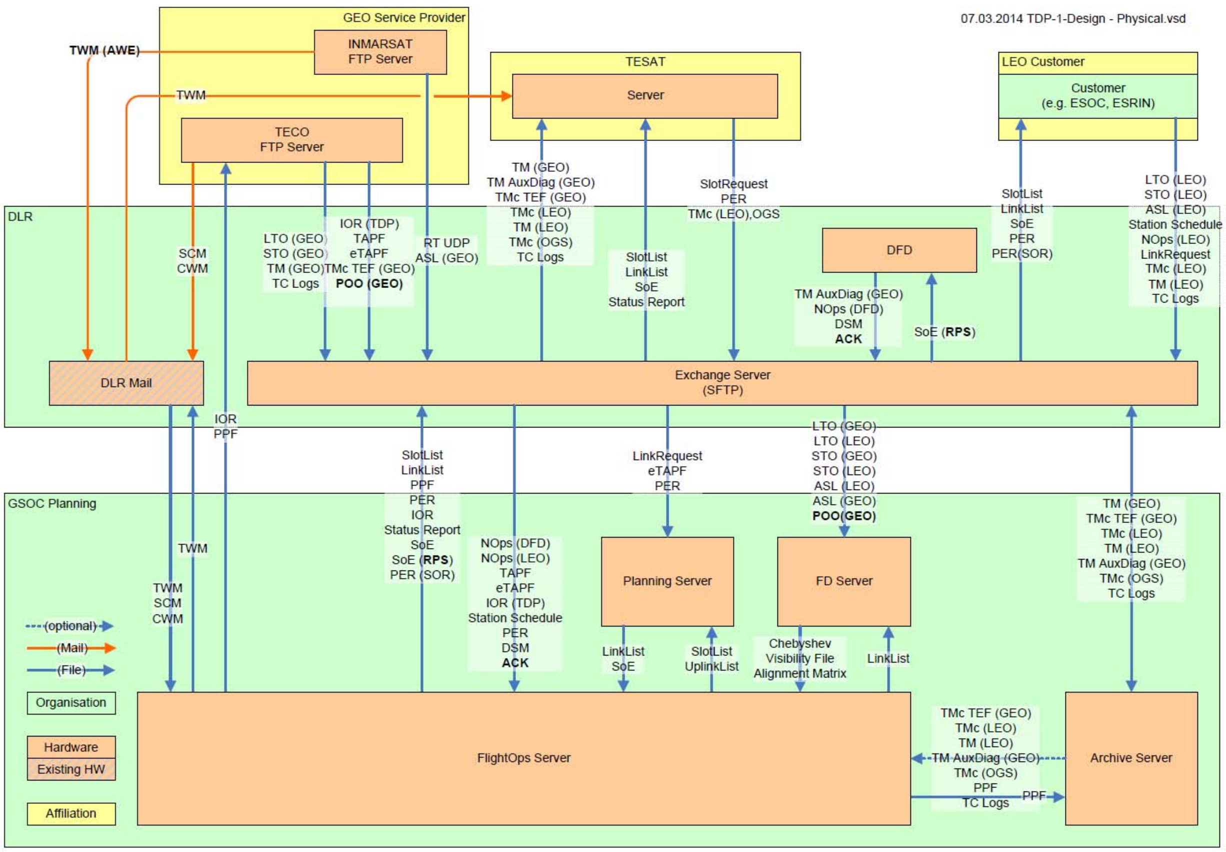

Fig. 4 TDP-1system physical layout

The system designed consists of the following components with specific tasks.

a) Flight Operations System (FOS) / GSOC Planning

The flight operations system manages and surveys the flow for the whole system. It is responsible for the routine and contingency operations for all LCTs supported by the system. In particular it is responsible for implementation and maintenance of all flight procedures in the system and handles almost all the outgoing traffic to the exchange server. It is comprised of:

- The flight operations server, which is the central control instance for the system. It houses all converters and processes all incoming and outgoing products.
- Planning server. The mission planning system is responsible for optimizing the link planning based on input from the different customers and taking specific constraints (spacecraft or ground) into consideration.
- The flight dynamics system which has the responsibility to calculate the visibilities between the individual LCTs, generate the Chebyshev coefficients for the laser acquisition and tracking and perform alignment calculations in periodic intervals.
- The archive server where the telemetry processing occurs and the data is stored and accessible for retrieval.

b) Data exchange server

Due to GSOC security policies the file exchange has to occur on an exchange server that is located outside of GSOC firewalls at the DMZ (Daten Management Zentrum). The exchange server is an FTP server that provides a data exchange point for the system. It hosts the SFTP server which provides the file transfer service to and from GSOC for external partners and the file transfer handler that distributes files to external hosts according to a label file that is provided together with that file.

D. TDP-1 Operations Concept

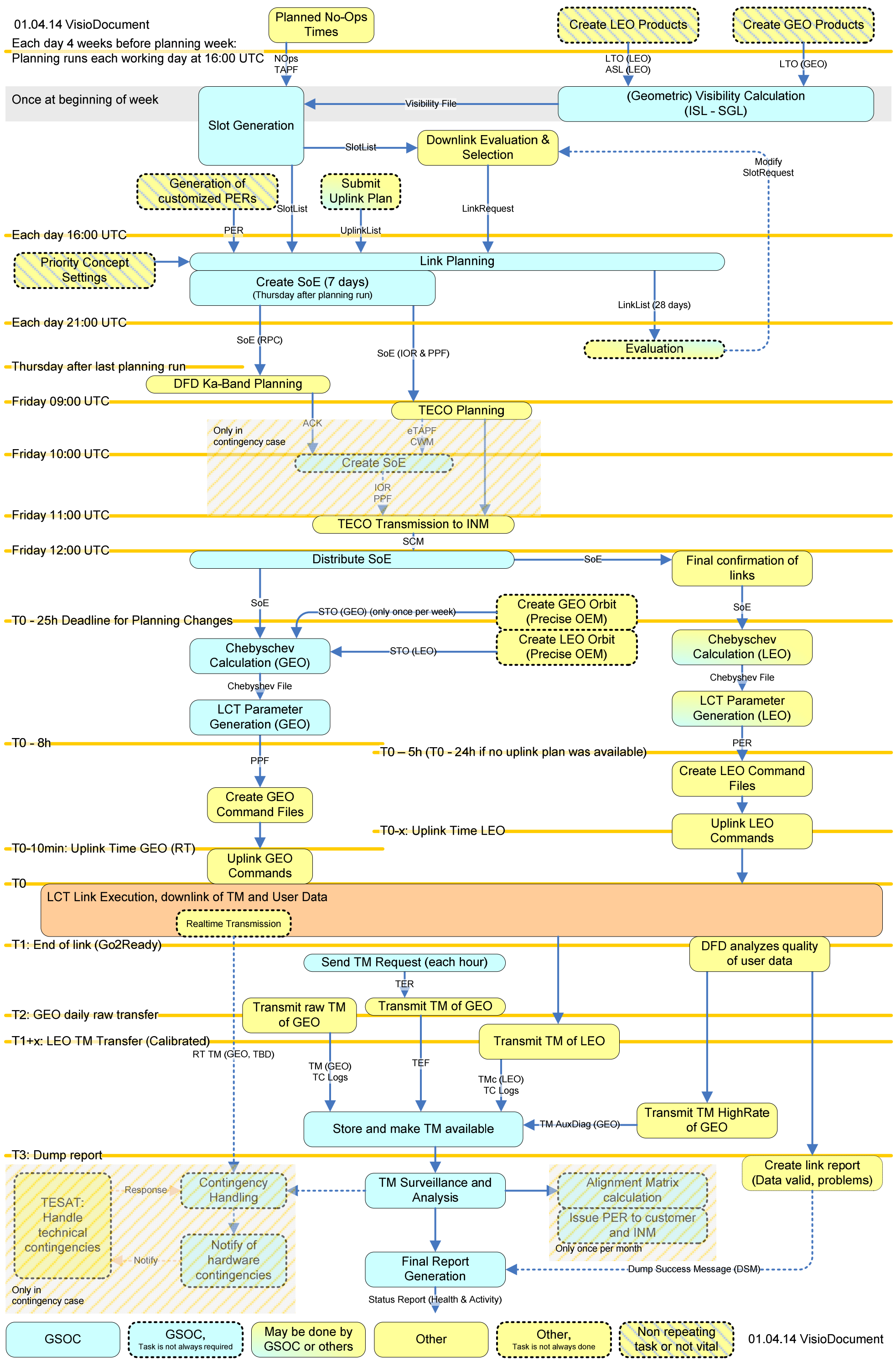

Fig 5. TDP1 Operations Concept

TDP1 is implemented as a planning system that runs once per day. Partners to the program can submit inputs any time, though it is not recommended to provide them earlier than four weeks out.

The first inputs required are the orbits of the participating spacecraft. Based on these the first geometric visibility calculations are performed. They cover a one week period starting on Saturday at 00:00 UTC. This is based on a planning cycle imposed by the satellite operator. Once the visibilities are determined the planning system takes any known constraints into consideration to create slot lists for possible links between any possible pair of OCPs. Such constraints could for example be maneuvers or power budgets or unfavorable satellite attitudes among other things.

The resulting slot lists are then provided to the customer for their selection of links which they then return together with Procedure Execution Requests (PER) to the MCC. These PERs give the MCC all necessary information to execute an inter-satellite link. PERs are optional if the LEO spacecraft operator decides to operate the LCT himself.

On Thursday of every week the final link planning for the operational week is done, resulting in a sequence of events (SOE) for TDP-1. From that time on no new requests for the following week are accepted and the only changes are deletion of links.

The SOE is then forwarded to the ESA coordination office (TECO) to deconflict and combine it with the operation requests of the TDPs and forward it to the Alphasat operator. At this stage links can be deleted in case of conflicts with other experiments or the Alphasat operations. By Friday 12:00 UTC the planning for the following week is fixed.

During the operations week the spacecraft operator provide the MCC with the most up-to-date orbit information so the TDP1 operations center can calculate the Chebyshev coefficients, necessary for acquisition and tracking of the laser terminals. These are then sent, with any additional required commanding information, to the respective spacecraft control centers for uplink.

The inter-satellite-link is then executed and the science data downlinked to the TDP1 receive station at DLR’s DFD, where some pre-processing is performed before the data is disseminated to the end users.

Instrument and spacecraft telemetry data of all participating terminals and host satellites are collected by the MCC for evaluation and archiving. Routine tasks performed with this data are among other things the periodic correction of the alignment matrix of the OCPs.

Operations:

The first activities for TDP1 after launch of Alphasat were to perform selftests and use Space-to-Ground links (SGL) for calibration purposes. The selftests were executed while the LCT manufacturer was on site at the Inmarsat control center, thus without active participation of the SCC. During that time though the complete data transfer chain went through the operational test phase. For the SGLs GSOC became involved in the operations cycle. During that period the planning process was verified, including the checks implemented in the system and so some inconsistencies within procedures and databases between the individual parties (Tesat/DLR/Inmarsat) were discovered and corrected.

At the time of writing of this paper the preparation for operational testing of the interfaces between the TDP-1 MCC and ESA for the Sentinel 1 A support were in final preparation.

Conclusion:

GSOC has further developed its capacity and experience in operating optical communication payloads from the TerraSAR LCT instrument to a complete system of multiple OCPs. Challenges are that when new terminal get implemented the complexity of the system can increase exponentially when new operation concepts and interfaces have to included into the planning system. Also due to the fact that TDP1 is operated as a hosted payload flexibility to late requests for datatransfers is not given.

The next step in the development is the EDRS ground system: First time commercial operational transfer of data from low earth orbiting spacecraft via laser data links to a geostationary relay satellite and forwarding of the data to the end user. GSOC will then be supporting the operation of a constellation of relay systems on host- as well as dedicated spacecraft and a dedicated ground station network for data reception and dissemination. The concept is described in [3].

Appendix A
Acronym List

DLR	German Center for Aerospace
DFD	German Remote Sensing Data Center (Deutsches Fernerkundungs Datenzentrum)
DMZ	Daten Managemnt Zentrum (Data Mangement Center)
EDRS	European Data Relay Satellite
FDS	Flight Dydnamics System
FOS	Flight Operations System
GEO	Geo Stationary (satellite)
GMES	Global Monitoring for Environment and Security
GSOC	German Space Operations Center
ISL	Inter Satellite Link
LCT	Laser Communication Terminal
LEO	Low Earth Orbit (satellite)
MDS	Mission Data System
MCC	Mission Control Center
MPS	Mision Planning Systen
SCC	Satellite Control Center
SGL	Space to Ground Link
TDP-1	Technology Demonstration Program 1
TECO	TDP ESA Coordination Office
TLM	Telemetry

References

Reports, Theses, and Individual Papers

[1]Wallrapp, F., Ballweg R. and Gataullin, Y, *"The European Data Relay System (EDRS) Operational Challenges"*, IAC-11.B6.2.4, 2011

[2] Kuhlmann, S. "*TDP-1 Planning Design Definition"*, GSOC 2012

[3]"*The Sentinels/EDRS Operations Constraints and Concept"*, ESTEC, 2010