TerraSAR-X Mission Planning: Strategic Concepts Embedded in an Automatic Environment

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Abstract. TerraSAR-X is an upcoming earth-observation mission equipped with a high-resolution radar sensor. It is operated by the German Space Operation Center (GSOC) and demands a highly autonomous mission planning system, satisfying the diverging interests of the different parties involved.
The mission planning system will autonomously process the expected daily five hundred incoming datatake requests, provide user feedback, schedule satellite datatakes as well as up- and downlinks to and from ground stations and keep track of the available satellite resources.
The need to split up fairly the satellite capabilities between the user groups leads to conflicts of interest. Whereas conflicts between individual competing datatake requests are solved automatically, the overall user behaviour influences deeply the predictability, stability and performance.
DLR/GSOC introduces an innovative strategic planning concept, which balances the interests between the user groups and at the same time encourages the individual user to place orders that can be optimized by the system. Mission management and a strategic planning team allocate a quota of points to the different user communities. As a side effect, this avoids senseless overloading of the mission planning system with unfeasible requests, aiding the planning process to concentrate on its main purpose: finding a feasible and optimal plan.

1 TerraSAR-X Mission Overview

The upcoming high-resolution radar satellite mission TerraSAR-X makes high demands on its space as well as its ground segment. The German Space Operation Center (GSOC) in Oberpfaffenhofen, which is part of the German Space Research Center (Deutsches Zentrum fr Luft- und Raumfahrt e.V., DLR), will operate TerraSAR-X during the envisaged mission time of 5 years. The TerraSAR-X project is financed by a public private partnership between DLR and EADS (Astrium / InfoTerra).

The main payload of the single satellite mission is an X-band synthetic aperture radar (SAR). Envisaged earth observation applications are geographic information products like topographic maps, infrastructure planning, crop stand measurements, flood damage assessment and geological structure maps. Other proposals include ship detection services, oil spill monitoring and traffic investigations on land and sea.

Secondary payloads are the high-precision GPS receiver TOR (Tracking, Occultation and Ranging) for precise orbit determination and the experimental Laser Communication Terminal LCT.

TerraSAR-X will launch in April 2006 using the Russian/Ukrainian Dnepr-1 vehicle from Baikonour, Ukraine. It will be confined to a high precision repeat orbit: frequent orbit manoeuvres will make sure that the satellite always stays in its envisaged reference orbit during the operational phase with a cross-track error smaller than 250m. The repetition time is 11 days. The nearly polar orbit with an altitude of 515km at the equator provides a good coverage of the earth surface. TerraSAR-X will fly sun-synchronous, so that the local equatorial crossing time will always be 18.00h 0.25h for the ascending pass. Additional satellite parameters are shown in table 1.

The SAR system has three prime modes: ”ScanSAR” provides 100km and ”Stripmap” 30km across track product coverage size with less than 3m and less than 16m geometric resolution, respectively. The geometric order length is variable. ”Spotlight” provides the smallest product coverage sizes, 10kmx10km or 5kmx10km, but a geometric resolution of less than 1m.

The TerraSAR-X resources are designed for carrying out about 500 datatakes per day. The user may choose between ”single orders” with one defined set of geographical coordinates or ”coverage orders”, where a specified geographical region is split automatically into atomic single orders by mission planning. ”Standing orders” allow the user to request periodical datatakes in a given time frame from one geographical target.

2 Mission Planning System

The common mission planning task consists of collecting requests for satellite payload operations and matches them with the availabilities of the system. The end product is a feasible and optimized plan that takes into account all constraints of both space and ground system. This plan must be distributed to the other parts of the system.

Total mass	1023 kg
Height	5.0 m
Diameter	2.4 m
Mass memory capacity	256 Gbit
X-Band Downlink rate	300 Mbit/s
Radar antenna center frequency	9.7 GHz
Typical Data Rate Spotlight	360 Mbit/s
Typical Data Rate Stripmap	580 Mbit/s
Geometric Resolution	$<$ 1.0m
Cross-track error orbit	$\pm$ 250m
Orbit repetition time	11 d
Altitude at equator	515 km

Table 1: TerraSAR-X characteristics

2.1 The DLR/GSOC state of the art Mission Planning System

The DLR/GSOC general mission planning system consists of a set of specialised tools that may be used as standalone applications as well as a part of an integrated system. The whole suite is designed to run on common available PC hardware. Typically, for each mission the planning system is adapted and complemented to match the requirements. Several missions have taken advantage of GSOC planning technology, e.g. X-SAR/SRTM, BIRD, CHAMP and GRACE. A general description of the GSOC/DLR planning technology can be found on the GSOC website (Wickler et al. 2004).

2.2 Demands for the Mission Planning System

The expected amount of user requests for the TerraSAR-X payload system gives crucial requirements for the design of the ground system. The mission planning system will be dimensioned to cope with an overload of about 100% , that is more than 1000 datatake requests per day must be handled.

During the scheduling process, the system automatically tracks the on-board resources using numerical models. Actual telemetry data is used to update the calculated results. Among other things this includes the mass memory and command buffer used, electric power, up- and downlink capacities from and to ground stations and a simple power/thermal model of TerraSAR-X.

The baseline ground segment scenario gives the following limitations: First, there is only one uplink station for commanding (Weilheim ground station, WHM). The limited onboard command buffer additionally tightens the situation. Also, only one downlink station for data reception (Neustrelitz ground station, NGS) is foreseen at the moment. However, there is the possibility to increase the downlink bandwidth by adding additional ground station from DLR side or from the commercial customer. This would also soften the next constraint: The onboard memory lasts, depending on the radar mode, for a maximum of 3min of datatakes. Last, thermal constraints of the space segment limit the instrument operation time. The allowed 50min operation time per day lead to 500 datatakes per day in average.

Challenging time constraints from the user side demand that mission planning accepts low priority tasks as late as three days and high priority tasks as late as 6 hours before the daily planning cycle for the next planning horizon. Adding the time span to the next uplink possibility and some safety margin, the latest possible order input is about 36 hours before execution.

Additional constraints for the mission planning system come from the public private partnership between DLR and its industrial partners. Heterogeneous user groups have varying access right to use TerraSAR-X: The commercial user group, represented by InfoTerra Deutschland, and the scientific user group, represented by DLR, make up the nominal users. They are allowed to order standard products. The radar-system calibration and experimental group, also represented by DLR, additionally possesses the right to order experimental datatakes and calibration tasks. The satellite resources, less the resources used up by the radar-system group, must be split up in a fair way between the involved scientific and commercial partners.

2.3 Automatic Mission Planning Approach

The above mentioned constraints make it clear that the sheer amount of datatakes that will be fed into the system cannot be handled by hand. The mission planning system for TerraSAR-X will automatically process the expected five hundred incoming datatake requests per day, provide user feedback, schedule satellite datatakes as well as up- and downlinks to and from different ground stations and keep track of the available satellite resources.

Figure 1 gives a simplified overview of the mission planning system modules and their mutual interactions.

The user gets feedback at various planning stages: First, he gets near real-time response by a sophisticated order preview system. On the one hand, this shows the user the geographical coverage of the final product. On the other hand, it tells him, after some plausibility tests, whether the order is feasible in principle. The plausibility checks include geometric considerations as well as time constraints. Unfeasible requests are rejected. After order placement, an extended feasibility check takes place. For both checks, the system makes use of the high-precision repeat orbit of TerraSAR-X: the target visibilities with respect to time and radar modes may be calculated in advance and are stored in a ”footprint” database. This database is not only used for the preview system, but also later on by the mission planning process to schedule the tasks. To obtain the required across track pointing accuracy of 200m, it is necessary to include a digital elevation model of the earth when computing target visibilities.

After successfully passing all checks, the orders are stored in a central database. For all these accepted requests, an

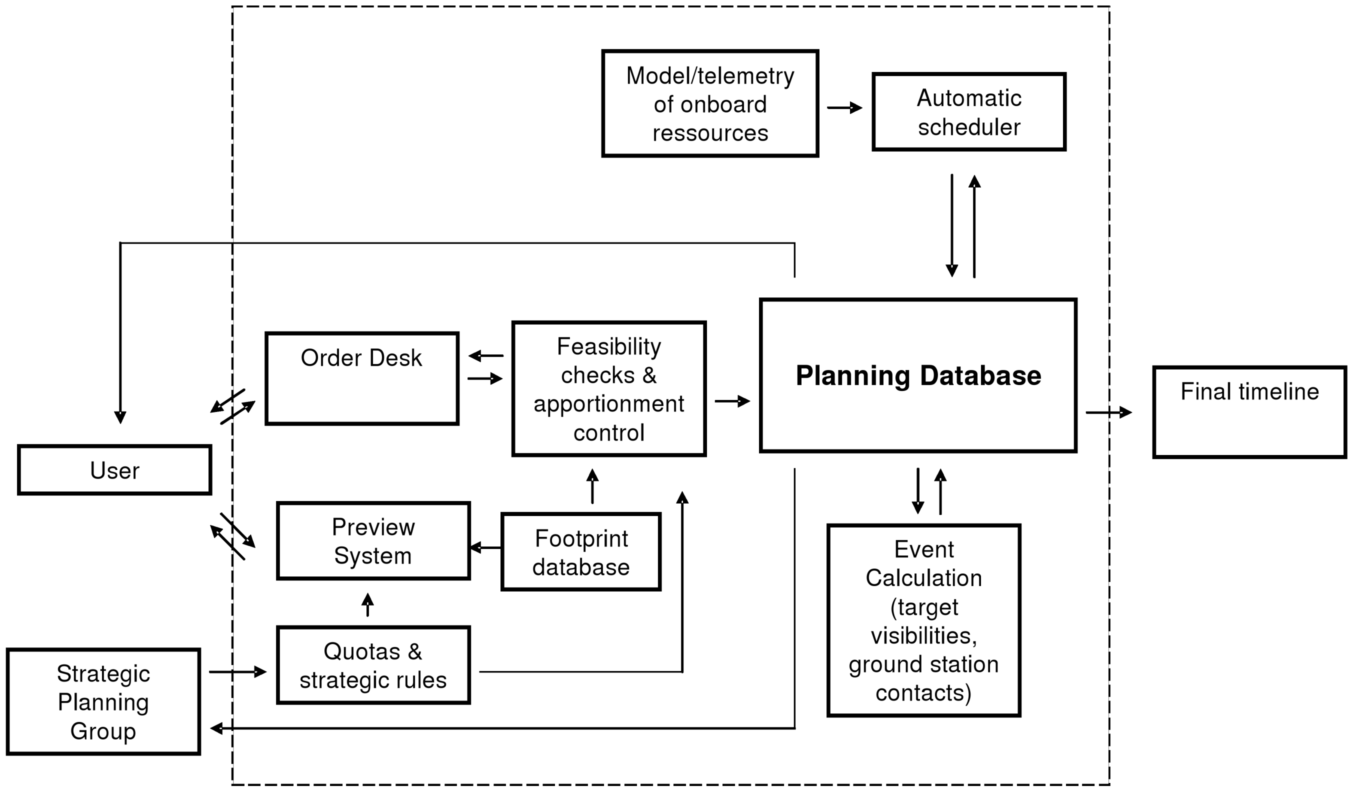

Figure 1: Mutual dependencies of the mission planning system modules (inside the dashed frame) and their interaction with the users and the strategic planning group (left side) as well as the production of the final timeline (right side)

event calculation tool computes the actual target visibilities. Together with the calculated ground station contact times, these data are the input for the automatic scheduler.

This constraint satisfaction problem solver Plato (PLanning TOol) has been developed by the planning technology group at DLR/GSOC. It can be and has been applied to a wide range of planning problems also outside the space sector. Descriptions of Plato can be found on the DLR/GSOC webpages (Wickler 2004). Lenzen (2004) gives an overview of the actual Plato implementation. As the complete source code is available for GSOC/DLR, specific adaptations to increase the efficiency for certain applications like the TerraSAR-X project are possible.

The scheduling task is highly challenging: The ground segment anticipates an incoming amount of 1000 datatake request per day. If the average datatake has an allowed execution time period of one month, this will lead to a database of 30000 in principle feasible orders for the current planning cycle. For generating the mission timeline for the next 3 days, the automatic scheduler has to choose 1500 tasks out of these 30000. The number of tasks too choose from could be lower, if the users gave smaller acquisition timeframes. However, if the users allowed large timeframes, the number could be several times higher. The scheduler has to take into account the opportunities when each order may be carried out, the priorities as well as the satellite resources. In addition to the datatake, also the uplink of the command and the downlink of the data have to be scheduled and coordinated. A datatake with no up- or download possibility is useless. The creation of the complete daily timeline must not exceed three hours to ensure that the schedule can be uplinked in time and that late time orders that come in as late as six hours before the planning cycle starts can be taken into account. An extensive presentation of the complete planning process and additional functionalities of the mission planning system have been presented by Braun et al. (2004).

During the planning process, the system informs the user automatically about all status changes: Orders may be in the queue waiting for planning, be planned on the long-term timeline, be scheduled for uplink or have been performed. However, status changes can also indicate when orders, due to conflicts, change from planned to waiting for planning or orders cannot be performed any more at all. The user has the choice to do nothing and hope for other conflicting datatakes to be cancelled or resubmit his order with a higher priority.

Conflicts between individual competing requests are solved automatically applying predefined rules: Datatakes with higher priorities are preferred. Another rule might be ”first come, first served”.

The overall user behaviour influences deeply the predictability, stability and performance of the mission planning system. The earlier the users place their orders, the earlier the planning system is able to generate a reliable schedule. Additionally, the mission manager might want to drive the customers e.g. using specific radar modes.

Also, the mission planning system cannot fulfill more user wishes than the space and ground segments are able to handle. If the system is overloaded, only a fraction of the user requests can be planned for execution. Customers will not be satisfied that their order could not be performed because of an overbooked system. Also the need to split up fairly the satellite capabilities between the scientific community on the one hand and the commercial partners on the other hand naturally leads to conflicts of interest, e.g. users may want less observing time in one time frame and more in a later time frame. Also, it has to be defined what 50% of the satellite resources really means.

Discussions between all partners showed that a new way of conflict resolution is needed. GSOC introduced an innovative strategic planning concept that prefers conflict avoidance instead of conflict resolution.

2.4 Establishment of Strategic Planning

The new strategic planning concept balances the interests between the different user groups and at the same time encourages the individual user to place orders that can be optimized by the system. As a side effect, this avoids senseless overloading of the mission planning system with not feasible requests. The main idea is to limit the number of datatakes a user group can order by introducing quotas of points. For every user request, the according number of points is calculated as a function of the datatake priority, the radar-mode, the time window and the time-point of order placement with respect to the first possible acquisition time.

Once a user group exceeds their quota during the nominal ordering process for a given time frame, the system accepts only low priority background tasks. Thus, it is always possible to feed the system with datatakes and make sure that the space segment is not idle. However, backgrounds tasks have a low probability to be performed.

The more the user limits the degrees of freedom of the order, the less the planning system is able to optimize the timeline and the higher is the quota usage. High-priority short-dated orders might overturn the complete schedule and therefore have to be adequate expensive. Therefore, the higher the priority of a request is, the more will be charged from the group quota by the automatic apportionment control functionality. The powerful ordering-preview functionalities inform the user right from the beginning about quota demands and feasibility, so that unfeasible datatakes and requests that exceed the quotas are rejected at once and are not fed into the system. The user always has the information at hand to optimize the ordering process according to his wishes: he could order a large amount of low priority or only a few high priority tasks. The limitation of the user helps the mission planning process to concentrate on its main purpose: finding a feasible and optimal plan to stay within all resources and to perform a high percentage of all requests. User feedback mechanisms inform the users automatically about the status of their orders during the planning process.

To make sure that the demands of all user groups are fulfilled as good as possible, a strategic planning group with representatives from all user groups, the mission management and mission planning will be established (see figure 1). This group, meeting periodically, e.g. monthly, has got all the rights to adjust the apportionment control to match the actual user needs or reach specific mission goals. The main tasks are the analysis of the existing order status, defining the mission goals and set the order quotas for each user group for the next time frame. It could decide for experimental campaigns to be flown in one of the next cycles, or could prefer one user over the over for a period of time. The strategic planning group also decides on changes in the mathematical formula which maps the user requests to the quota usage in order to adapt to changing mission goals or user behaviour. The priority levels a user group is allowed to use also may change.

The mission planning system supports strategic planning by providing appropriate means: Quota usage statistics with respect to the user groups will be generated and may be used by the different participants for discussing on how to distribute the user quotas in the next time frame. Potential conflicts, like overlapping data requests or overbooking in a certain time span, are located at an early time and, if no automatic solution is possible, may be presented to the strategic planning group for further discussions. Monitoring the satellite resources helps identifying shortages in the TerraSAR-X ground segment and enables the strategic planning group to search for solutions like using additional ground stations for downlink.

Wurman et al. (2001) and the references therein give an overview of the actual research regarding auction mechanisms for free market systems. Further investigations are necessary to decide whether the scenarios presented there are applicable to the TerraSAR-X strategic planning system with its restricted degrees of freedom for the users. The system is not a ”free market” comparable to e.g. ”Ebay”: The user cannot put as many bids as he likes for one datatake. The system hinders him to update a datatake to a higher priority without any effort: A higher ”bid” for a datatake requires a cancellation of the previous ordered one, and cancellations cannot be done without consulting the responsible user help desk. An auction system with quasi continuous bidding would contradict the user wish of having a predictable timeline. Additionally, requesting one datatake can have influences on datatakes at completely other locations in time and space. However, intensive tests of the mission planning subsystem alone as well as its interplay with the other ground segment modules will show eventual existing problems early enough to resolve them until mission start. During the nominal phase, the strategic planning group will deal with misbehaviour by adapting the system or negotiating with the different parties.

Apart from the strategic planning group, no human involvement is necessary. Thus, the nominal planning process is still automatic.

3 Summary

This paper presented an overview of the mission planning system for the new radar satellite TerraSAR-X. Due to the manifold potentials of the satellite and the high demands from the user side, an automatic planning system is essential. Estimations show that the system will have to handle up to 1000 user request per day. Without order limitations, the system would be overloaded within a short time, a great fraction of the user orders could not be fulfilled and there would be no way of managing the payload operation to reach envisaged mission goals.

The strategic planning concept, although limiting the freedom of the individual user, helps to build optimized payload and ground segment schedules. Together with the fully automatic planning process, the TerraSAR-X mission planning system shows the following advantages:

- It assures the fair sharing of the satellite resources.
- It maximizes the probability that orders entered into the system will be performed within the given time frame and thus leads to the desired customer satisfaction and acceptance.
- The users get all information about the feasibility, the status and status changes of each order immediately (online).
- Each user or user group can decide about the priority of his or its orders and thus influence the probability that the datatake will be performed. User groups can distribute their quota internally.
- The number of overall orders is limited to a meaningful amount with respect to the bottle-neck resource availabilities and system performance.
- Possible conflicts are avoided in advance instead of solving them during the original planning process.
- The system is flexible enough to be adapted to changing user demands during the mission.
- Even if users ordered in a for them disadvantageous way and exceeded their quotas with only a few requests, they could still put in low priority background orders and the payload would not be idle.
- At any time in the mission, all means will be provided to allow the mission management analyse the current situation.

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