The exploitation of the COSMO-SkyMed Interoperability, Expandability, Multimission-Multisensor capabilities for the SIASGE System of Systems

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***Abstract*— COSMO-SkyMed is an Italian Earth Observation system born to cope with Dual-Use (i.e. military and civilian) and Multimission (MM)/Multisensor (MS) (SAR, Optical, …) requirements. Within this perspective, it is a highly innovative system capable to be expanded to other systems and sensors.**

SIASGE is a Space Earth Observation System set-up by an international cooperation between Italy and Argentina for complementary utilisation of COSMO-SkyMed and the SAOCOM CONAE (Comisión Nacional de Actividades Espaciales) Mission.

This work describes how a system already in operation (COSMO-SkyMed) can be used, thanks to its IEM (Interoperability, Expandability, Multimission/Multisensor) native capabilities, to form, jointly with a new-developed system (SAOCOM), the complex SIASGE "System of Systems".

***Keywords*— SIASGE; COSMO-SkyMed; IEM; SAOCOM; satellite; SAR**

I. Introduction

Historically, Earth Observation (EO) missions have largely been technology-driven. A promising idea for an instrument design has often been the starting point for a satellite mission specifically conceived to satisfy certain scientific requirements. This situation has led to a high number of scattered facilities each providing different specific, regional, thematic functions such as near real time data production and distribution, off-line archive and distribution, and added-value services with complex data and information flows.

This has created a high level of complexity for the users to find and access the EO (Earth Observation) data, and an infrastructural overcapacity in the basic data services with operational and cost inefficiencies over such different EO systems.

SIASGE is a Space Earth Observation System set-up by an international cooperation between Italy and Argentina for complementary utilisation of the Italian Mission COSMO-SkyMed and the Argentinian Mission SAOCOM. It has the main purpose of generating information on Risk Management with synergetic observations with synthetic aperture radar (SAR) operating in L- (SAOCOM) and X- (COSMO-SkyMed) band.

It's the first time ever that an already in operation SAR dual EO system, COSMO-SkyMed, is joint to a new other EO system, SAOCOM, in an International "System of System", able to satisfy the two partners' needs both with the two mission single products and with joint products. This collaborative system must continue to satisfy all the single systems' security requirements (also the Defense ones for COSMO-SkyMed). It must not influence on the singles systems' performance, but has to take advantage of the analysis and upgrades of the years of COSMO-SkyMed operative phase, also in the Integrated Logistic and Operations fields. Some other "System of Systems" initiatives have already been implemented for Earth Observation missions, such as Copernicus [1] and others will be implemented in the future, such as EUMETSAT-NOAA Joint Polar System (JPS) [2]. They all aim to find a viable way to exploit both the systems' capabilities and to provide cost-effective solutions, but they do not deal with the Civilian part of a native dual and multimission system or with a system already in operational phase, so they not have to preserve some characteristics (es. Security, previous performances, etc.). In this sense, SIASGE is considered an innovative system.

The main challenge of this work is to analyze all the possible capabilities required by SIASGE system that can be realized applying the COSMO-SkyMed IEM capabilities, including some of "COSMO-SkyMed di Seconda Generazione" (CSG) ones (external to the Memorandum of Understanding, but however to keep into consideration).

II. The Involved Systems

A. *COSMO-SkyMed*

1) *The Mission*

COSMO-SkyMed (*COnstellation of small Satellites for Mediterranean basin Observation, CSK*) [3] [4] is the largest Italian investment in Space Systems for Earth Observation, commissioned and funded by Italian Space Agency (ASI) and Ministry of Defence (MoD), and it is "natively" conceived as a Dual-Use (Civilian and Defence). It is composed of a Space

Segment, a Ground Segment and an Integrated Logistics and Operations Segment (ILS&OPS).

The system consists of a constellation of four Low Earth Orbit mid-sized satellites, each equipped with a multi-mode high-resolution Synthetic Aperture Radar (SAR) operating at X-band and fitted with particularly flexible and innovative data acquisition and transmission equipment. PFM (Prototype Flight Model) was launched in 2007, FM4 (Flight Model n. 4) in 2010 and today all satellites are in orbit and still in good health [5].

The set of requirements imposed at highest level has brought to strict performances, in terms of:

- daily acquired images,
- Satellites worldwide accessibility,
- All weather and Day/Night acquisition capabilities,
- Image quality
- Capability to be a cooperating, interoperable, expandable to other EO missions

Due to the need of many combinations between image size and spatial resolution the SAR was chosen as a multimode sensor operating in:

- A Spotlight mode, for metric resolutions over small images
- Two Stripmap modes, for metric resolutions over tenth of km images; one mode is polarimetric with images acquired in two polarizations
- Two ScanSAR for medium to coarse (100 m) resolution over large swath

2) IEM key principles

The “native” high versatility characteristics of COSMO-SkyMed led ASI and It-MoD to further promote these characteristics, looking forward an actual multi-mission architectural framework. This challenge envisages the COSMO-SkyMed system capable to be integrated and cooperating with heterogeneous Partner’s EO systems, in order to plan multi-mission requests, and to exploit mission data from heterogeneous EO sensors, thus also saving not only operational costs, but development and integration as well.

The IEM [6] [7] (Interoperability, Expandability, Multi-Mission/Sensor) concept objective is hence to support cooperation scenarios between COSMO-SkyMed System and other EO systems.

In general terms, “Interoperability” is the ability of two or more elements to mutually exchange data, information, and access to their provided services through specific "exported" interfaces. COSMO-SkyMed provides a full set of capabilities to interoperate with foreign systems, through a variety of implementation solutions, ranging from “simple” exchange of products (by means of ad hoc protocols), to plugging of partner’s architectural elements into the COSMO-SkyMed architecture to give local, autonomous, capabilities (ingestion, production, etc).

The “Expandability” is instead the ability of an architecture to embody mission-specific components “imported” from Partner’s EO System, thus designated as PFI (i.e. Partner’s Furnished Items). The COSMO-SkyMed architecture is designed to manage several PFI’s from different Partner’s Systems, such as: Acquisition Chain, Processing Chain, and Programming Chain, in order to locally achieve multi-mission and multi-sensor capabilities. Reciprocally, COSMO mission-specific components can be configured as PFI to be exported towards Partner’s EO Systems. A clear specification of PFI’s scope and interfaces constitute key issues for COSMO architecture expandability feature.

“Multisensoriality” is the generic ability to manage several sensors, in terms of submission of related requests, programming, and products delivery. Multisensoriality is obtained by the concurrence of Management (the ability to coordinate the monosensor capabilities) and Interoperability (the ability of the monosensor capabilities to interact among them). Multisensoriality can be reached through a procedural approach or through an architectural approach. COSMO-SkyMed implements it through an architectural approach, i.e. providing an environment (supported by H/W and S/W) capable to provide multisensor services, with the objective to increase Standardization, Effectiveness, Response Time, Reproducibility, Reliability.

3) Ground Segment

The CSK Ground Segment is responsible for the operations and control of the entire system including the generation and dissemination of the final products. It is composed of:

- the Core Ground Segment, including Satellite control facility, TT&C, Internal Communication Network, Flight Dynamics System
- Mission Planning and Control Centre, including Mission planning facility (CPCM)
- Receiving, processing and archiving centres, including Processing and archiving facility, Satellite data receiving stations, Data exploitation, Calibration & validation, Data distribution
- Communication infrastructure including Terrestrial links
- Remote Ground Stations, including External TT&C Network, Satellite data receiving stations
- Mobile Acquisition and Processing Stations
- Fiducial Network, which provides GPS ephemeris and correction data necessary to improve precision in Precise Orbit Determination (POD)

An Integrated Logistics and Operations Segment (ILS&OPS) includes all necessary operations & logistic resources and services required for operating the Space Segment throughout the whole system lifetime

B. SAOCOM

The SAOCOM [8] [9] CONAE Mission consists of two satellites, flying in constellation, provided with a Polarimetric Synthetic Aperture Radar in L Band (Polarimetric L Band SAR). Its objectives are:

- provide all weather, day/night polarimetric L band SAR information in real time/store mode, with high spatial resolution (10 –100 meters), and with different incidence angles.

- obtain specific L band SAR derived products,
- obtain L band interferometric SAR derived products, in particular DEM's, terrain displacement maps and forest features, which represent a great help for the major applications mentioned.

The two satellites are planned to be launched starting from 2018 and they will be directly injected in a Sun Synchronous (SSO) nearly-circular frozen orbit and will be able to acquire in 2 modalities: Stripmap and TOPS modes. The nominal orbital position will be decided in order to form the more efficient constellation taking into consideration also the four CSK satellite.

1) Ground Segment

The Ground Segment for the SAOCOM Mission includes the following multiple facilities:

- the Ground Acquisition Stations: one located in Cordoba and one provided by ASI in Italy
- the Mission Operations Center (MOC) for Mission Planning, Command encoding and routing, Telemetry decoding and monitoring, Orbit determination and maintenance
- the Users' Segment Services (CUSE), a portable User Terminal
- the Orbit Dynamics Service (CODS) for orbit dynamic information useful for all other components of the CONAE GS

III. Results: The Exploitation of COSMO-SkyMed IEM to form SIASGE

As above described, SIASGE is a system of systems aimed to exploit the capabilities of the Italian COSMO-SkyMed and Argentinian SAOCOM missions. It is composed by:

1) A percentage exploitation of the capabilities/services belonging to COSMO-SkyMed and SAOCOM Systems in agreement of predefined resource sharing policies;

2) A Common Ground Infrastructure deployed in Argentina and in Italy, with the aim of:

- interfacing SIASGE Users with capabilities outside the already available ones
- interfacing COSMO-SkyMed and SAOCOM, for standard product requests and reception with capabilities outside the already available ones;
- generating, exploiting and distributing Joint Value Added Products.

In the following, a methodology to exploit the COSMO-SkyMed IEM in order to fulfil SIASGE requirements will be described. Such a methodology can be summarized in two main steps:

1. Analyze the SIASGE mission requirements as for Memorandum of Understanding between ASI and CONAE
2. Identify how to apply the IEM COSMO-SkyMed capabilities ("IEM Portfolio") to SIASGE

These two steps will be separately detailed for Mission (5.1) and Ground Segment (5.2) designs. For what concern the algorithm generating Joint Value Added (X+L) Products, it shall consist in a data fusion between CSK X-Band and SAOCOM L-Band Products. The generation of CSK and SAOCOM products involve the COSMO IEM Capabilities and PFIs, as described below. The X+L Products generation requires instead an ad-hoc developed algorithm, because it takes as input the outputs of the two systems and no fusion between different data is foreseen in CSK and SAOCOM systems. Figure 1 shows the flow chart of the full analysis:

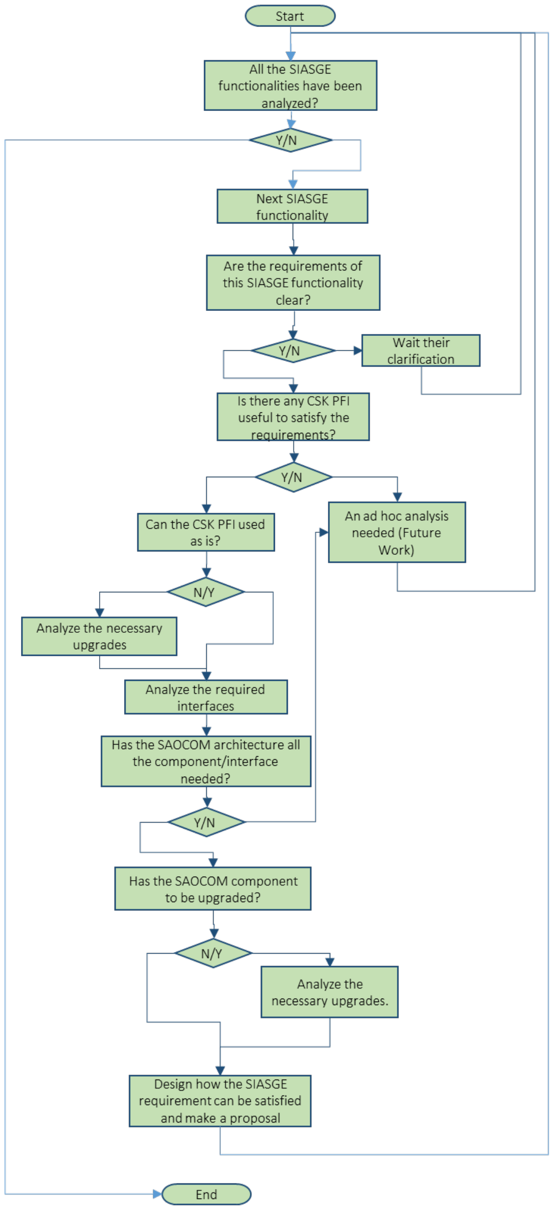

Fig. 1: The research flow-chart

A. The analysis on SIASGE Mission

In this section the result of the mission analysis on SIASGE are presented. Considering that the CSK satellites are already in orbit (but some manoeuvres, if needed, would be possible), the main impacts will be on the SAOCOM (and CSG) satellites

1) The SIASGE Mission Requirements

The SIASGE orbital requirements are, briefly:

1. A SAOCOM (or CSK) satellite shall pass after a CSK (or SAOCOM) satellite after few minutes in order to be able to identify fast changes on the same zone with the same acquisition geometry
2. The manoeuvres on the CSK satellites (if needed) shall take into account the residual propellant
3. The orbital configuration shall minimize the collision risks among the satellites
4. The orbital configuration shall take into account the SAOCOM launcher accuracies
5. The orbital configuration shall take into account CSG future launches

2) The SIASGE Mission Design

a) Inclination

Both CSK and SAOCOM orbits are SSO [10]. Their inclination can be subject, as other orbital parameters, to natural changes caused by the oblateness of the Earth, gravitational attraction from the Sun and Moon, solar radiation pressure, and air drag (they are called "perturbing forces"). So some compensation manoeuvres are necessary to maintain the satellite in the same orbit; they are not needed if all the orbital parameters are fixed in such a way to compensate the natural perturbations.

The CSK orbital parameters are already established and applied in that way. Also the SAOCOM orbital Inclination should be defined in order to minimize these manoeuvres (it is a “gold value” very near to 98 degrees).

b) True anomaly

The SAOCOM True Anomaly would be defined in order to avoid collision risks with CSK satellites and to satisfy the needed SIASGE revisit time requirements, i.e. acquiring in the same zone with the same acquisition geometry with the lowest possible time gap. The better true anomaly at the time being is shown in the next figure:

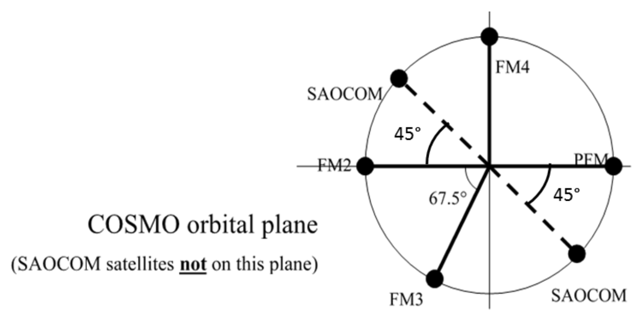

Fig. 2: SAOCOM satellite possible True Anomaly

It is worth to underline that CSK and SAOCOM satellites are not on the same orbital plane.

c) Right Ascension of the Ascending Node (RAAN)

If we have a X+L images couple with a few minutes’ gap, we can monitor every fast event (for example flooding) in a more efficient way. So, a SAOCOM satellite will be able to pass after a CSK satellites after few minutes on the same area (or vice versa). The orbital parameter to be controlled is the RAAN.

A SAOCOM orbit RAAN very near to CSK one, doesn’t increase collision risks, but requires a way to handle two subsequent satellite passes on the common Ground Stations (Matera and Cordoba). In fact, SAOCOM and CSK satellites will share the same antennas in Matera and Cordoba. To handle two subsequent passes, this Ground Stations can:

- **Handle all the passages with a single antenna**: this antenna would be able to be auto-reconfigured in the time gap between the two passages. It is requested to have few minutes between two subsequent passages, so a reconfiguration time too low and impossible to realize would be necessary.
- **Handle every mission with a dedicated antenna**: in this way we should have a CSK-dedicated and a SAOCOM-dedicated antennas. This solution is the easiest one and allow (because there are several available compatible antennas in Matera and Cordoba) to handle all the passages also with a small gap.
- **Have two (or more) antennas with an automatic switching between the two missions**. In this way every single antenna would be automatically reconfigured to handle a CSK or SAOCOM pass. In addition to the previous solution, in this way we can easily manage an antenna failure.

The last solution is obviously the best one, but the most complex. So, it won’t be probably possible to implement it before the SAOCOM first satellite’s launch. The proposed solution is to adopt the second solution in the meanwhile, and, when the implementation of the last possibility will be ready, switch to it.

Taking into account these considerations and adopting the proposed solution, the SAOCOM RAAN could be defined in order to have the desired gap with CSK one (this last one could be different from the value at the launch because of manoeuvres and a natural long term sinusoidal oscillation)

3) Other constraints

Other constraints have to be considered:

1. The launcher accuracy: the mission analysis must always consider the launcher accuracy to grant the satellites safety;
2. SIASGE Mission requirements concern only CSK and SAOCOM satellites (because it started several years ago), not CSG ones (they will be launched in 2018 and 2019). The optimal “CSG only” configuration (from time performance and

interferometric points of view) is being refined. The optimal CSK+CSG configuration will be studied trading off the "CSG only" performance and the overall constellation performances. The possibility to simultaneously have in orbit CSK, CSG and SAOCOM satellites is very realistic at this point, so the CSK+CSG+SAOCOM configuration must be studied. If the SAOCOM satellites will be located in the position depicted in Figure 2 and the "CSG only" configuration will require 180° of delta True Anomaly, a possible configuration could be the one in the next figure:

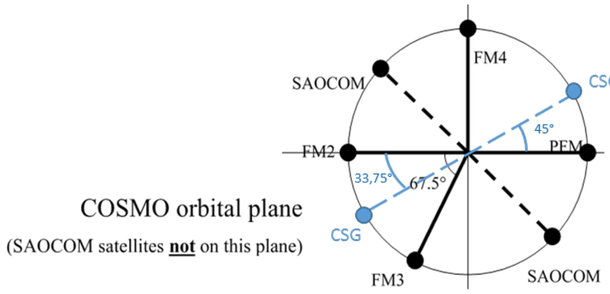

Figure 3: CSG possible True Anomaly

B. The analysis on SIASGE Ground Segment

1) The SIASGE GS Requirements

In the planned solution, the following main functionalities can be identified:

1. A User Care Layer in charge to "interpret" the user requests, to submit to the Multisensor Layer the related Programming Requests, to receive the standard products, and to produce/deliver the joint products (X+L) [11].
2. A Multisensor Layer in charge to take the programming requests coming from the User Care Layer for any sensor, and to dispatch the related standard products to it. It also includes the harmonization process.
3. "X+L" Product Layer, devoted to Multisensor Products generation
4. The Monosensors: it represents the capability at monosensor level of programming, acquiring, processing, dispatching the monosensor products. It is mission specific and does not need any modification
5. The Planning: because it is mission-specific, no modifications are necessary

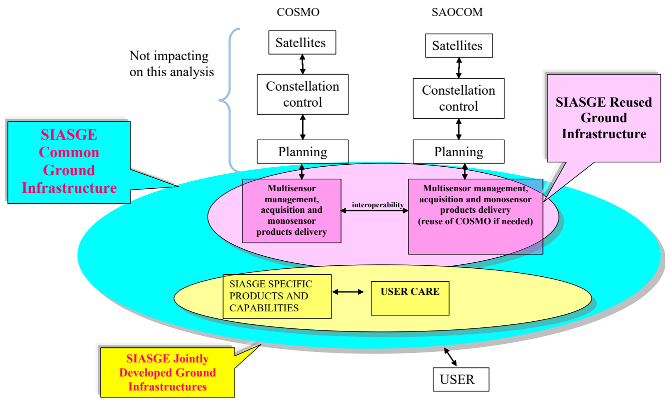

Figure 4: SIASGE needs resume

a) "COSMO-SkyMed di Seconda Generazione" IEM improvements useful for SIASGE.

"COSMO-SkyMed di Seconda Generazione" (CSG) [12] [13] [14] [15] has been conceived at the twofold need of ensuring operational continuity to the currently operating "first generation" constellation, while achieving a generational step ahead in terms of functionality and performances. CSG User Ground Segment, in continuity with CSK architectural key principles, is based on an interoperable and multi-mission design.

A subset of functionalities of the CSG User Ground Segment is implemented in the MSI-UGS (Multi-Sensor Interfacing User Ground Segment), representing the unique front end of the final user and composed of the following CSG Ground Segment subsystems and tools:

- Interface Management S/S (S-IM)
- Production Management S/S (S-PM)
- Remote Programming Functions S/S (S-RPF)
- Network LAN, WAN and Network Services (SNET)
- Logistic Tools

The MSI-UGS is being integrated into First Generation system in these months, several months before the launch of the first CSG satellite, adding some new functionalities, especially in the User Interface and in the IEM capabilities.

IV. CSG S-IM

The CSG Interface Manager (S-IM) subsystem shall interface the CSK and CSG catalogues and potential catalogues of further Mission GS supporting the same protocols and also different ones (for example SAOCOM).

For this reason, the catalogue plug-ins interface contains the definition of a set of methods (Common Catalogue Service Methods) needed to allow the overlapping of the functionalities foreseen by the CSK and CSG Interoperability protocols and, additionally, by the most common and standard Catalogue Protocols (e.g.: OGC). In this way it is possible the integration of a plug-in developed to interface catalogues supporting services that this new plug-in manages as its own specialized implementation of the Common Catalogue Service Methods.

The plug-in approach is used also to provide the access to ordering services supporting different protocols. It is used to interface the feasibility tools foreseen by CSG, CSK, CSK+CSG and it is easily expandable to SAOCOM. The CSG S-IM subsystem will interface the CSK and CSG feasibility and check conflict functions and potentially feasibility and check conflicts functions of foreign Mission GS supporting the same protocols and also different ones. It's important to state that it could also be used to for SAOCOM feasibility with a minor configuration. The same approach is used also for harmonization management. The S-IM internal server shall be able to manage the CSK and the CSG harmonization and potentially harmonization of request for a foreign Mission GS. Also for the expandability of the production and delivery functionalities it is foreseen a common interface defining the signatures and relevant parameters for the production and delivery methods to be implemented by specialized plug-ins according to the server to be interfaced. For all these reason, the S-IM allows an important improvement of the COSMO-SkyMed IEM capabilities showing all the characteristics needed by the SIASGE Multisensor Layer.

b) User Care and Multisensor Layers

The User Care is the layer needed to support users, with the following functionalities:

- technical information about the offered services e.g. geographical coverage of zones in which is allowed to order products and/or services, technical characteristics and features of the product generated by the system, type of data needed to realize a Value Added product and so on
- Commercial Information about the offered services
- Service Order information like status of orders, percentage of completion and so on

The Multisensor includes common functions to be used by both components (Argentina+Italy) in order to guarantee the interoperability between COSMO-SkyMed and SAOCOM. The current baseline of the identified solution is to fully use the multisensor capabilities of COSMO. Thanks to its native characteristics, the COSMO-SkyMed MSI-UGS subsystem can be used, with minor updates, to satisfy all the SIASGE Multisensor needs, taking the programming requests coming from the User Care Layer for any sensor, and dispatching the related standard products to it.

In fact, Multisensor Services in the current COSMO-SkyMed baseline encompass:

- multi and monosensor Imagery Customer Requests (ICR), programming request and Product Delivery Request and mono-sensor product elaboration request. The foreseen levels of multi-sensors requests are:
    - coupled acquisition: the area has to be imaged by both L-Band and X-band, with respect of a maximum delay condition between two radar acquisitions,
    - mixed acquisition: it is accepted that the area is covered partly by L-Band and partly by X-band, as long as the whole area is covered.
- visualization services designed as multi-sensor services at multi sensor level, or mono sensor level
- deposit tools at multi sensor and at mono sensor level. Whenever possible, the mono sensor level information will be automatically proposed to the deposit operator, according to the multi sensor level information he has defined.
- progress reports capable to manage multi-sensor request status and provide feed-back to the deposit operators.
- raw data catalogue access through a multi-sensor imagery request function. This means that a single catalogue request, shall allow to browse COSMO-SkyMed catalogue and SAOCOM catalogue.
- Capability to issue product generation request from either the multi-sensor level or from a mono-sensor level.
- Access to catalogue of products through a multi-sensor imagery request function.

It's also clear that the S-IM component can be configured in order to constitute the SIASGE User Care Layer, interpreting the User requests and sending the products to the Users.

c) The Monosensors

The Monosensor represents the same capability at monosensor level, i.e., it takes care to program, acquire, process, dispatch the X and L products.

CSK has followed an architectural interoperability approach. It implements interoperability for specific UGS functions (e.g. Programming Requests elaboration, science data acquisition, processing) using architectural components of the Partner UGS. As such, a SIASGE UGS encompasses "Partner Furnished Items" (PFI) as **monosensor components** through which it can perform the relevant functions of the Partner UGS and can interact with it in given modalities.

In details, COSMO-SkyMed IEM capabilities, several CUTs (Commercial User Terminals - portable Ground Segments with some functionalities simplified) have been realized and nowadays are in different countries. A CUT can be realized and moved in Cordoba, in order to allow the CONAE system to directly request COSMO-SkyMed products and receive them using the CUT antenna. In the same way a SAOCOM CUSE can be moved in the Matera Space Centre to allow COSMO-SkyMed system to download the SAOCOM data using CUSE antenna in Matera. In this way both in COSMO-SkyMed and SAOCOM User Ground Segments will be possible to download the data of both the missions.

d) Harmonization

This COSMO-SkyMed harmonization capability can be used to harmonize Italian and Argentinian requests at the

monosensor level, both in Matera (the harmonization capability is already present in First Generation system and is improved with Second Generation S-IM, so no modifications are required) and in Cordoba (automatically starting from the SIASGE Phase 2 (see 5.2.2.5)).

e) A possible SIASGE architecture implementation

For what concern the possible SIASGE architecture implementation, only the User Ground Segments, the most interested Centers, is detailed; the other Centers, for example the CSK and SAOCOM External Stations (useful to maximize the possible acquisitions per orbit and to reduce the System Response Time) don't show very interesting updates and are not detailed in this work.

Considering the time needed for the design, implementation, test and validation of the automatically-switching antennas, an ad-hoc scheduling is necessary (see 5.1.2.3). This scheduling allows to exchange the SAOCOM and CSK data in very few time, and improving the SIASGE User Services, also adding new ones, progressively.

The scheduling can be divided into 3 phases:

0. **Phase 0**: for what concern the X-Band products an already operative antenna able to acquire CSK raw data and send them to Matera C-UGS in Cordoba will be used. For L-Band products, a dedicated Acquisition Station will be located in the Matera Space Centre and will be in charge to acquire Argentinian RAW data and send them to Cordoba to be processed. The User Care Layer is a very preliminary state in this phase and it is able to allow the Users to order and receive both CSK and SAOCOM data. The Partner Data (i.e. CSK data for Argentinian Users and SAOCOM Data for Italian Users) are sent from a Centre to the other, already processed.
1. **Phase 1**: in this phase Portable Acquisition and Processing Terminals (CUT for CSK and CUSE for SAOCOM) are configured in the partner Centre. CUT and CUSE are almost full UGS replicas and allow all the needed service (i.e. feasibility, submission, harmonization, acquisition, production). In this way it is now possible to acquire and process both SAOCOM and CSK data both in Matera and Cordoba Centers. The Interface between the portable terminals and the User Care is still operational. The User Care Layer is upgraded to be able to produce Standard and Higher Level X+L Products.
2. **Phase 2**: in this phase the COSMO-SkyMed S-IM is installed both in Matera and Cordoba Centers. In this last phase all the interfaces are automatic:
    a. the Interface between S-IM and the CSK subsystems (CUT and I-CUGS) is automatic by design
    b. the interfaces between S-IM and the SAOCOM subsystems (CDAE+CUSE and GS) is easy to be set, thanks to its CSK IEM capabilities (the SAOCOM subsystems are seen as PFI).

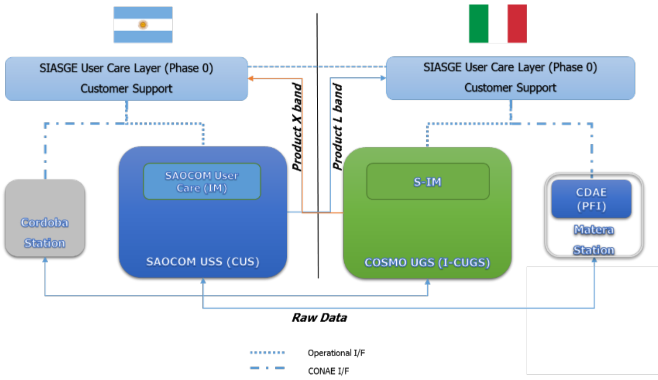

Figure 5: Phase 0 Architecture

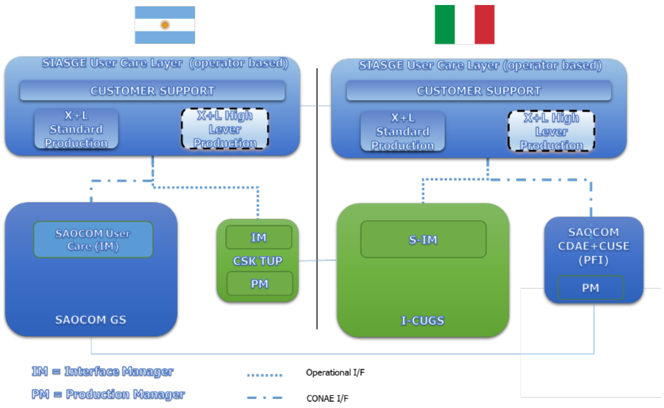

Figure 6: Phase 1 Architecture

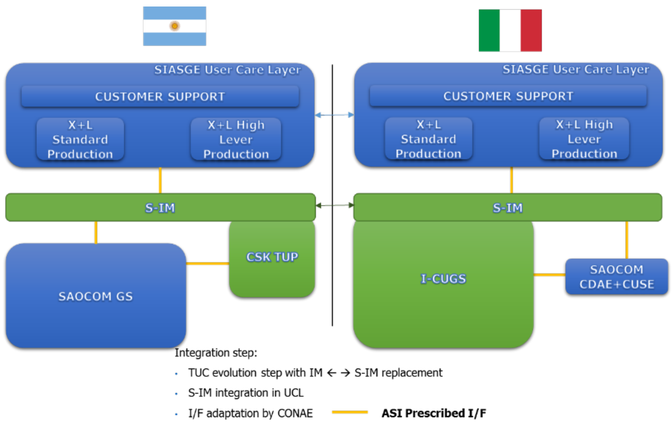

Figure 7: Phase 2 Architecture

V. CONCLUSIONS AND FUTURE WORK

This work describes how the SIASGE User Requirements can be satisfied using COSMO-SkyMed native IEM capabilities jointly with SAOCOM system. The analysis has taken into account the fact that COSMO-SkyMed is an already in operation dual EO system with performances and security constraints to be continuously granted. In this work almost all the SIASGE functionalities are described; some other required capabilities, for example the X+L joint products, are not detailed because they requires an ad-hoc algorithmic analysis not involving the CSK IEM capabilities and they won't use any

COSMO-SkyMed PFI (main topic of this work). This residual functionalities can be object of future works.

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