TerraSAR-X Mission Planning System: Automated Command Generation for Spacecraft Operations

E. Maurer, F. Mrowka, A. Braun, M. P. Geyer, C. Lenzen, Y. Wasser, M. Wickler

***Abstract*—On June 15th 2007 TerraSAR-X was successfully launched from Baikonur, Kazakhstan. On board TerraSAR-X, a high resolution X-Band Synthetic Aperture Radar (SAR) instrument is being operated as the primary payload. The user community requesting SAR products is composed of commercial and scientific partners as documented in a Public-Private-Partnership (PPP) agreement. The operations of the TerraSAR-X bus as well as payload operations are performed by the Mission Operations Segment (MOS). The Mission Planning System (MPS), a part of the Mission Operations Segment, has been designed to handle complex payload and standard bus operations in an automated manner. The purpose of this paper is to describe the concepts and the TerraSAR-X realization of the Mission Planning System.**

***Index Terms*—Mission Operations Segment, Mission Planning, Timeline, Scheduling, TerraSAR-X**

I. Introduction

The TerraSAR-X ground segment consists of the Payload Ground Segment (PGS), the Instrument Operations and Calibration Segment (IOCS) and the Mission Operations Segment (MOS) [1][2][3][4]. The Mission Operations Segment hosts the TerraSAR-X control room and is responsible for overall spacecraft operations. This includes satellite bus control, orbit maintenance, up- and downlink encryption, data downlink and payload operations. The Synthetic Aperture Radar (SAR) instrument is classified as the primary payload, while the on board Tracking, Occultation and Ranging payload (TOR) and the Laser Communication Terminal (LCT) are considered as secondary payloads.

Satellite and payload operations are carried out by MOS system engineers and a multi-mission command operator team. Long term system monitoring and contingency operations are performed by the system engineer team, while multi-mission command operators guarantee satellite surveillance 24/7 for the whole year. Orbit maintenance tasks are performed by the Flight Dynamics Subsystem [5][6]. SAR instrument operations consist of two main aspects: On one side, the SAR instrument calibration and monitoring activities need to be accomplished; on the other side, routine payload operations, in order to execute users' acquisition requests must be carried out. The first aspect is covered by the SAR instrument team from the Instrument Operations and Calibration Segment (IOCS) and completing the Mission Operations Segment (MOS) subsystem engineer team. Routine SAR payload operations are handled by the Mission Planning System. Instrument calibration results are entered into the Mission Planning process via the Request to Command Converter service (R2CC) (see Section IV) provided by IOCS. On request of the MPS it delivers detailed instrument parameter settings for SAR data takes.

Routine payload operations issue the following challenges for the MPS:

-- As a consequence of limited satellite resources, only a part of the requested SAR data takes can be executed. The MPS has to select a subset of all requested data takes whose acquisition is compatible with the technical aspects of the satellite.

-- The execution of SAR data takes entail the performance of accompanying activities, for example file handling tasks, downlinks or switching between different instrument activation levels. These tasks need to be scheduled together with the SAR data takes.

Due to a wide TerraSAR-X user community, the Mission Planning System has to deal with a high number of SAR acquisition requests. The MPS design was driven by the requirement that the system must be able to handle peak loads of up to 500 acquisition requests per day. In practice, during the operational phase an average of 60 to 70 acquisition requests are posed to the TerraSAR-X ground segment per day. The high number of acquisition requests, as well as the need for additional payload tasks cause a complex payload timeline (in the order of 800 commands per day).

Furthermore, short order - delivery response times of SAR images are often demanded, for example in commercial or disaster monitoring applications. Therefore, the scheduling process needs to be re-worked frequently (for TerraSAR-X

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timing details refer to Section II).

The problem of generating a complex timeline in short time intervals can only be managed with a high degree of automated command generation. Therefore, the TerraSAR-X Mission Planning System has been developed as an End-To-End automated processing chain [7][8]. The complete TerraSAR-X Mission Planning System has been designed and implemented at the German Space Operations Center (GSOC), DLR, at Oberpfaffenhofen (Germany).

The principal output of the MPS is the master timeline, which is a sequence of commands with execution times. In addition to SAR payload commands, it also contains standard repetitive tasks for bus operations. It is converted into an interpretable format for the mission control system. During ground station contacts, the master timeline with the commands to be executed on board is transmitted via S-Band link to the spacecraft. The uplink is initiated in the TerraSAR-X control room by the multi-mission command operator on duty.

In detail, the master timeline embeds the following tasks for spacecraft operations:

-- Commands for SAR instrument operations

-- Commands for switching transmitters on and off for both S- and X-Band (the S-Band is used for telecommand uplink, as well as for satellite telemetry downlink, while the X- Band is used for SAR data downlink)

-- Commands for satellite housekeeping dumps

-- Commands for on board key handling for downlink encryption

-- Commands for spacecraft attitude roll maneuvers in order to enable non-standard SAR instrument orientation for left-looking acquisitions

Instrument operations include the command generation for:

-- SAR data takes

-- On board file handling (allocation and deletion of SAR data files)

-- SAR instrument sleep levels, controlling the different activation stages of instrument powering

-- Encrypted SAR-data downlink

-- On board memory configuration changes for SAR acquisitions with a split antenna.

II. MPS Challenges

The most demanding challenge for the TerraSAR-X MPS is to determine a safe, technically feasible timeline which satisfies the user goals as far as possible. Since the TerraSAR-X mission is implemented in a Public-Private-Partnership (PPP), the MPS receives acquisition requests originating from both user groups, commercial as well as scientific [9]. In general, the acquisition requests compete against each other for satellite resources and not all of them can be executed.

The technical satellite aspects relevant for payload execution have been formulated in nearly 100 constraints. Satellite capacities have been abstracted in mathematical resource models. Payload activities in general affect one or more resources. A technical feasible payload timeline must not violate the upper or the lower limit of all resources.

In the course of a Mission Planning run, all data takes with a potential acquisition time in the planning time horizon are regarded. In the master timeline scheduling process, the feasibility of data take combinations is checked with respect to all applicable constraints. In general, the master timeline including all data takes as requested by the user may lead to a violation of satellite resources. Therefore in most planning runs only a subset of all data takes ordered for acquisition in the regarded planning time horizon can be executed (details on the selection algorithm are described in Section VI).

TerraSAR-X customers have a strong interest to place their acquisition requests as late as possible. They are allowed to order a few hours before the S-Band uplink contact preceding the data take's execution. This creates high demands on the MPS processing performance. Currently, the order deadline is fixed to six hours before the upcoming S-Band contact. In the near future, the deadline will be decreased to 1h 50min for test purposes. For Short Notice Planning (SNP), with limited timeline update, a deadline of only 45min has already been achieved [10].

In order to be able to accept late-input orders for SAR data takes into account, the planning process has to be repeated before each upcoming S-Band uplink. The part of the master timeline containing commands to be executed between the upcoming and the following uplink has to be uploaded to the spacecraft in the upcoming S-Band contact. However, for operational continuity it is desirable to load more commands on board than absolutely necessary. This ensures error tolerance against possible future uplink failures. The balance between short-term response time and mid term commanding means that the MPS has to support a re-commanding feature. The chosen concept is detailed in the following.

III. MPS Commanding Concept

The Mission Planning scheduling process is triggered 6 hours before each uplink session (an uplink session is defined as the set of one or two close consecutive ground station passes with S-Band uplink support). During the Mission Planning process, a timeline starting from the upcoming uplink reaching three days into the future is established. The length of the planning time horizon of three days assures that midterm constraints in a range of up to three days can be handled.

The temporal section of the master timeline starting from the end of the upcoming uplink session until the end of the second following uplink session is extracted and the spacecraft is commanded accordingly (see Figure 1).

The definition of the extracted time interval shows the following advantages:

-- Even the failure of an entire uplink session does not lead to an interruption of the SAR operations.

-- At any given time, the MPS has to deal with only two overlapping timeline extracts. This keeps the re-commanding complexity for the MPS to a reasonable limit.

The overlapping timeline extracts can be handled using the MPS re-commanding feature. Due to late inputs, the newly generated timeline (referred to as timeline n+1) can differ from timeline n, which was generated before the previous uplink session. The MPS is able to determine the difference between timeline n and timeline n+1 on a single command level. Timeline n+1 may contain new commands compared to timeline n. Also, timeline n might include commands which are no longer valid and shall not be executed according to timeline n+1. For uplink, the MPS delivers a command file to correct the difference between timeline n and timeline n+1. Newly inserted commands and on-board deletion commands for obsolete tasks are embedded.

The mechanism is robust with respect to uplink failures: It is always ensured that a technically correct timeline is on board, which can be executed safely. The only consequence of an uplink failure is that late input orders are not executed.

IV. MPS Interfaces

The fact that the MPS is a central point for SAR operations is reflected in a high number of interfaces. Figure 2 shows the input to the MPS, whereas Figure 3 details the MPS output to various systems.

The principal input to the Mission Planning System comes primarily from the TerraSAR-X users. Desired SAR acquisitions are forwarded in form of acquisition requests by the Data Information and Management System (DIMS, part of PGS) to the MPS. For calibration [11], maintenance or specific scientific purposes, the System Engineering and Calibration (SEC) user from the Instrument Operations and Calibration Segment (IOCS) may introduce non-standard orders using the system order interface. Since the TerraSAR-X reference orbit needs to be precisely controlled, orbit maintenance tasks have priority to SAR acquisitions. Therefore, the Flight Dynamics subsystem ingests information on necessary SAR outages due to orbit correction maneuvers. Furthermore, precise corrections to the reference orbit are automatically transferred from Flight Dynamics to the MPS. X-Band ground stations, for SAR data reception, provide input on their availability times and the GSOC internal scheduling department provides information about the scheduled S-Band uplink contacts.

Using a dedicated internal website, the command operator in the TerraSAR-X control room provides feedback up to which point the master timeline was successfully transmitted to the spacecraft. This command feedback is given after each S-Band uplink session.

As described in Figure 3 the central interface of the MPS is the spacecraft itself. The master timeline output is transmitted to the satellite via the commanding system. Furthermore, the ground segment needs secondary information. X-Band downlink stations require detailed information about which passes will be used for future downlinks and which data takes are included in the data stream. In order to provide the X-Band ground stations with keys for the decryption of the SAR data from the spacecraft, the MPS informs the key management facility about commanded X-Band downlinks. Subsequently, the key management facility exports the corresponding keys to the ground stations. To guarantee the success of the commercial as well as scientific exploitation, it is essential to provide the users with up-to-date information about the status, progress and feasibility of the requested SAR data takes. In addition, a defined set of products containing detailed information about performed data takes is delivered to the IOCS to support long term archiving and for monitoring purposes.

The Request to Command Converter (R2CC) service, already mentioned in Section I, is called by MPS for each single data take. The MPS delivers the satellite position and velocity during data take execution, the selected radar beam and 3-dimensional information on the footprint of the radar beam on the Earth’s surface. On return, the R2CC provides detailed parameters for SAR data take commanding and resource consumption.

The Swath Preview is a service provided by the MPS: On request, it provides the possible image acquisition times and incidence angles for a desired geographical region. This service is used by the PGS and is integrated into the ordering process.

V. MPS architecture

The design of the Mission Planning System was driven by the following requirements:

-- The MPS has to be able to receive inputs at any time.

-- The input content has to be preprocessed for master timeline scheduling purposes.

-- All input information and parameters derived in the preprocessing has to be accumulated and stored in a central place.

-- Whenever an S-Band uplink session is coming up, a new version of the master timeline has to be generated and the derived commands must be provided for uplink.

Continuous input reception capability is ensured by the File Ingestion and Acquisition Request Ingestion modules. The File Ingestion receives all XML files, such as system order inputs, Flight Dynamics information and ground station availability times. The Acquisition Request Ingestion module consists of a standard SOAP (Simple Object Access Protocol) interface to the Data Information Management System (DIMS), forwarding all user acquisition requests.

Whenever input is ingested via the File Ingestion or via Acquisition Request Ingestion, further preprocessing is triggered. Follow-on software modules are automatically activated using Windows Message Queues. When ground station availability times are ingested into the MPS, the File Ingestion module triggers the Opportunity Calculator, which determines the exact station contact times. Acquisition requests also have to be prepared for scheduling. A single acquisition request may lead to a set of data takes in case the desired geographical region of interest cannot be covered by a single data take. The Coverage Splitter module, which is activated by the Windows Message Queues, selects a set of data takes for execution, which completely covers the specified region. In the acquisition request to data take preprocessing chain, a third module comes into play: the R2CCListener. It acts as the MPS interface to the R2CC service. For each data take, various information like the on board memory consumption or the minimal temporal distance to previous data takes are determined prior to scheduling making use R2CC service.

All applications displayed in Figure 4 (except for the Swath Preview, which is introduced later) read from and write to the MySQL based MPS database, the central element of the Mission Planning System. The MPS database contains all information on the SAR acquisition requests/ data takes, master timelines and models of satellite resources as a function of time. All information is archived on midterm scale, cleaning is done roughly once per year.

In addition to the fact that the MPS database serves as the working platform for the MPS modules, it also plays a key role in routine operations. The MySQL Query Browser offers the operations team the possibility to directly access the MPS database and to retrieve combined information using the Standard Query Language (SQL). Experience from the TerraSAR-X mission revealed that a direct and flexible access to the MPS database is necessary in spacecraft and ground contingency cases. The delivery of user information after contingencies has been often requested as well as the provision of statistical information. For the Mission Planning System engineers, the direct write access offers an easy way to adapt the MPS resource models to the situation on board in contingency cases.

In contrast to the highly dynamic MPS database, the Footprint database is a static product. It correlates possible acquisition times to footprints of the radar beam on the Earth's surface. The illuminated area, the SAR swath, depends on orbit geometry, S/C attitude and beam definition of the SAR instrument. Since TerraSAR-X is flying on an eleven-day repeat cycle, it is possible to pre-calculate all feasible SAR swathes on the Earth's surface with respect to an eleven day basis. The result is stored in the Footprint database, which has been calculated by the MPS prior to the launch. Information of swathes for any point in time is extracted by the MPS using the Footprint database. One copy is hosted in the MPS operational network environment, another copy is provided for external access.

The core task of the MPS is the provision of new versions of the master timeline, following the rhythm of available S-Band uplink stations. The master timeline scheduling chain consists of the modules Prepare Scheduler, Scheduler and Command Exporter. The modules run in exactly this sequence, where each triggers the following via Windows Message Queues. The first module, the Prepare Scheduler, is triggered by the MPS Timer, which recognizes that an uplink session is coming up. The Prepare Scheduler evaluates the on board resource situation due to the master timeline executed before the upcoming S-Band uplink station. The result provides the initial condition for the Scheduler, which selects the subset of feasible data, takes and embeds them together with all tasks listed in Section I into a timeline. The resulting timeline is stored in the MPS database. Finally, the Command Exporter generates the output files, which are sent to the spacecraft. Furthermore, the Command Exporter supports the MPS re-commanding feature, described in Section III, and compares the updated timeline to the previous one.

After each S-Band uplink session, the command operator provides feedback to the MPS using the internal Command Feedback web page. The information by the command operator closes the chain: The Prepare Schedule, Scheduler and Command Exporter run before the follow-on uplink session are based on the operator information up to which point the previous master timeline version has been successfully sent to the spacecraft.

The Status Report Generator sends status information on acquisition requests and attached data takes to the Data and Information Management System (DIMS). Its functionalities can be triggered externally by DIMS on demand at any time. Additionally, a status message is actively sent by the MPS to DIMS; for example, whenever a data take has been commanded or acquired. The Status Report Generator triggered on external demand or in the master timeline generation rhythm, is graphically oriented in the middle of Figure 4 reflecting its position in the MPS architecture.

The Swath Preview, already introduced in Section IV, is located in an environment allowing external access. Its internal algorithms are based on the footprint database described above.

VI. Scheduling

The Scheduler is the core component of the master timeline generation work-flow. As described in Sections II and V, it selects a subset of all desired data takes which are compliant to the available satellite resources and includes them into the timeline. To manage conflicting orders, a priority concept has been developed in the TerraSAR-X ground segment: The user groups assign a priority to each acquisition request. The acquisition priority ranges between 0 (lowest priority) and 9 (highest priority). In case of conflicting orders, the data take with the higher priority is performed. If the acquisition priority is identical, the data take which has been ordered earlier is preferred.

The scheduling work-flow is handled as displayed in Figure 5. All data takes which have an opportunity in the timeline horizon are selected. An opportunity is defined as the time interval when the region of interest is visible, with respect to the TerraSAR-X orbit geometry. From the data take set with opportunity, the one with the highest priority is selected. Thereafter, the corresponding data take triple is preliminarily scheduled. A data take triple consists of three components: the data take and its up- and downlink. The SAR data file allocation and data file deletion are regarded as part of the up- and downlink, respectively. The scheduling of the data take triple is done in the following way: The data take is placed into the timeline in its first opportunity. The resulting changes in the instrument activation timeline, referred to as the instrument sleep levels, are updated. In the next step, the uplink, followed by the memory file allocation, is scheduled. This is done as late as possible in order to avoid unnecessary blocking of memory resources. The downlink, including the subsequent file deletion, is scheduled as soon as possible. Once the data take specific changes have been embedded in the timeline, the result is checked against all constraints describing the satellite conditions. In case no conflict is detected, the data take triple changes are accepted. If the preliminary timeline is not feasible, the data take triple changes are withdrawn. In case further follow-on opportunities exist, the scheduler tries to move the data take triple to these opportunities. If all data take opportunities are exhausted, the scheduling process for this data take is stopped. In any case, if the data take triple could be finally scheduled or not, the process is repeated for the remaining data takes. Next, the one with the next highest priority is selected. The algorithm is repeated until every data take with an opportunity in the timeline horizon has been treated.

Because TerraSAR-X is flying on a reference orbit with an eleven-day repeat cycle and the planning horizon is fixed to three days (see Section III), the scheduling process is slightly simplified with respect to Figure 5. Each data take has a well-defined starting time within the eleven day repeat cycle. Consequently, within one three-day scheduling process only one opportunity of each data take has to be considered. This means that either a data take is placed in the timeline at the one and only opportunity, or not at all. However, depending on the acquisition time window specified by the user, the data take may have further opportunities in the follow-on eleven-day repeat cycles. But these opportunities lie beyond the considered timeline horizon of three days. They have to be respected in later scheduling runs. If the execution of the data take is not feasible within the acquisition time window, the order expires and the user has to place a new one.

After scheduling of each data take triple, the compliance with all constraints is checked. All satellite and ground boundary conditions have been formulated in nearly 100 constraints to be fulfilled. Experience from the commissioning and operational phase confirmed that, beyond the obvious fact that only one data take may be executed at the same time, the resources memory consumption and orbit usage are most frequently exhausted. The term ‘resource orbit usage’ refers to a limitation of the sum of all data take durations in a time interval of one orbit length.

Resource availabilities at the start of a new timeline are calculated on basis of the on board executed timeline by the Prepare Scheduler (see Section V). The resource profiles extrapolated by the scheduler can be visualized by the MPS application PINTA (Program for INteractive Timeline Analysis).

VII. Operational Experience and Contingency Operations

The Mission Planning system, with its complexity as detailed in this paper has been specifically developed for the TerraSAR-X mission. Most of the components were not operationally validated in former missions. Nevertheless, the TerraSAR-X Mission Planning System was used for SAR instrument command generation from the very beginning of instrument operations. Even the very first SAR data take acquired near to Wolgograd, Russia, on June 19th 2007 has been commanded by the MPS. However, during the first two months after launch, each Mission Planning run required manual inspection by the MPS system engineers and the master timeline needed to be corrected occasionally. In this context, the timeline visualization tool PINTA revealed to be indispensable. Error detection in the complex master timeline is only feasible if major spacecraft resources and its allocation by activities in the master timeline is graphically displayed.

After two months of supervision, the TerraSAR-X MPS had sufficiently proved its reliability. Since then, the MPS is running fully automated and extensive supervision by the MPS engineer team is no longer required.

Nevertheless, the MPS still requires support of a three person operations team to fulfill the following tasks:

-- On call support and routine supervision of the MPS functionalities

-- Answering questions from users

-- Provide statistics for the management about the utilization of the SAR-Instrument

-- Inform the ground segment in case of interruptions of the SAR timeline execution due to ground or spacecraft contingencies

-- Testing new MPS software versions before the integration into the operational system

The MPS has all information on acquisition requests, executed master timelines, satellite resource usages, S- and X-Band downlinks at disposal in the Mission Planning database. Therefore, the MPS operations team is often asked to provide the ground segment, the users or the management with detailed information. The last point in the list above, the MPS software test, turned out to be the most demanding and time-consuming one. The TerraSAR-X Mission Planning System is obliged to evolve continuously, primarily during the commissioning phase but also during the operational phase. New aspects in the ground or space segment have been discovered during operations or special campaigns needed to be supported. In order to cope with numerous component updates extensive system tests have been necessary.

Spacecraft contingencies may require manual interaction into the Mission Planning System. In the TerraSAR-X operational phase the MPS team has faced different kinds of impacts on the system:

-- The execution of SAR data takes is not desired due to an on board contingency: In this case, a maintenance phase of defined duration can be entered into the Mission Planning System via a dedicated Web Site. Consequently, the MPS automatically generates an output file containing the deletion commands of all SAR data takes originally planned during the maintenance phase. The downlinks and file deletions for already executed data takes are not deleted. The fully automated MPS mode does not have to be interrupted. SAR operations do not suffer any additional outage due to MPS resets.

-- Due to contingencies, individual data takes are corrupted: The MPS distributes lists of affected data takes, but again the fully automated mode can proceed.

-- The uplink of a master time line fails: As a consequence the resource models in the MPS data base differ from the real situation on board and the automatic planning process needs to be interrupted. The MPS resources must be reset to the situation after the last successful uplink. The MPS automatically generates backups of the MPS database after and before each planning run. For recovery, the backup after the planning run before the last successful uplink is restored by the MPS operations team. Up to now, the automatic planning mode could always be resumed before the follow-on uplink session. Due to the MPS commanding concept (see Section III) SAR operations do not suffer any interruption.

-- The MPS internal resource models are out-of-sync with the real on-board situation: This situation can be induced if for example, file handling tasks are not executed due to spacecraft contingencies or erroneous commanding. Several recovery strategies have already been practiced. Manual commands were sent to re-execute failed tasks. Therefore, the on-board resources were adapted to the MPS models. The other way around direct access to the MPS database allows the MPS operations team to directly adapt the available resources to the on board situation. Both strategies could only be applied if the situation was clear and manageable. As a last resort, the MPS was reset by adapting all resources to the initial start values. On-board, all resources need to be freed as well. The master timeline on board must be cleared from any instrument commands and all files in the on board memory must be deleted. This situation was experienced twice in the operational phase, once due to a spacecraft contingency and once due to erroneous commands. The interruption of the SAR outage due a complete reset is in the order of one day.

VIII. Conclusion

The TerraSAR-X Mission Planning System is an End-to-End automated processing chain adapted to the needs of TerraSAR-X operations. It has been successfully applied since day 4 of the mission. The MPS schedules activities for payload operations as well as repetitive standard transmitter switching and housekeeping dumps. The outstanding characteristics of the TerraSAR-X MPS are:

-- It is fully automated.

-- Complex payload operations are successfully handled; the master timeline is checked against nearly 100 constraints during the scheduling process.

-- The TerraSAR-X MPS is able support automatic re-commanding. Executing acquisition requests with very late order time and sufficient acquisition priority may require the deletion of already commanded low priority data takes.

-- Successful strategies to handle impacts on the master timeline generation due to contingencies have been developed.

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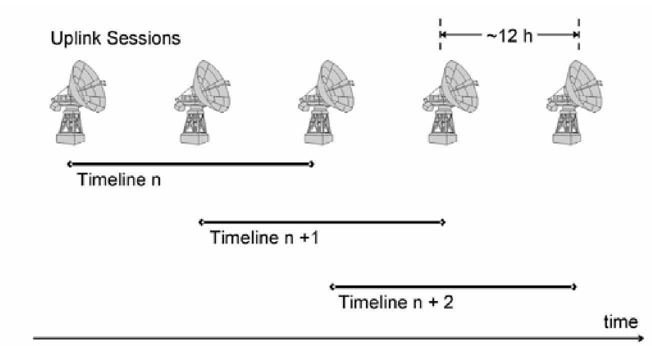

Fig. 1. Schematic overview on the Mission Planning Commanding concept. Each antenna symbol represents the support of an S-Band uplink session. In the standard TerraSAR-X ground station network two uplink sessions are supported per day with time separations of approximately 12 hours. For each uplink session a new timeline version is generated and an extract is provided for uplink. The timelines are numbered consecutively. Each timeline starts after the uplink of timeline n and ends after the uplink of timeline n+2. Thus, at any given time, exactly two timelines overlap. Recommanding has to be supported comparing two timelines only. In case of uplink session failure, the continuity in SAR operations is assured.

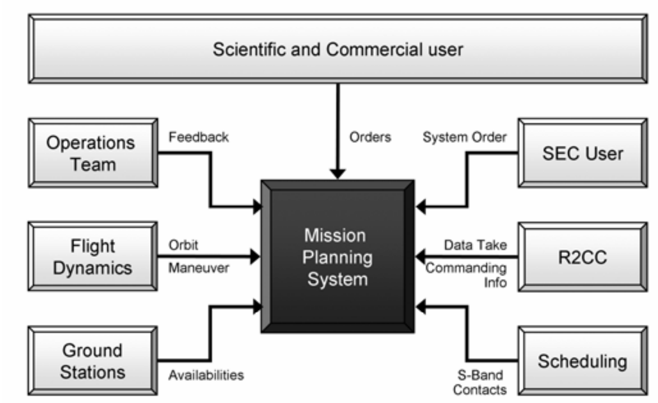

Fig. 2. Information flux from the ground segment to the Mission Planning System: Interface partners are displayed in rectangles with light grey scale, whereas MPS is shown in dark grey scale. The extended bar on top represents the wide TSX SAR user community. For non standard order an interface to the System Engineering and Calibration (SEC) user has been established. Arrows indicate the information flow towards Mission Planning. The interface content is briefly described next to the arrows. The Data Information and Management System (DIMS) in between the user and MPS is not displayed for simplicity.

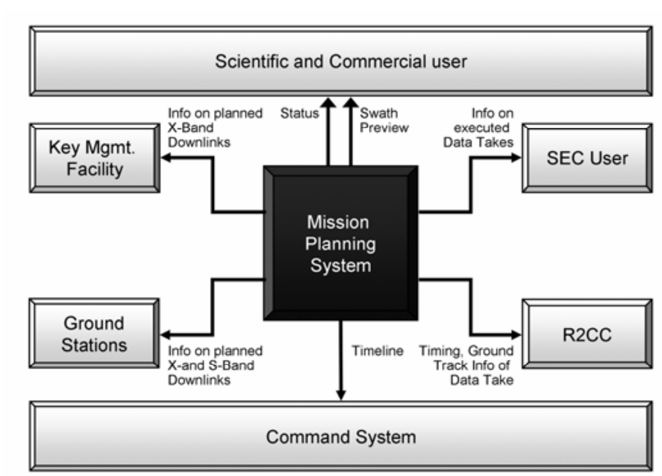

Fig. 3. Information flux from Mission Planning to the ground segment and the spacecraft: Interface partners are displayed in light grey scale. The extended bar on top represents the user community. The principal output of Mission Planning, the timeline, is sent via the Command System to the spacecraft. For each interface the direction is symbolized by arrows and the content is briefly described next to the arrow. System Engineering and Calibration is abbreviated by "SEC".

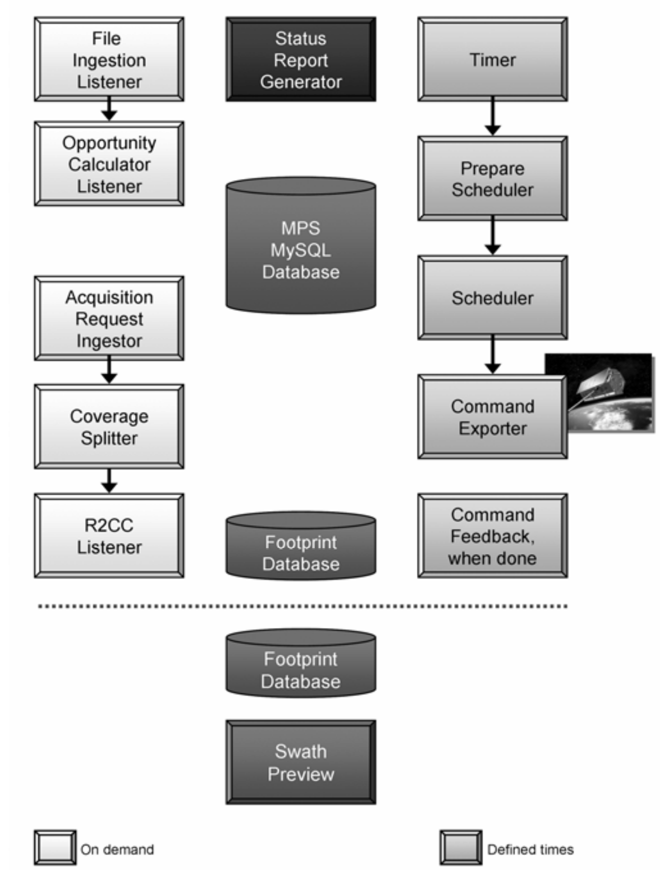

Fig. 4. Simplified Mission Planning System Architecture: Software Modules are represented by rectangles in different grey scales. Databases are displayed with cylindrical shapes. Mission Planning items are hosted in two different network environments. The division is indicated by the dashed line. The upper part is, compared to the lower one, situated in a more protected and safer environment. Light grey applications on the left hand side, are part of the input preprocessing chain. The modules are triggered if the corresponding input has been received (on demand). Applications on the right hand side represent modules in the master timeline generating process. Timeline generation is triggered before a planned uplink (defined times). Arrows connecting modules on both sides, mark a direct communication between the previous module and the following module via Windows message queues. User notification on Acquisition Request status is assured by the software module Status Report Generator. The MPS MySQL Database is the heart of the Mission Planning System. All modules in the same network read from and write into the database. The footprint database is a static collection of all possible swathes for SAR acquisitions on Earth for the eleven day repeat cycle. One copy of the footprint database is located in each network environment. The Swath Preview Service is called by users prior to SAR image ordering. It returns visibility times or incidence angles for the potential future acquisitions.

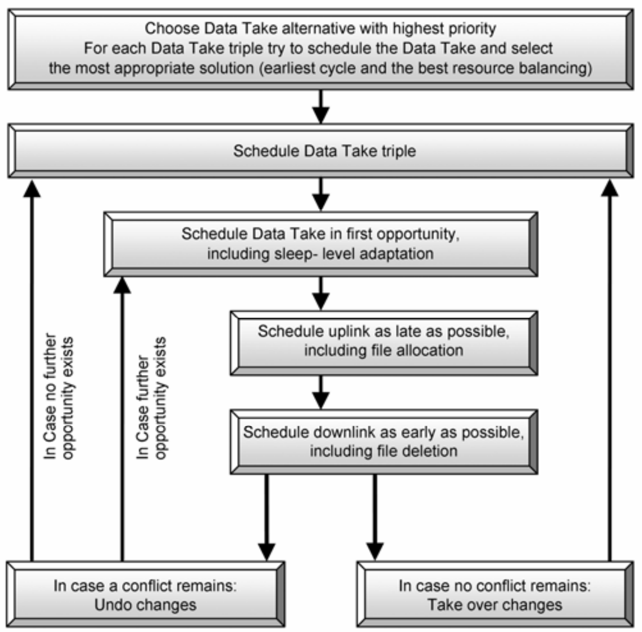

Fig. 5. Schematic scheduling algorithm: A well defined priority sequence is given for the pool of data takes with opportunity in the timeline horizon. The scheduling process loops over all data takes following the priority sequence. For each selected data take in the chain, the data take triple is scheduled on a trial basis. Depending on the result of the succeeding conflict check, the data take triple is accepted or rejected. In case of a negative result, further opportunities are tested. Afterwards, the next data take in hierarchy is selected.