ANALYSIS OF SENTINEL-1 MISSION CAPABILITIES

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ABSTRACT
Sentinel-1 mission is designed to be a source of continuous and reliable collection of C-band SAR imagery. As part of the complete family of GMES Sentinels, Sentinel-1 guarantees continuity of C-band SAR data and products availability to scientific and institutional users who exploit satellite radar imagery since ERS 1 operations.

Drivers for EO satellite missions operations are typically fast reaction and response times but also, in the case of Sentinel-1, complete Earth surface coverage within every orbit repeat cycle (12 days). Sentinel-1 mission capabilities and the defined operational scenario currently selected by the ESA Mission and System Manager will be presented in this paper.

1. INTRODUCTION
The Sentinel-1 (S-1) satellite operates in a sun-synchronous repeat-track low earth orbit at about 700Km of altitude; the repeat cycle is 12 days with 175 orbits. The spacecraft is a 3-axis stabilized satellite, weighs about 2300 Kg and implements cut-edge technology on power and propulsion subsystems, to support very challenging requirements regarding orbit and attitude manoeuvres and payload operations.

The S-1 payload is a multi-mode dual-polarisation C-band SAR operating in TOPSAR [2] (Interferometric Wide Swath and Extra Wide Swath), STRIPMAP and WAVE (sampled STRIPMAP) modes. The continuous and systematic data acquisition and download required for the S-1 mission asks for identification of predefined Mission Timelines, i.e., sequences of SAR imaging fulfilling as much as possible the mission operational drivers and requirements, in line with system sizing and resource constraints, such as:

- a frequent revisit of specific “high-priority” areas of interest (e.g. maritime transport zones). This means that data over some regions should be taken as often as possible, in principle every time the satellite overpasses them.

Mission analysis tasks in the frame of the GMES S-1 program identify realistic mission operational scenarios to demonstrate the capabilities of the system. The ESA selected scenario foresees usage of the main S-1 SAR mode, the Interferometric Wide Swath, to acquire data over land masses, ice areas and maritime transport zones, while oceans are acquired in WAVE mode. Interferometric Wide Swath (IWS) is a TOPSAR mode (ScanSAR with progressive azimuth scanning) and provides a swath larger than 250Km covering a range of incidence angles from about 30° to 46°.

The satellite is able to operate for up to 25 minutes per orbit in any SAR imaging mode, including IWS. This is one of the main constraints to be considered in the search of realistic operational scenarios. Furthermore, to get realism and flexibility, the operational mission timelines have to be feasible whatever their start time is; this adds a remarkable goal to the task which forces system resources exploitation to be independent from where the operations start time is placed. The concept of moving time-windows must be applied.

\[\text{Figure 1: Moving window concept}\]

Figure 2 shows the access times, per orbit, over the IWS acquirable regions. The simple approach to acquire data at
every single access opportunity is not possible since it would need satellite operational capability per orbit largely exceeding the available 25 minutes.

2. SYSTEMATIC ACQUISITIONS

A number of software tools have been used to find an operational scenario fulfilling the well-defined criteria. The algorithm is based on point- and time-priority. Geographical points with fewer observation opportunities get a higher point-priority than frequently observable points (e.g. at high latitudes). Points with higher point-priority are the first to be inserted into the schedule. The other points are included into the schedule following a time based priority which depends on a number of factors such as the ascending/descending passes, number of SAR modes switches per orbit, etc.

A preliminary solution is presented in this section. Figure 3 shows the coverage performance of the scenario. The map provides, through a colour scale, the number of acquisitions to each location of the region of interest within the orbit repeat cycle (light blue means one only acquisition in 12 days, dark blue is more than 6 acquisitions in 12 days). Complete coverage is met, since all targets are acquired at least once within the orbit cycle. Some areas, in particular maritime transport zones and part of Europe (zoomed on the right of Figure 3), are observed several times (up to five accesses) and this allows the revisit time on such areas to be strongly reduced. The average revisit time is 2.7 days on maritime transport zones and 4.4 days on Arctic and Antarctic areas.

The conformance of the SAR schedule to the satellite operational duty cycle constraint of 25 min/orbit is shown in Figure 4, where the orbit-by-orbit acquisitions duty cycle is always below the maximum limit (red line). The constraint is actually satisfied over any 98-minute (one orbit long) time window, independent on the window start time (duty cycle on moving windows) as presented in figure 5. Figure 5 shows the histogram of the duty cycle computed along the whole orbital cycle for each of four instances of the moving window, represented by different colours, time-shifted by one-fourth of orbit with respect to each other.

Analyses take actually into account shifts of 30 seconds, resulting in about 197 moving window instances.
Figure 6 shows the value of the duty cycle of ten orbits for the same four instances of moving windows. The duty cycle variation is visible over each moving window (the shift of the orbits’ start time causes the inclusion in the orbits of different acquisitions), being in any case below the maximum limit (red line).

3. NON-SYSTEMATIC ACQUISITIONS

The scenario presented in Section 2 refers to a fixed pre-defined systematic SAR acquisitions sequence (Mission Timeline) designed to cope with pre-defined mission objectives. The possibility for the system to manage additional sporadic non-systematic or on-demand acquisitions, coming from acquisition requests submitted to the system (e.g. for management of emergency operations), are included in the mission objectives, and need to be reflected in the characteristics and “performances” of the mission timeline.

A reservation in the nominal mission timeline of spare capacity, during every orbit, for potential inclusion of probable on-demand orders would not properly fit with the Sentinel-1 operational concept. The Sentinel-1 mission, differently from other specifically designed Earth Observation satellite systems (like COSMO-SkyMed), is designed for systematic data collection and not for fast and prompt reaction to asynchronous on-demand requests. A reservation of spare capacity would result in an under-exploitation of available system resources to face with sporadic and un-frequent on-demand requests.

More complex analyses are needed to finalise the identification of the “optimal” operational scenario. What may happen when an on-demand acquisition request is presented to the system is that the first acquisition opportunity for that data-take is or is not already part of the nominal pre-defined mission timeline. In the first case, the nominal timeline (and its relevant data products) already fulfils the on-demand needs. In the second case, the mission timeline needs to be modified to include the acquisition satisfying the order; this may imply the replacement of some scheduled acquisition with the new one if residual operational duty cycle is not enough to simply plan an additional conflict-free acquisition to the timeline.

An emergency order is defined as any order for which the first SAR acquisition opportunity is “out of the nominal schedule”.

Based on the operational scenario in Section 2, the following emergency probability map is presented in figure 7. The gray tone on the map represent the probability that an on-demand order submitted for a particular location at any given time is an emergency order (white is probability = 0, black is probability=1). This probability is directly related to the ratio between the number of possible satellite accesses on a single target (acquisition opportunities) and the number of actual acquisitions scheduled in the nominal mission timeline weighted by the time gaps between the opportunities.

The emergency probability map only shows the regions where the need for addition to the nominal mission timeline of the relevant user acquisition is likely, but does not answer the question whether the addition is actually feasible. To derive the feasibility the current margin in the system resources needs to be taken into account.

Figure 8 addresses this issue. Only the cases where the inclusion of the on-demand acquisition yields to an overrun of the available duty cycle are added-up in the probability computation. Some dark strips in the map are apparent which show that emergency orders over those regions could not be included in the plan without replacement of other acquisitions in relevant “critical orbits”.

Figure 6: Duty cycle with a moving window approach

Figure 7: Emergency probability map
In Figure 8 many geographical zones are affected by the duty-cycle overrun probability, so that some mission timeline refinement is needed.

4. FINAL OPTIMISATION

The final step for the characterization of the optimal Sentinel-1 operational scenario consists in adjusting the nominal mission timeline in order to remove as much as possible “dark strips” without much loss on the main mission performance like global coverage or revisit time on high-priority regions.

As an example, one could in principle proceed identifying the acquisitions in “critical orbits” corresponding to the bright strips and shifting such acquisitions to other less critical orbits if and where opportunities exist. In this way, coverage would not be affected at all as well as average revisit time.

This exercise has been done successfully starting from the nominal timeline presented in Section 2 and relevant results are shown in the figures 9 and 10, where it is shown that global coverage is still achieved and revisit time on high-priority regions is still comparable with previous results (average revisit time is now 3.4 days vs. previous 2.7 days on maritime transport zones and 6.7 days vs. 4.4 days on Arctic and Antarctic areas); the duty cycle overrun plot is now much better than the previous one. This indicates that system operations driven by the new optimal timeline would meet the possibility to successfully react to non-systematic “external” requests in emergency circumstances.

5. REFERENCES
