THE CAPELLA X-BAND SAR CONSTELLATION FOR RAPID IMAGING

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ABSTRACT

The Capella constellation of 36 X-band SAR Satellites will provide global hourly imaging opportunities for the entire earth and InSAR collection intervals of 4 hours. With the successful launch of the first satellite last year, Capella is prepared to launch the first operational this year and the first incrementally launch 36 satelites over two years. In addition to providing short revisit times, Capella will provide game-changing image request and delivery services where users can request imagery on-demand and receive it in a matter of minutes not days or weeks.

Index Terms— SAR, smallsat, x-band, remote-sensing

1. INTRODUCTION

Synthetic Aperture Radar has enabled significant contributions in scientific, commercial, and government operations; however, the use and development of SAR applications has been greatly limited by the scarcity of SAR imagery. With only a few exceptions such as Japan's ALOS, the European Union's ERS and Sentinel-1 missions, and USA's upcoming NISAR mission, access to SAR data has also been inhibited by gatekeepers that require a long proposal process, significant cost, or both [1] [2][3]. This has been mainly driven by the high cost for building and launching SAR satellites. Capella Space's microsat SAR satellites overcome the launch costs, while maintaining high quality SAR performance and capacity. This enables the rapid build-out of a large constellation, drastically reducing image acquisition latency and cost. This paper outlines the constellation design as well as the image acquisition tasking and image delivery system.

2. CONSTELLATION DESCRIPTION

Capella's first satellite was launched in December of 2018 and the second will be launched this Winter. Over the next two years Capella will incrementally deploy 36 satellites. At each stage the revisit time will improve as described in table 1. With the full constellation, the maximum SAR revisit time for points on the equator will be less than 2 hours and less than 1 hour on average, with more frequent access at higher latittudes. Additionally the InSAR revisit time will be 4 hours.

Each Capella satellite has a three-year design life. By continuuing launching 12 satellites per year, the constellation will maintain its imaging capability indefinitely and have the ability to continually update and refresh the satellite technology, providing improvements to the constellation and radar performance.

Total number of satellites	6	12	24	36
Average revisit (hours)	< 4	< 2	1	< 1
Maximum revisit (hours)	12	6	4	< 2
InSAR Revisit (hours)	24	12	6	4

Table 1. Capella constellation timeline and capability.

Frequency band	X-band (9.4 – 9.9 GHz)
Polarization	Single and Dual
Orbit	Polar
Orbit time	90 minutes
Inclination	90 deg.
Altitude at the equator	500 km
Imaging modes	Stripmap, multi-swath stripmap, staring spotlight, sliding spotlight
Antenna Area	> 8 m^2
Transmit Power	600 Watts
Operation duty cycle	> 10 %

Table 2. Capella system specifications.

2.1. Satellite Description

In designing any satellite radar there many competing design goals that need to be carefully balanced. In particular for building a constellation with high temporal revisit opportunities, size, weight and performance are critical. The satellites need to be small and light weight in order to be able to launch more satellites at a time. Being able to launch multiple satellites at a time is not just to reduce launch costs, but more

importantly because launch opportunities are limited. In order to provide high-quality imagery, a SAR system must have the required "Power-Aperture-Product", which is essentially you need the combination of a large antenna and a high power amplifier. One can trade antenna gain for higher power, but it should be noted that antenna gain factors into the radar performance on both transmit and receive. Capella's radar systems have a very large deployable antenna that provides very very high gain, in fact the area of Capella's satellites is larger than Exquisite systems such as TerraSAR-X or Cosmo-Skymed. This enables capella to transmit a lower peak power providing more imaing opportunities. This does result in a narrower swath, but this is not a problem for many applications.

Capella SAR satellites will operate at X-band with a bandwidth of up to 500 MHz. Ground resolution, swath-width, and NESZ vary with look angle, but users will be able to select a combination of transmit bandwidth and PRF to meet their imaging requirements. Each satellite will be capable of imaging upto 10% of each orbit and cover a swath of 5-10 kilometers. The first operational Capella radar will operate with a single polarization, and the following satellites will be capable of dual polarization collections. Improvement in radar system performance and capabilities such as wider swaths and increased duty cycle are planned for future generations of Capella satellites.

2.2. Radar Imaging Modes

The Capella satellites will be capable of imaging in several modes, including staring and sliding spotlight, traditional stripmap, and multi-swath stripmap. These modes are described below. Note that for most modes, the user can select the image size, and is able to trade resolution for imaging quality.

2.2.1. Spotlight

Capella satellites will be capable of staring-spotlight imaging, in which the beam is focused on a single point on the earth throughout the acquisition. In this mode, azimuth resolution is limited by the duration of antenna beam on the target. The customers will be able to select the resolution somewhat arbitrarily. In some cases the resolution of the imagery may be limited by current US goverment regulations which limits imagery to 0.3m ground resolution. Longer image collects can still greatly enhance detected products and capella will use longer spotlight collects to provide multi-looked imagery at 0.3 meters resolution but with an imporved radiometric resolution, which can greatly enhance the detectability of objects in the imagery.

Capella satellites will also be able to acquire multiple staring spotlight images adjacent to each other. Each acquisition will have a shorter dwell time than the maximum dwell time possible with a single-spot staring spotlight acquisition, so either the resolution of each spot will be degraded as the number of spots increases, or the number of looks available for multi-looking will decrease as the number of spots increases. This mode is useful for extending the width (swath) of an area being imaged. For imaging a larger area in the along-track direction, i.e., increasing the length of a spotlight acquisition, sliding spotlight (see below) is more efficient.

2.2.2. Sliding Spotlight

Sliding spotlight is a combination of stripmap and spotlight imaging modes. The beam slew rate is set so that it does not track a single point on the earth surface as in spotlight mode, but dwells on points for longer than that in stripmap mode. This mode is an approach to achieving a higher resolution pseudo-stripmap mode. Sliding spotlight scene size and possible azimuth resolution are inversely proportional.

2.2.3. Stripmap and Multi-swath Stripmap

Stripmap mode is standard synthetic aperture radar stripmap imaging mode, where the swath is limited by a combination of the look angle, the radar beamwidth, and the PRF selected for the acquisition. The PRF is selected to either provide maximum swath with reduced azimuth ambiguity sidelobe ratio, or reduced swath with better azimuth ambiguity sidelobe ratio. The minimum slant range resolution is 0.3 m. Like in spotlight mode, adjacent swaths may be imaged from incremental squint angles.

2.3. Interferometric Capability and Geomeetric Accuracy

Capella's systems have been designed with interferometry in mind. This includes using ultra-stable oscillators, very fine steering, three frequency GPS, and propulsion to maintain a repeat track orbit. Capella satellites will be able to collect both long spotlight collects and squinted stripmap imagery to enable full 3D deformation studies as well as the removal of atmospheric effects [4]. Geometric accuracy of the radar imagery depends on various factors, such as available DEM accuracy, wet troposphere estimates, orbit determination, and other factors. Orbit determination products will be made available according to the schedule shown in table 3. In this table, latency is defined as the time from telemetry downlink to orbit product availability, and position accuracies are given as 3D RMS values. The accuracy of the ultra-rapid product is limited by errors in estimates of the GPS satellite clocks which are accurate to 1 m at time of processing.

Orbit Product	Latency	Orbit Determination Accuracy
Ultra-Rapid	$<$ 15 min	$<$ 20 cm
Rapid	1 - 2 days	$<$ 10 cm
Final	12 - 18 days	$<$ 5 cm

Table 3. Capella Orbit Determination Products

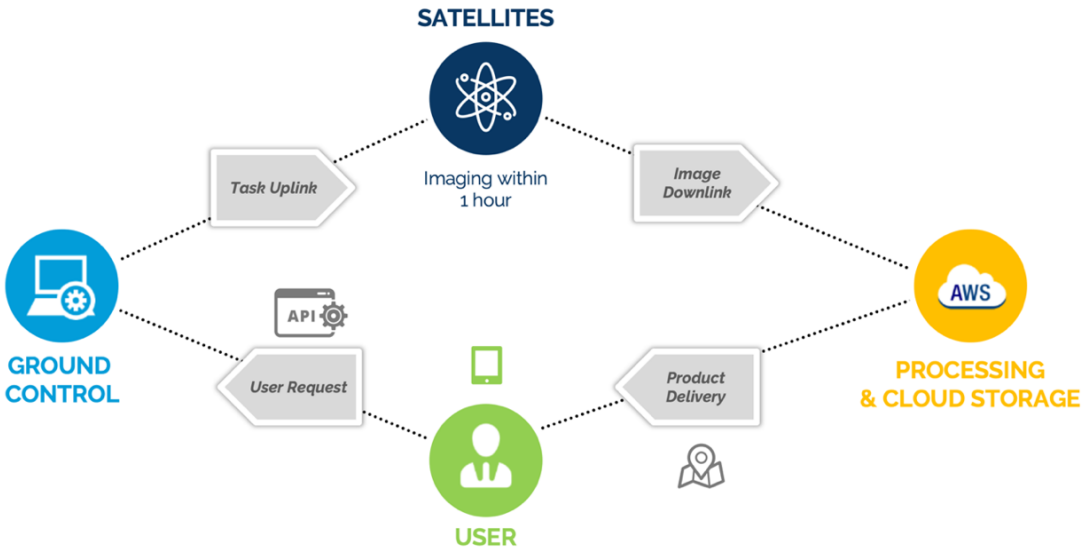

Fig. 1. Tasking and Delivery Paradigm.

3. TASKING AND DELIVERY

Requesting SAR data from commercial SAR satellites has typically taken significant effort, days to weeks to know if the request was accepted, and days to weeks to receive the imagery. Capella Space is designing a novel tasking platform that reduces this to hours and even minutes in many cases. Capella provides a web portal through which customers can submit requests for SAR acquisitions. The requests are automatically processed, optimized, and queued by the Capella scheduler. Capella also offers an API for tasking requests fig. 1.

Capella's offering will be more affordable and convenient through tiered pricing and service levels as described in table 4. In order to meet customer needs in timeliness and reliability fe following principles are maintained:

- All collection service levels include guaranteed collection within the corresponding collection window. No collection requests will be bumped entirely from the tasking plan once an order has been confirmed 6 .
- All orders are planned on a first come first served basis with a target acquisition time identified at the time of ordering.
- Any order can be placed any time prior to acquisition providing the collection is feasible in the tasking plan.
- For Diamond and Platinum levels, the image collection time may be moved within the collection window in the event of a conflicting acquisition at a higher level.
- If an image acquisition time is moved, it will be moved in a way to ensure collection within the window corresponding to the collection service level.

Capella's standard imagery delivery will be less than 6 hours after a collect. Rush delivery will be less than an hour after a collect, and Capella is continuing to develop real-time detection and alerting with response times in minutes after image collection.

3.1. Data format

The Capella SAR data will be available several ways including GeoTIFF and Sensor Independent Complex Data (SICD) format [5]. Additionally users will be able to request specific portions of an image to download in order to reduce data transfers and accellerate user applications. In addition to traditional single look complex images (SLC), Capella will offer SLC stack products that are coregisted based on a DEM and atmospheric model such that users can create flattened interferograms by simply cross-multiplying images, similar to UAVSAR's stack product[6]. Capella will also offer geocoded and orthorectified products for easy use with geographic information systems.

3.2. Live Maps

Live Maps is a new concept of SAR imagery provisioning that leverages Capella's high revisit capabilities. Cities, ports and straits of prominence across the world will be monitored at a regular cadence. With the entire constellation deployed 225 cities with populations exceeding 2M people, will be monitored daily at 1-meter resolution. In addition, SAR images will be collected on 140 of the world's busiest ports and on 25 shipping lanes up to hourly up to 1-meter resolution. This novel information stream will be used to measure changes at local scale, such as infrastructures and transportations, and to

Collection Service Level	Collection Window
Standard	Image is collected within a one-week window of the user's selected tasking time.
Platinum	Image is collected within a one-day window of the user's selected tasking time.
Diamond	Image is collected within the first possible window.
Real Time	Image order is placed within 30 minutes of collection time. If no space available, converts to diamond tasking.

Table 4. Data Collection Service Levels and Collection Windows

inform on large patterns evolving over time, giving insight on economical functionalities of the most productive hubs and measuring ecological trends related to it.

4. CONCLUSION

The Capella X-Band constellation will be launched incrementally over the course of the next few years and will enable science and monitoring for applications requiring high temporal revisit as well as rapid response such as natural difsasters. With affordable imagery, easy ordering rapid delivery, and easy to use image formats, Capella's data will enable unprecedented studies and applications.

5. REFERENCES

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