Planning Area Coverage with Low Priority

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Abstract

There exist multiple papers about how to plan satellite image acquisitions in order to cover an area of interest which is larger than one image swath. All of these consider the case that the to-be-covered area is of greatest interest and that the resulting plan may be executed without disturbance.

Within the *EnMAP* mission however, images of higher priority are requested such that they are acquired using one pass only. Requests to cover a whole area are reserved for the background mission, which has lowest priority and is introduced to fulfill secondary mission goals on a longer time horizon. Planning for the background mission must therefore take into account that any time before sending the commands to the spacecraft, new requests may be received, whose acquisitions block planned acquisitions of the area coverage.

In this paper we describe the different options the *EnMAP Mission Planning* team considers to handle this scenario.

1 Introduction

In 2022, the *EnMAP* satellite will presumably be launched into a Sun-synchronous orbit (inclination = $97.96°$) with equator crossing time at 11 o'clock local time, heading South. On-board the *EnMAP* satellite, a hyper-spectral instrument will be mounted, which allows acquiring images of the Earth within an angle of $\pm 30°$. At nadir, a ground sampling distance of $30\,\text{m} \times 30\,\text{m}$ will be achieved with a swath width of about $30\,\text{km}$. The orbit and looking angle assert that each target is re-visited latest after 4 days. More details on the characteristics of the instrument may be found in [8, chapter 2.1] and [19, chapter 2].

The *EnMAP* mission allows two ways to image a region of interest: First, a customer can define a region of interest for which the *EnMAP Mission Planning* System (see [4, 17]) will then report possible imaging opportunities, from which he or she can then choose one swath that covers the area. In this case the area might not be imaged completely but only the patch corresponding to the selected swath. The choice which of the possible swaths is selected and later planned with a high priority is in the hands of the customer. In contrast, the second option, the area coverage request, aims to fully cover a region of interest on a longer time horizon. Here, the selection of the swaths that are imaged subsequently is done by the *EnMAP Mission Planning* System in the background.

The expected regions of interest for the *EnMAP* background mission are less than $1000\,\text{km}$ in diameter, which allows the imaging instrument to record swaths in one pass that correspond to the maximum extent of the target area. Uplinks to the satellite will be performed via the Weilheim ground station, which will be visible around 11 UTC and 22 UTC. The proposed algorithm therefore shall provide a rule how to generate and plan image acquisitions for area coverage requests for the upcoming ≈ 12 hours.

In the following chapters we will describe the challenges of implementing the area coverage request for *EnMAP* and we discuss possible solutions.

2 The Area Coverage Problem

Typically, an optimization of the problem at hand is performed for longer time intervals with the aim of covering the region of interest completely (see e.g. [10, 16, 18]). Such an approach is not applicable for *EnMAP*, because we expect many acquisitions of the low-priority area coverage requests to be blocked by future nominal orders, thus invalidating the previously found optimal solution.

Instead we only consider the upcoming export horizon, i.e. the time frame from the next uplink opportunity until the succeeding one, similar to [1]. The problem is thus broken down into several short planning horizons for which we have to select the currently optimal swath (of all possible swaths) which on the long run still yields a somehow good coverage.

2.1 Comparison with other solutions

In order to find suitable swathes, many planning systems discretize a region of interest using a suitable grid. In particular all planning systems which use *CLASP* ([2]) use this approach, e.g. *ECOSTRESS* ([21]), the *Orbit Carbon Observatory 3* ([12]) and *NISAR* ([3]). This approach is best described in [11]: the 2-dimensional region of interest is replaced by the set of the grid's vertices which lie within the area. This way, the overlapping part of two regions consists of those vertices which lie in both regions. The vertices may be prioritized based upon the priorities of the regions of interest to which they belong to. The selection of the best swathes therefore is driven by the goal to include as many vertices of as high priority as possible (the details about how to calculate and combine the vertices' priorities is project specific). *CLASP* also discretizes in time such that each time step can be seen as a variable. *CLASP*'s approach is to find strips, i.e. sequence of consecutive time steps with equal roll angles, that cover many high priority vertices and which can be combined according to the spacecraft's slew constraints. This way *CLASP* integrates the logic of coverage within the search algorithm, which allows *CLASP* to find synergies between different requests and generate plans which avoid unnecessary duplications. This should be particularly beneficial when planning a mission whose requests are known in advance.

For *EnMAP* the planning system shall consider each request as a unique and separate entity. If a region has already been covered within the desired circumstances, scientists may retrieve the respective data from the archive. Otherwise a request is sent to the *EnMAP* planning system, which shall be considered regardless of other requests of the same area. The *EnMAP* planning system therefore doesn't have to discretize the region of interest: For standard requests, it calculates the start- and stop-times and the roll angles of a request's image opportunity.

In order to extend *EnMAP* planning system to support area coverage requests, the non-discretized approach requires some non-trivial calculation methods for unifying and intersecting target areas and calculating the size of an area, in particular as the underlying *SCOTA* library (see chapter 2.3) does not implement a flat 2D geometry as provided by *Plains* (see [9]) but the geometry of an ellipsoid's surface, see [6]. Still it yields more precise results and should also reduce the size of the memory used to represent an area, as only the edges of the area need to be stored, not all vertices within.

2.2 Problem Size

According to the requirements posed by the *EnMAP* project, we shall be able to plan up to 50 image acquisitions per day, covering up to 5000 km swath length (as mentioned before: swath width at nadir is about 30 km). Assuming an oversubscription of the timeline of a factor 2, the *EnMAP* mission planning system must be able to cope with up to 100 datatakes per day, of which 50 may be planned. The planning horizon shall cover 2 weeks visible future and up to 1 week invisible future, in order to allow the timeline to stabilize before customers are informed about planned and unplanned requests. Additionally, we plan to keep 4 weeks of history in memory in order to allow browsing through the timeline using PintaOnWeb, our web-frontent for displaying and editing the model (see [15]). Our system therefore has to cope with

- $3*7*100 = 2100$ image acquisitions within the planning horizon
- $3*7*50 = 1050$ planned image acquisitions within the planning horizon
- $4*7*100 = 2800$ image acquisitions within the history
- $4*7*50 = 1400$ planned image acquisitions within the history

In addition to these, we expect up to 10 area coverage requests. In order to remove load from our system, in particular on orbit updates, and according to the low priority of the background mission, which allows any nominal request to block an already planned area coverage acquisition, the *EnMAP* planning system generates and plans swaths for area coverage requests not until their commands need to be exported. This means that only 12h of the planning horizon may contain acquisitions of the area coverage requests. Assuming that within a 12h time frame the target will be passed up to 2 times, for each of which up to 2 swaths are generated, the following numbers of acquisitions need to be added:

- 40 swathes within the planning horizon
- 20 planned acquisitions within the planning horizon
- $40*2*7*4 = 2240$ swathes within the history
- $40*2*7*4 = 1120$ planned acquisitions within the history

In total, the *EnMAP* mission planning system has to cope with

	planned	in model
planning horizon (3 w)	1100	2200
history (4 w)	2500	5000
total (7 w)	3600	7200

Table 1: Expected number of *EnMAP* image acquisitions in memory (rounded)

The *EnMAP* Mission Planning System is based upon the Reactive Planning framework, formerly known as Incremental Planning [20]. Its approach is to adapt the timeline immediately when new input is received. Due to the number of acquisitions within the planning horizon, a full optimization of the timeline can hardly be implemented with this approach, because an optimizing planning process may be outdated by new input long before it has finished. With a quick heuristic algorithm on the other hand, the system may inform the affected customers about newly ingested and adapted requests' states immediately. This way the customers may react immediately, e.g. place a different request in case their original request has been excluded from the timeline. Experiences from the *TerraSAR-X/TanDEM-X* missions, which have been analysed in preparation of the discontinued *TerraSAR-X II* mission, show that this reactive pattern is more valuable to GSOC's customers than an optimization of the timeline.

Therefore, instead of defining the common variable/value model of a *CSP*, the *EnMAP* mission planning system uses GSOC's modeling language ([7]) to easily model all relevant constraints and GSOC's planning library *Plains*, which allows finding conflict free timeline entries for swaths, which are previously generated by *SCOTA*.

When planning a new request's acquisition, the algorithm compares the priorities of possibly planned conflicting acquisitions with the priority of the new acquisition. If the new acquisition has greater priority, the previously planned acquisition will be displaced in favor of the new acquisition, i.e. the acquisition is removed and a different acquisition of the same request is added, if possible. The priority is, roughly speaking, calculated from the following criteria, the weight of each criterion is configurable:

- science benefit: a value assigned by the *EnMAP* science board
- cloud forecast and cloud statistics
  - as long as no cloud forecast is available: prefer acquisitions which are statistically less likely to be clouded
  - when a cloud forecast is available
    - for clouded acquisitions: set the priority below the background mission's priority
    - for unclouded acquisitions: prefer acquisitions, which are statistically more likely to be clouded
- timeline stability
  - prefer already planned acquisitions
  - prefer already planned requests

This separation of swath generation and planning allows avoiding any discretization, because *SCOTA* may calculate precise swaths without a grid; in principle this comes with the drawback that the planning algorithm is restricted to the pre-calculated swaths.

In the following sections, we describe how *SCOTA* tackles the problem to locally select swaths, which should result in a good coverage of the target regions on the long run. We will also provide some ideas how we intend to overcome the issue of overlapping swaths in the future, reducing or eliminating the drawback of separation of swath generation and planning.

2.3 Planning and Swath Generation

As mentioned in the previous section, on reception of new information the *EnMAP Mission Planning* System incorporates the new data into the model and updates the timeline accordingly. On reception of a standard Earth observation request, target swaths are generated using the *Mission Planning Spacecraft Orbit and Groundtrack Analysis Tool* (*SCOTA*) [6] and, if possible, one of these swaths is included into the timeline.

For standard requests, there exists no flexibility in creating the swaths: They are fully determined by the properties of the request and the orbit of the satellite. For each standard request the planning algorithm therefore calls *SCOTA* for swath generation once on reception of the request and once on every orbit update in order to generate and update the swaths.

For the area coverage the situation is different. It shall be used for the background mission only and therefore, as mentioned in the abstract, its goal is to cover its target regions, using available resources which remain after planning the standard requests. The task of the *SCOTA* swath generator therefore is first to determine all passes of the target area within the short planning horizon. For each of these passes, one swath shall be created which the planning algorithm may add to the timeline, either unmodified or shortened to solve a conflict in resources like *memory*, *power* or *instrument availability*. After all imaging opportunities have been determined, the second task of *SCOTA* is to select the swath per pass that contributes best to our goal to eventually cover the whole target area. As depicted in figure 1, the *EnMAP* satellite can turn in roll direction in order to point its instrument across-track. Thus, the *SCOTA* coverage optimization can in principle select any viewing direction from the off-nadir angle range of $[-30°, 30°]$, i.e. from an infinite set of swaths.

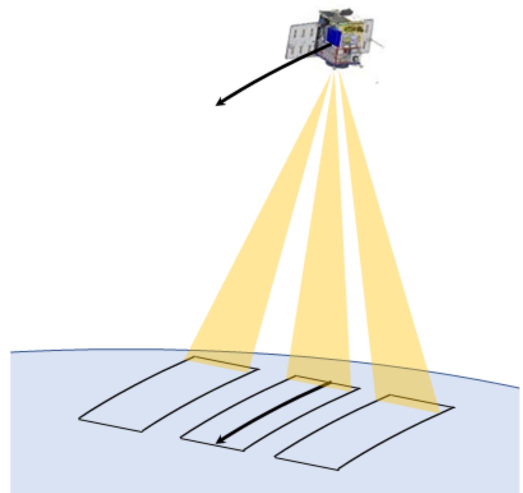

Figure 1: For the *EnMAP* satellite swaths can be selected continuously, i.e. the center off nadir angle can be chosen continuously within the possible viewing range of $\pm 30°$.

2.4 Criteria for the Area Coverage Optimization

The challenge is to define a rule for a good local solution (e.g. to select a swath that overlaps best with the yet uncovered part of the target), while concurrently building up a reasonable global solution for the area coverage request. A possible set of global criteria is:

a) cover the complete target area in as little time as possible

b) cover as much target area as possible within the request's time window

c) prefer small off-nadir angles for better image quality

Note that all three criteria counteract each other: whereas b) prefers swaths which don't overlap, a) prefers swaths which don't leave narrow gaps, and both of them would prefer large off-nadir angles, because larger off-nadir angles imply broader ground tracks, opposing c).

Due to EnMAP's repeat orbit character, an additional criterion about when a sub-region will be re-visited is not considered.

2.5 Swath Gaps vs. Swath Overlaps

As usual in Earth observing satellites, we have to distinguish between swaths of the ascending and descending part of the orbit, i.e. whether the satellite heads north or south. With

EnMAP we also deal with an optical sensor which usually requires target illumination by the Sun. In the following, we assume that our background mission restricts to the region between the two polar circles and therefore all applicable swaths of the target area are of the same direction (usually descending). Together with the Sun illumination restriction, the direction in which the satellite passes the target area is always similar, however rarely equal.

From the global criteria defined in 2.4, we consider c) as secondary, since all allowed angles yield sufficiently good images. From each of the other two criteria, we can derive a simple strategy to find a possible, although not necessarily optimal, coverage:

i) *"Standalone Swath":* Always select the swath with the largest coverage of the remaining area (e.g. [16]). In case of a very short time frame, this corresponds to optimization criterion b).

ii) *"Neighbour Swath":* After selecting the first swath either according to i) or by starting on the left or right, select the next swath attached to the already selected swath without a gap. For small changes in ground track directions, this corresponds to optimization criterion a)

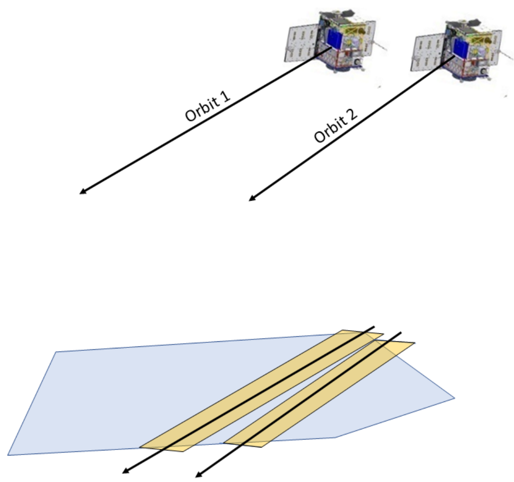

Figure 2: Swath selection avoiding overlap.

Although option i) optimizes the area covered in the first orbits, it might leave gaps which will require additional swaths that cover only the small, still remaining patches of the target (figure 2). Option ii) on the other hand may cause large overlaps in case of a significant difference in directions of two succeeding swaths (figure 3).

3 Swath Selection

Each time the satellite has an opportunity to image the target area, an infinite set of swaths has to be considered as the satellite can be turned continuously around its roll axis.

3.1 Algorithm

Our solution to this problem is a two-step algorithm:

1. Generate a finite set of swath *candidates*.

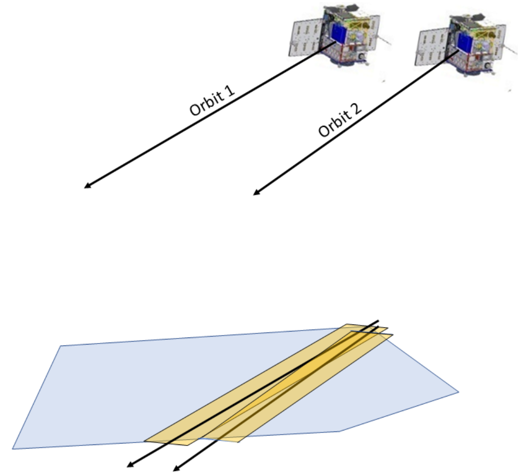

Figure 3: Swath selection avoiding gap.

2. From the set of candidates, select the "best" swath for observation.

Concepts for the candidate generation (step 1) will be the subject of section 4.

3.2 Benefit Function for Optimization

To select the best swath from the candidate set, the algorithm has to quantify the quality of each swath according to the criteria in section 2.4; in particular, a viable strategy should somewhat balance the disadvantages of options i) and ii) described in section 2.5.

To do so, we map the criteria directly into an analytical expression, which defines the *Benefit* of a given swath s. The swath s with the greatest benefit represents the optimal swath:

$$B(s) = \frac{A(s)}{W(s)} - w_O \frac{O(s)}{W(s)} - w_E E(s) \qquad (1)$$

with

$W(s)$ = width of swath s
$A(s)$ = size of target area covered by swath s
$O(s)$ = size of target area covered by swath s which is already covered by another swath
$E(s)$ = length of edges of swath s which are not covered by another swath

and configurable weights

$$w_O, w_E \in \mathbb{R}_0^+.$$

The first term describes the maximum area criterion i), i.e the larger the covered area the greater is the benefit. Since the aperture of the imaging instrument is constant for each viewing direction, the width of swaths increases for larger off-nadir angles. We therefore introduce the width normalization factor $1/W(s)$ to avoid a bias towards swaths with higher off-nadir angles. Although $W(s)$ ensures that the benefit function does not oppose criterion c), swaths imaged from small off-nadir angles will not be favoured in this approach.

Since the mere area benefit does not lead to a proper global solution we have to introduce two penalties: If parts of the swath have already been recorded by other swaths, we reduce the benefit by exactly the size of the overlap (again normalized by the width of the swath). To model the gaps criterion, i.e. giving a penalty to swaths that do not attach to recorded areas, we measure the length of the edge of the swath that lies within the target area and is *not* covered by any other swath. Because of the conflicting nature of the two penalty terms, as discussed in section 2.5, we expect that tailoring both counteracting weights will improve the results significantly.

Broadly speaking, the configuration value w_O allows specifying whether already covered areas are of full interest ($w_O = 0$), of little interest ($0 < w_O < 1$), of no interest ($w_O = 1$) or shall be avoided ($w_O > 1$). The configuration value w_E indicates how much overlap shall be preferred to a gap. Assuming that we are not interested in already covered areas (i.e. $w_O = 1$), w_E has the following meaning:

$w_E = 0$ we don't care about gaps - always plan the swath with maximum newly covered area

$w_E = \frac{1}{2}$ assuming swaths don't cross: use swaths with one covered edge unless more than half of the area is already covered

Note that all three terms of the benefit function have the same dimension to be comparable: All of them describe an effective length, i.e. the length of the total area covered, the effective length of the overlapping area, and finally the length of the unattached edge. By considering the effective length rather than considering the covered area, we also avoid preferring swaths of greater off-nadir angle, which would oppose optimization criterion c).

4 Swath Candidate Generation

Swath generation algorithms must balance the overall benefit gain achieved by selecting from a large candidate set against the calculation effort and the corresponding loss in performance. In the following, we present several concepts that we investigate for *EnMAP*.

4.1 Swath Overlap Discretization

In the simplest case, for every pass over the target area, *SCOTA* derives the set of swaths according to a predefined set of off-nadir angles for which the swaths are computed. We generate these off-nadir angles by specifying a percentage how much of the current swath should overlap with the next swath of greater off-nadir angle, see figure 4. The larger the number of configured angles is, the better the selected swath will be on average, but obviously this comes with a penalty on run-time or memory performance.

4.2 Extreme Point Approach

Another candidate generation concept tackles the problem in a geometric way: for each connected sub-area of the re-

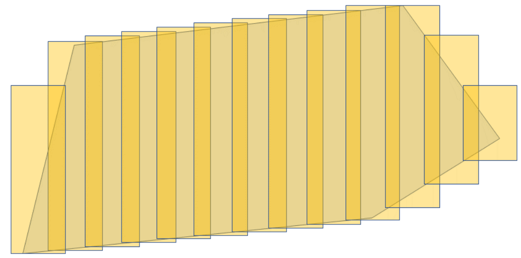

Figure 4: Swath candidates selected from overlapping swathes

maining target area, the following four points (see figure 5) are determined:

p_S := earliest point where the footprint of the total possible field of view sees the target

p_E := latest point where the footprint of the total possible field of view still sees the target

p_R := rightmost point w.r.t. the satellites path where the footprint still sees the target

p_L := leftmost point w.r.t. the satellites path where the footprint still sees the target

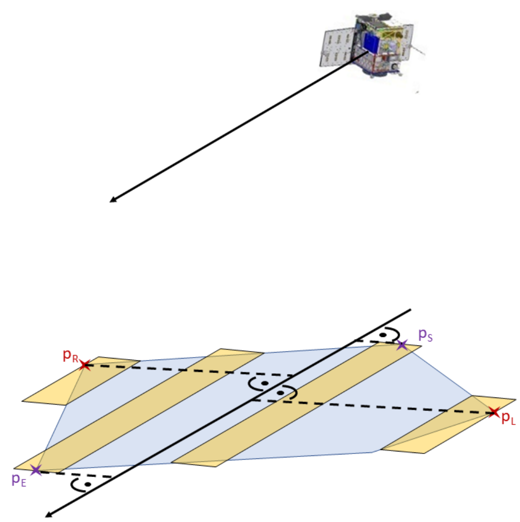

Figure 5: Generation of the first swath. The black line indicates the ground track of the satellite.

The footprint of the total possible field of view corresponds to the line on Earth's surface which can be seen from the satellite, in the case of *EnMAP* within the $\pm 30°$ off-nadir range, at a certain epoch. For each of p_S and p_E we generate a swath which starts or ends at the given point and which completely traverses the target area. For p_L and p_R we select a swath with the given point on the left or right edge of the swath and the swath completely traversing the target area. In case the target area exceeds the visibility of the satellite on the left resp. right, the corresponding swath is replaced by the leftmost resp. rightmost visible swath of the pass.

p_S and p_E result in swaths which have a good chance to maximize the covered area, which is captured in $\frac{A(s)}{W(s)} - w_O \frac{O(s)}{W(s)}$ of our benefit term, see (1). p_L and p_R on the other hand keep the resulting area in a good shape (one edge lies outside the remaining area), which is captured by $-w_E E(s)$.

5 Clustering

After selecting the first swath for a target area, we may end up with a remaining target area which is split in two halves. In case of 4.2, this is usually the case if the first selected swath has been derived from p_S or p_E, see figure 6. When searching for a suitable swath for a succeeding pass, usually both split target areas have one new corner, which is both, either p_S or p_E and either p_L or p_R. If the direction of the next pass is similar to the one of the first swath, the next swath will be one derived from one of these new corners. Otherwise a new swath cluster will be started either at the edge or at a completely new location. The configuration parameters defined in 3 allow steering this decision according to the mission's requirements.

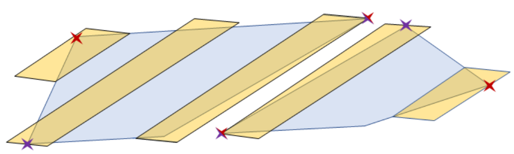

Figure 6: Generation of the second swath: the remaining target area is split in two, for each of which 4.2 may be applied

No matter which swath candidate generation approach we choose, the selection of the swath according to the configured *benefit* groups orbits according to their path direction:

- in case the swath's direction differs significantly from an already imaged swath, the subtraction by $-w_E E(s)$ for a non-overlapping swath is smaller than the subtraction by $-w_O \frac{O(s)}{W(s)}$ of the overlapping swath, thus a non-overlapping swath will be selected, see figure 8
- in case the swath's direction is similar to an already imaged swath, the subtraction by $-w_E E(s)$ for a non-overlapping swath is larger than the subtraction by $-w_O \frac{O(s)}{W(s)}$ of the overlapping swath, thus the swath overlapping with the already imaged swath will be selected.

Note that not all swaths of such a group have similar satellite ground track directions, instead all pairs of neighbouring swaths should have similar orientation. Nevertheless this approach results in clusters of swaths which are closely attached to each other as depicted in figure 7, without having too much overlap and therefore reducing the number of gaps of small areas, which remain in course of time.

Also note that when using 4.2, we may have to create two swaths for a point which is both p_S or p_E and p_L or p_R in order to allow starting a new cluster directly next to an already existing cluster, such as the yellow and the green clusters in figure 7.

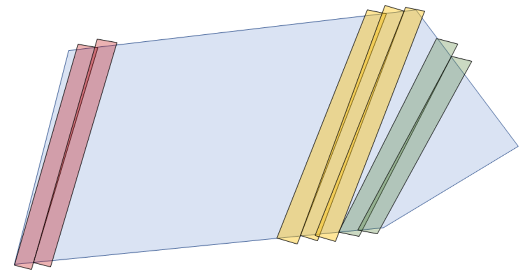

Figure 7: Clusters of swaths with similar directions

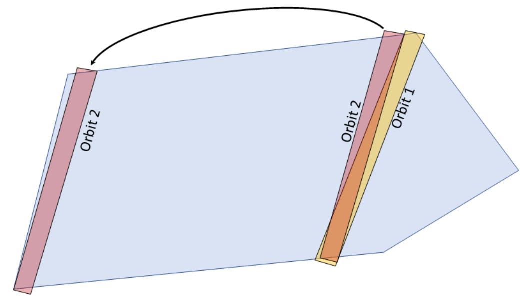

Figure 8: Separation of swaths according to their directions

The charming aspect of our *clustering benefit* approach is that it allows configuring how to balance the overlap of swaths on the one side and the number of gaps when clusters meet on the other side. For *EnMAP*'s polar orbit, we expect that such an approach will work well for elongated targets that are oriented perpendicular to the trajectory and lie within moderate latitudes. However, the clustering might be problematic around the poles since the orientation of the swaths varies continuously as their orientation changes proportionally to Earth's rotation for each orbital revolution of the satellite.

6 Performance

The *EnMAP* mission planning system will be the second mission using the *Reactive Planning* framework, after the *TDP-1* mission, which will migrate to the *Reactive Planning* framework in August 2021. Real operational data, which could be used to estimate the performance of the new system, is therefore not available. However, detailed analysis of the profile calculation sub-library of *Plains* showed similar performance as the profile calculation sub-library used in the *TerraSAR-X/TanDEM-X* mission planning system (see [5], [13] and [14]), which turned out to be the bottleneck of the planning algorithm. The model of the *TerraSAR-X/TanDEM-X* mission with its multiple sliding windows and the power model requires propagation of more resources than the *EnMAP* planning model. The *TerraSAR-X/TanDEM-X* planning algorithm considers up to 2500 swaths during its 3-days horizon and for the last swaths it takes up to 2 sec. to add an acquisition into the timeline. For an *EnMAP* planning run, which only has to add one swath, possibly removing one or two opponents of lower priority, we therefore expect not to exceed 6 sec. when adding an acquisition at the beginning of the planning horizon and removing two opponents. Actually we hope to be much faster, but real data will not be available until our performance tests will be implemented end of 2021. Together with latencies of multiple partner systems and network transitions, through which a request must pass, we expect that the feedback to the customer about the success of planning its request, should be available within less than 30 sec., provided that no long lasting calculation is ongoing, such as an orbit update.

7 Possible Improvements

For the practical implementation of the coverage we expect constraints imposed by the currently planned timeline to be the most restricting drawback of our approach. If operations show that this is indeed a limiting factor, we may implement some of the following improvements:

7.1 Creation of Alternative Swaths

The swath generation process may generate multiple alternative swaths, e.g. of different lengths, from which the planning algorithm may select e.g. the longest one which can be planned. If there are conflicts in the timeline, for instance a standard image acquisition is shortly before the satellite sees the target of the background mission, swaths can be reduced in duration to reorient or calibrate the instrument.

Another improvement could be that the swath generator may return alternative swaths according to different criteria, in particular short swaths which fill gaps or corners of the remaining target area. swaths like this can also be used to improve the geometry of the remaining area, see figure 9.

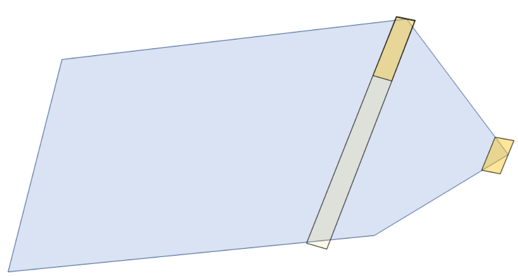

Figure 9: Alternative swaths

7.2 Restricting Swath Generation

The planning algorithm may provide information to the swath generator about blocked times and limitations on the duration of further swaths due to resource availability (power, memory). The swath generator shall restrict the generation of new swaths accordingly. For this approach to work, the swath generation for area coverage requests must be delayed even further just in time before the command generation process is triggered in order to avoid last minute requests to block the newly found solution. In case there exist multiple area coverage requests, each area coverage request must be processed completely, incl. generation and planning of swaths, in order to assure that the constraints of this request are considered during generation of the swaths of the next area coverage request. Although this seems to be the most promising improvement, it also seems to be the most challenging one.

7.3 Separate Swath Clusters

In section 5 we rely on the *benefit* not only to decide when to start a new cluster but also where to start it. This way it may happen that after a cluster is started by one swath, two new clusters are started directly next to this swath on both sides, making it impossible to proceed with the first cluster, see figure 10. To avoid this, an additional strategy is required, which improves the selection of the location where a new cluster is started. One possibility would be to define a minimum cluster distance and then select the swath candidates via 4.1, restricted to this criterion or select the candidates via 4.2, where the remaining target areas are restricted to this criterion.

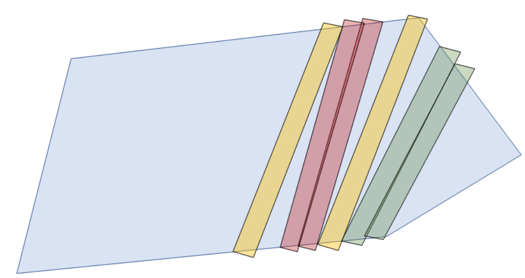

Figure 10: Blocked Swath Cluster

7.4 Merge Opportunities to Observations

In section 2.1 we mentioned the way *CLASP* prioritized target vertices according to the priorities of all requests this target point belongs to, which allows *CLASP* to find swathes which covers regions of interest of more than one request (see [11]). Although *SCOTA* does not discretize the target region, it is still possible to create image acquisitions which serve more than one request:

In case an image acquisition of a low prio request can't be planned, because a conflicting image acqusition is already planned, the algorithm may check whether extending the already planned acquisition (i.e. starting earlier and ending later) may serve the otherwise blocked request. Depending on the type of the request of lower priority, this may include a check whether the requested center coordinate is close enough to the center of the swath or – e.g. for area coverage requests – whether the extended swath covers a sufficiently large section of the requested region, see figure 11

Additionally the covered regions of all planned requests may be removed from the remaining areas of coverage requests. This way, calculation of new swaths of an area coverage request will avoid regions which have already been covered for a different request.

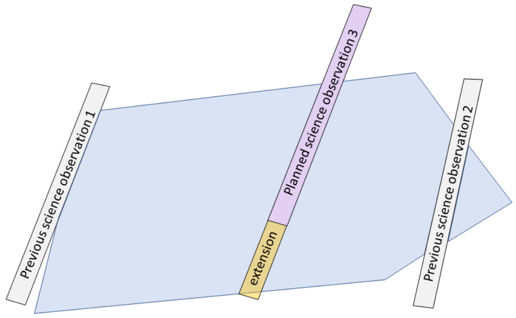

Figure 11: Restrict remaining region of interest and extend already planned acquisitions

8 Conclusion

In this paper, we have illustrated a simple way to include area coverage requests of low priority into a mission of otherwise single pass requests. We introduced a series of criteria a viable algorithm has to obey or rather balance. From this we derived a benefit function which expresses the quality of eligible swaths for finding optimized swaths. We further sketched out ways to improve the performance of the selection by preceding filtering of optimization steps. Currently we are in the process of evaluating which algorithm is best suited to be incorporated in the planning system to serve *EnMAP*'s background mission.

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