ARCHITECTURES ANALYSIS FOR THE FUTURE EUROPEAN SSA SYSTEM

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ABSTRACT

As defined by ESA, Space Situational Awareness (SSA) is the understanding and maintained awareness of the Earth orbital population, the space environment (including NEOs) and possible threats to space assets. At the moment, European SSA is relatively poor and many studies are performed in that domain to propose an autonomous European system. At the last Ministerial Council held in November 2008, a SSA preparatory programme has been decided in order to propose the way forward in such domain and to envisage a common framework for addressing space weather (SW) and space surveillance (SS) user needs.

This paper will present the analysis of the possible architectures for such system focusing on its incremental development (with respect to the services available to the users) and on the correlations between the SW and SS domains which appear when proposing cost-efficient solutions.

These correlations are mainly due to the fact that some space-based assets may be required for both domains, especially Sun-Synchronous platforms or sub-GEO platforms. Sun-Synchronous platforms are interesting for space objects survey and tracking in high altitude orbits, Sun X-ray imagery, solar UV flux measurement, electrons and protons radiations or ionospheric TEC measurements. Sub-GEO platforms may be used for GEO objects imaging and environment as solar related measurements. The feasibility of such space-based assets will be presented.

Other correlations are due to the fact that the future European SSA system has to be considered as an information system acquiring, processing and providing data to users. The data policy and security aspects for such system will be especially important to be analysed. This paper will present the possible relations with the Users of such system depending on available data and subscribed services and depending also on their profiles. Another important point to be managed by the system is the access to resources which will also depend on the users' profiles. At last, the volume of data, the amount of time processing will be major topics which will size directly the ground segment design and cost and need to be analysed.

INTRODUCTION

Space systems are taking more and more importance in the life of European population, in the European economy and the European policy of security and defence. But too much reliance on space-based assets, including in the economy sector, could induce new vulnerabilities in case these systems are defeated. The recent collision between two spacecrafts generating thousands of debris in a high and crucial altitude domain demonstrated the importance of space situation knowledge and awareness.

In fact, many objects, particles or radiations can endanger operational satellites, with any size or energy, natural or man-made, intentional or unintentional, on any orbit type (LEO, GEO, MEO or HEO). As defined by ESA with Experts from different Member States, "Space Situational Awareness (SSA) is the understanding and maintained awareness of (a) the Earth Orbital Population (EOP), (b) the space environment and (c) threats to/by the orbit population". SSA is an upper-set of space surveillance which is itself defined as "the routine, operational service of timely detection, correlation, characterisation, and orbit determination of space objects".

In the domain of Space Surveillance, Europe gets some information for free from the United States and is not autonomous to acquire it by own means. Although, it has some detection or tracking capabilities by way of facilities implemented by some European Member States, the SPASEC Report [1] has identified the lack of European Space Surveillance capabilities as "one of the capability gap common to the non-security related communities and security / defence community". In other domains of SSA, Europe is no more autonomous.

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The objective given to this work is to define the baseline architecture of a future European SSA system (ESSAS) able to provide to the users verifiable, dependable, accurate and timely information in order to:

- Identify non-compliance with relevant international treaties and recommendations,
- Enable the assumption of responsibility (e.g. as launching state, owner, or operator), and support confidence building measures,
- Support safe and secured operation of space assets and related services,
- Support risk management (on orbit and during re-entry) and liability assessment,
- Assess the functional status and capabilities of space systems.

Information must be provided with integrity, with an architecture enabling the implementation of a data policy, based on an autonomous European SSA system.

This paper will present successively the proposals for functional and physical architectures of the ESSAS and the proposed incremental development both in terms of functions and physical assets.

FUNCTIONAL ARCHITECTURE OF THE ESSAS

The future Users of the ESSAS want to be aware of the Space Situation composed of:

- Trackable space objects (i.e. Earth orbital population),
- Space environment (radiations, untrackable space objects),
- NEOs

They want to be aware of the Threats against space assets of interest or coming from space:

- Collisions,
- Break-ups,
- Re-entries,
- Interferences,
- Charging, aging, mechanical effects or arcing due to particles …

They want to be autonomous in Europe thanks to verifiable, dependable, accurate and timely information.

Therefore, *the functional ESSAS architecture* is based on three main functions (MF) and two constraint functions (CF):

- MF1: Provide information to Users relative to Earth Orbital Population
  - MF1.1: Acquire the information (orbital parameters, physical parameters, mission and status parameters, detailed information).
  - MF1.2: Maintain the information.
  - MF1.3: Handle the transactions with Users.
- MF2: Provide information to Users relative to Space Environment
  - MF2.1: Acquire the information (for post-event analysis and nowcasts).
  - MF2.2: Predict the information (for qualitative forecast and quantitative forecast).
  - MF2.3: Handle the transactions with Users.
- MF3: Provide information to Users relative to Threats
  - MF3.1: Detect on-orbit fragmentations and release events.
  - MF3.2: Predict and evaluate the risk of on-orbit collisions.
  - MF3.3: Predict and detect disruption of mission and/or service capabilities.
  - MF3.4: Predict and evaluate the risk of re-entries/de-orbiting.
  - MF3.5: Handle the transactions with Users.
- CF1: Comply with Data Policy Rules.
- CF2: Comply with Resources Sharing Principles.

From this description, we can conclude that the ESSAS is primarily an information system which gathers, processes and provides data to Users. As some of these data may be sensitive, Data Policy rules will have to be established in order to control and restrict the data distribution. Moreover, as the ESSAS may be partly based on external assets/sources for information gathering, resources sharing principles will also have to be established with contributing partners in order to manage the access to such data.

FUNCTIONAL DEVELOPMENT OF THE ESSAS

The proposed incremental development of the functional architecture of the ESSAS is based on three steps:

- IOC (Initial Operating Capability):
  - Acquisition and maintenance of the orbital parameters of space objects in LEO, MEO and GEO and of the owner of detected space objects [1],
    - For detection of LEO objects, maximal altitude is 1000 km, minimal size is 10 cm and maximal revisit time 1 day.
    - For detection of MEO objects, minimal size is 1 m and maximal revisit time 1 week.
    - For detection of GEO objects, minimal size is 1 m and maximal revisit time 2 days.

[1] The knowledge of the owner of detected space objects is required for the data policy rules application. The decision on data delivery to Users will depend on the Owner's decision.

- Acquisition and maintenance of the information required for post-event analysis and nowcasts of effects due to space environment,
    - Thermosphere and ionosphere knowledge is required.
    - Radiation knowledge in LEO, MEO and GEO is partly required.
    - The resolution and timeliness are both fixed to 5 minutes (nice-to-have).
- Acquisition and maintenance of the information required for NEOs based on existing assets or assets needed for Earth Orbital Population.
- Prediction of threats to space assets of interest or coming from space based on the available information.

- BOC (Baseline Operating Capability):
  - Acquisition and maintenance of the orbital parameters of space objects in LEO, MEO, GEO and GTO and of the owner of detected space objects1,
    - For detection of LEO objects, maximal altitude is 2000 km and other requirements are unchanged.
    - For detection of MEO/GEO objects, requirements are unchanged.
    - For detection of GTO objects, minimal size is 1 m.
  - Characterisation and maintenance of the physical parameters, mission and status parameters of detected space objects in LEO, MEO and GEO,
  - Acquisition and maintenance of the information required for space weather qualitative forecasts.
    - Thermosphere and ionosphere knowledge is required.
    - Radiation knowledge in LEO, MEO, GEO (2 longitudes) and in an eccentric orbit GTO or HEO is required.
    - X/UV images of the Sun and UV flux measurements are required
    - Solar wind measurements are required.
    - The resolution and timeliness are both fixed to 5 minutes (nice-to-have).
  - Acquisition and maintenance of the information required for NEOs based on assets needed for Earth Orbital Population.
  - Prediction of threats based on the available information.
- EOC (Enhanced Operating Capability):
  - Acquisition and maintenance of the orbital parameters of space objects whatever their orbits and of the owner of detected space objects1,
    - For detection of LEO objects, requirements are unchanged.
    - For detection of MEO objects, minimal size is 20 cm and maximal revisit time 1 week.
    - For detection of GEO objects, minimal size is 20 cm and maximal revisit time 2 days.
    - For detection of GTO objects, minimal size is 50 cm.
  - Acquisition and maintenance of detailed information relative to detected space objects in LEO, MEO and GEO,
  - Acquisition and maintenance of the information required for space weather quantitative forecasts,
    - All requirements are unchanged except the necessity of radiation knowledge in GEO (4 longitudes).
  - Acquisition and maintenance of the information required for NEOs based on assets needed for Earth Orbital Population.
  - Prediction of threats based on the available information.

PHYSICAL ARCHITECTURE OF THE ESSAS

In order to fulfil previous functional requirements, *the physical ESSAS architecture* makes appear two segments:

– The ground data segment,
– The sensor segment.

These elements of the system are presented in the following Figure as their relations with the external assets.

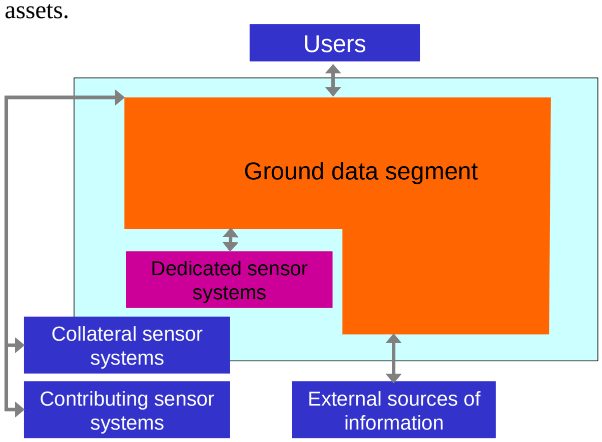

Fig. 1 – Schematic representation of the ESSAS and its relations with external assets

Data acquisition is made through sensor systems or external sources of information. In order to clarify the vocabulary, we adopt the following definitions:

– A sensor system is the set composed of one or several sensor(s) plus some eventual stages of local sensor(s) tasking and/or local data processing.
– A dedicated sensor system is fully under ESSAS control and its primary mission is to provide information to the ESSAS.
– A collateral sensor system is fully under ESSAS control but its primary mission is other than to provide information to ESSAS.
– A contributing sensor system is not under ESSAS control and its primary mission is other than to provide information to ESSAS.
– An external source of information is not under ESSAS control and is not always based on sensor information (i.e. public launching information).

Ground Data Segment of the ESSAS

The ground data segment is a crucial element of this information system since it manages all the processes for data acquisition, data processing and data handling for Users. The main elements of the ground data segment are presented in the following Figure.

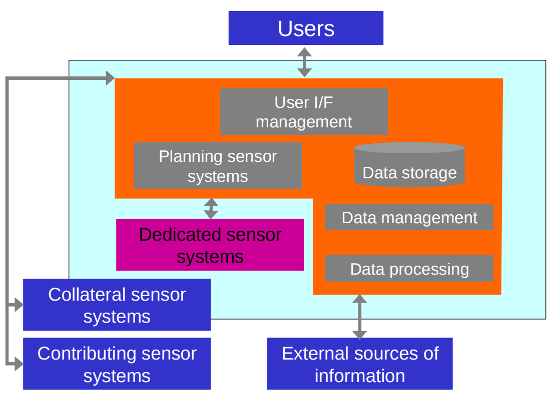

Fig. 2 – Schematic representation of the ground data segment

The data management element encodes all acquired or processed data in a convenient structure [2] in order to keep for each piece of information the source, the accuracy, the related data and the data policy attributes. This element manages the priorities for data acquisitions or calculations.

The planning element manages the data acquisition from tasked sensor systems whatever their types taking into account the resources sharing principles defined for the collateral and contributing systems. We suppose that the tasking is performed by the sensor system itself.

The data processing element processes the acquired data in order to get higher-value data and products or services for the Users. Of course, due to the domains treated by SSA, data processing will not be unique. Data processing will be necessary for space objects cataloguing, space objects characterising, space environment data processing, NEOs processing and added-value services for space assets of interest (i.e. threat warnings).

The data storage element archives all data from raw information to higher-level products or services.

The User interface management element handles the transactions with the Users. The transactions depend on the Users' profile and the data access fixed by the data policy rules (i.e. Dissemination control matrix) or the resources' access fixed by the resources sharing principles (i.e. Resource Allocation Matrix).

Two Users' types are defined:

– The Trusted User (TU) can request tasking from the system and access to data. TU could be member of national or international space institutions (like CNES, ASI, ESA), civil governments involved in the project, military agencies etc.
– The Public User (PU) can only access to data from the system. PU could be member of the general public or interested third parties (e.g. scientific researchers).

Three TU profiles are defined:

– Low priority TU#1: Trusted User as the satellite operator who has subscribed to ESSAS services to benefit of ESSAS assets to have quality information to control his satellite fleet.
– Medium priority TU#2: Trusted User as the ESA country member who has priority to use ESSAS assets to control his spacecraft fleet, as he is owner of part of assets. TU#2 is related to civil entities.
– High priority TU#3: Trusted User as the defence organization of a European country member of ESSAS. TU#3 is related to defence entities.

Three PU profiles are also defined:

– PU#1: General Public User as any internet User.
– PU#2: Public User with some more authorisation access than PU#1 as the satellite operator who can access to his satellite fleet information (access to owner data). PU#2 is related to civil entities.
– PU#3: Public User with maximal authorisation access as the defence organization of a European country member of ESSAS (access to National

Eyes only data). PU#3 is related to defence entities.

The distribution of ground data segment is another issue to consider. Trade-off analysis have shown that a distribution per domain (EOP survey and tracking, EOP characterising, space weather, NEOs) is a good solution. Nevertheless, data security issues require that some operations remain handled by a Common Data Control Centre. The following Figure represents the proposed ground data segment and its different Data Centres and their relations with Users and sensors.

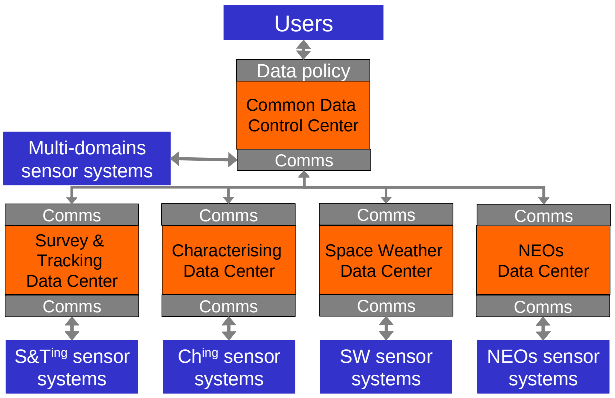

Fig. 3 – Schematic representation of the distribution of the ground data segment

The Common Data Control Centre contains the User interface management element, the planning element for multi-domains sensor systems, the long-term data storage and the management of Specialised Data Centres (including the delivery of services/products between Specialised Data Centres), Key Management facilities to ensure security aspects.

The Specialised Data Centres per domain (Survey and Tracking, Characterising, Space Weather and NEOs) contain the planning element for specialised sensor systems, the specialised data processing element and the short-term data storage.

In terms of development, the structure of the ground data segment shall be fully defined for IOC since it constitutes the ESSAS core on which the sensor segment will be incrementally "plugged". Once the structure of the ground data segment is defined, taking into account existing sensor systems, any new sensor segment will be easily plugged if it complies with the ESSAS external Interfaces requirements. This requirement has a major implication on the data processing element which must be conceived to integrate and process low level data (i.e. raw measurements from sensors) and high-level one (i.e. products from contributing sensor systems, information from external sources). In terms of services, the ground data segment will progressively provides them depending on the available sensor segment at IOC, BOC and then EOC.

Sensor Segment of the ESSAS

The sensor segment constitutes the information source for the system which gives to it the required autonomy, especially the dedicated/collateral part of it.

The sensor segment will be initiated with the pre-existing European collateral/contributing sensor systems. The following sensors will be considered (subject to the final acceptation of contributors):

– LEO survey by the VHF bistatic survey radar system GRAVES (France).
– LEO tracking by the TIRA-L band radar system (Germany).
– GEO survey by the following optical systems: STARBROOK (Cyprus), ZimSMART (Bern), TAROT (France and Chile).
– GEO tracking by the following optical systems: STARBROOK North (Cyprus), ZimLAT (Bern) and ESASDT (Tenerife).
– Thermosphere and ionosphere data via existing data sources and measurements performed by PROBA-2 and SWARM missions.
– Radiation monitoring via in-situ existing detectors (i.e. METOP, JASON-2, SAC-D, GALILEO IOVs) and UV solar imaging via PROBA-2.
– Untrackable debris monitoring via beam-park experiments of tracking ground-based sensors and in-situ detectors.

For IOC, the pre-existing sensor segment will be completed by new dedicated sensor systems such as:
– LEO survey by one UHF radar system: The characteristics of such radar system are not fixed yet as they will result from a dedicated study under work actually [3]. First possible design is a bistatic CW concept, functioning at 435 MHz, 1000 km range over a 10cm sphere, with a FoV (Field of View) of 180° in azimuth and 20° in elevation (from 20° to 40°) – Possible location is in Spain.
– LEO tasked tracking by one S-band radar system: First possible design is functioning at 3.2 Ghz ± 20 MHz, with a 1500 km range over a 10 cm sphere, with a 0.6° FoV and a FoR (Field of Regard) from horizon to horizon – Possible location to confirmed is in Kourou.
– MEO survey by two dedicated 0.4m diameter, FoV 6°x6° optical systems, one each in Tenerife and the Marquesas Islands.
– MEO and GEO tasked tracking by four 0.5m

optical systems, one each in Tenerife, Cyprus, Perth and the Marquesas Islands.

- GEO survey and tasked tracking by one 0.3m, FoV 10°x10° space-based telescope aboard a Sun-synchronous platform.
- Radiation monitoring and untrackable debris monitoring via in-situ detectors on-board the SSO platform.
- Untrackable debris monitoring via beam-park experiments of dedicated tracking ground-based sensors.

The timeliness requirement for space weather issues will only be fulfilled by using a GEO DRS (Data Relay Satellite). This relay could also be equipped with detectors for space weather monitoring and X/UV imager of the Sun and UV flux sensors. The decrease of the timeliness requirement is actually analysed in order to see the impact on the architecture (and then, the possible transfer of the X/UV Sun imager and UV flux sensors onboard the SSO platform as a possible secondary mission).

The following Figures present schematically the IOC sensor segment, first from the ownership point of view (Figure 4) and secondly, from the functional point of view (Figure 5).

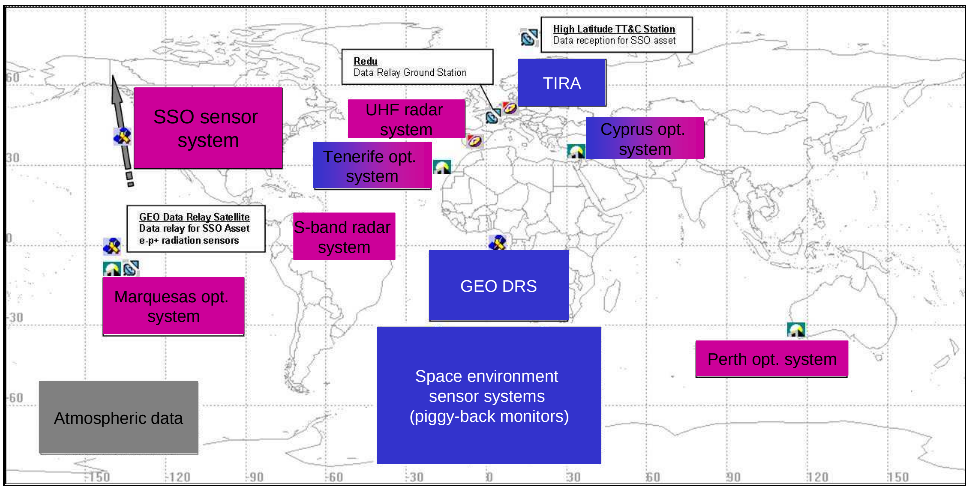

Fig. 4 – Schematic representation of the IOC sensor segment (pink=dedicated sensor system, blue=collateral/contributing sensor system, grey=external source of information).

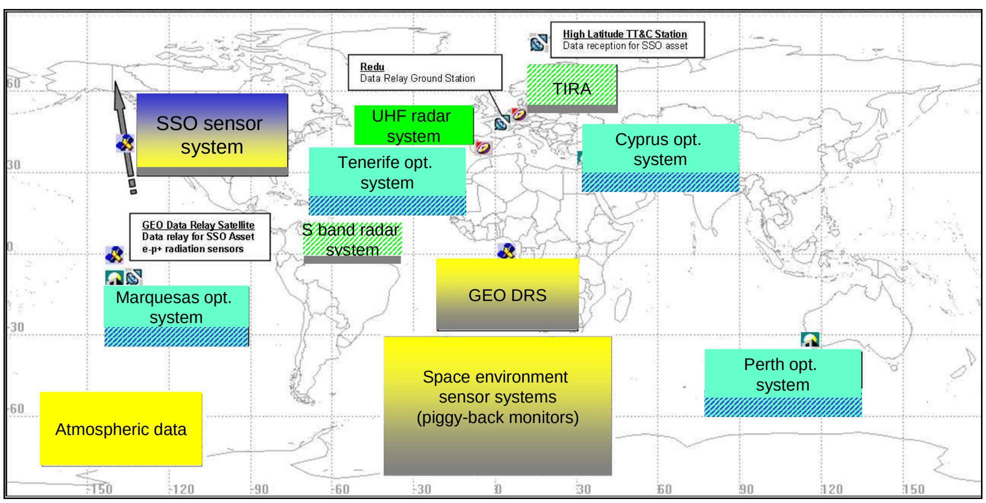

Fig. 5 – Schematic representation of the IOC sensor segment (green=LEO area, light blue= MEO/GEO area, dark blue=GEO area, yellow=space weather function, grey=untrackable debris function, plain= EOP survey function, dashed=EOP tracking function).

For BOC, the sensor segment is upgraded from IOC with the following sensor systems:

– LEO survey by an extended UHF radar: 1500 km range over a 10cm sphere.
– LEO imaging by the contributing radar system TIRA.
– GTO/HEO survey and tracking by 0.3m telescope from another SSO platform.
– GEO imaging by 1m space-based imager from a sub-GEO platform.
– MEO imaging would be performed by a 1m space-based imager from a sub-MEO platform, but in any case, this is a very difficult issue since as many platforms as planes would be necessary or an on-orbit servicing vehicle (refuelled in LEO orbits).
– Radiation monitoring and untrackable debris monitoring via in-situ detectors on-board the new SSO platform.
– X/UV Sun imager and UV flux measurements on-board the new SSO platform (to be confirmed in accordance with the IOC analysis for the first SSO platform).
– Solar wind measurements from an L1 platform.

The following Figures present schematically the BOC sensor segment, first from the ownership point of view (Figure 6) and secondly, from the functional point of view (Figure 7).

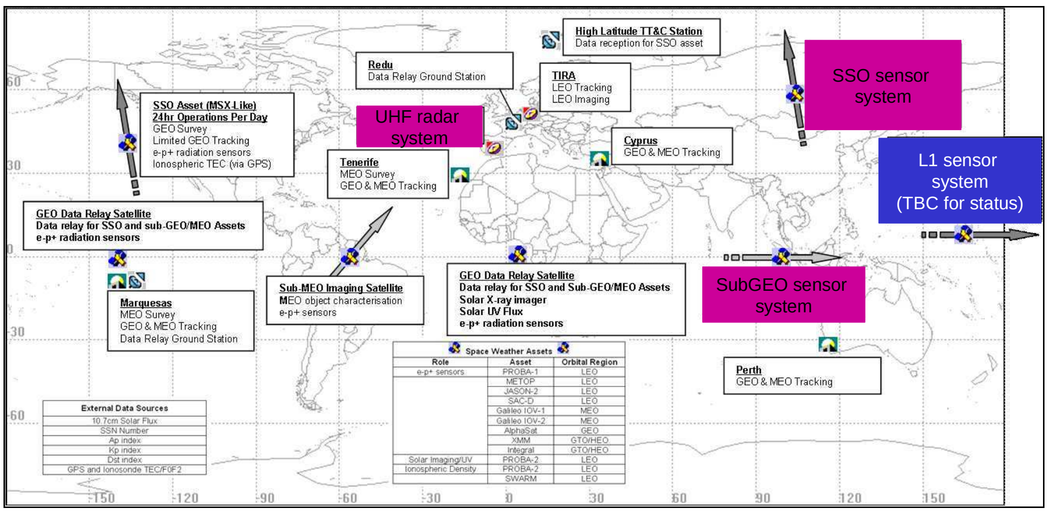

Fig. 6 – Schematic representation of the upgraded sensor segment at BOC (pink=dedicated sensor system, blue=collateral/contributing sensor system, grey=external source of information).

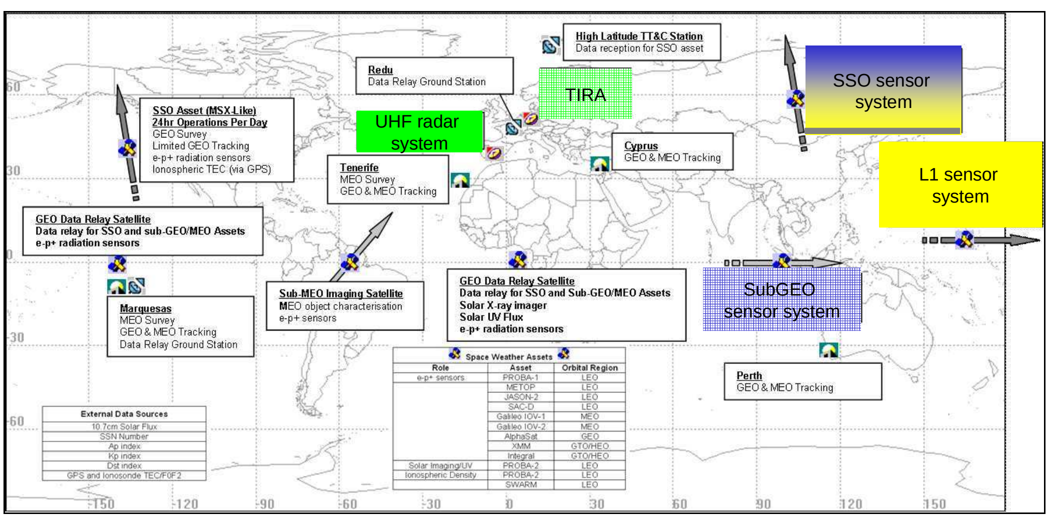

Fig. 7 – Schematic representation of the upgraded sensor segment at BOC (green=LEO area, light blue= MEO/GEO area, dark blue=GEO area, yellow=space weather function, grey=untrackable debris function, plain= EOP survey function, squared=EOP imaging function).

For EOC, the size of space objects to be detected in MEO and GEO is decreasing and the ways of obtaining this requirement are open: either ground-based telescopes with large FoV and large aperture, either space-based telescopes coupled with the BOC imager on the sub GEO platform. For MEO, issues are very difficult from space-based assets for the same reasons as those given at BOC.

PHYSICAL DEVELOPMENT OF THE ESSAS

As presented in the previous paragraph, the proposed incremental development of the physical architecture of the ESSAS is based on three steps:

- IOC (Initial Operating Capability): Realisation of the ground data segment with part of the sensor segment (necessary for acquisition and maintenance of the orbital parameters and the owner of space objects, for post-event analysis and nowcasts of effects due to space environment, for prediction of threats to space assets of interest based on the available information)
- BOC (Baseline Operating Capability): Acquisition of the sensor segment necessary for characterisation and maintenance of the physical, mission and status parameters of space objects, for space weather qualitative forecasts and prediction of threats based on the available information.
- EOC (Enhanced Operating Capability): Acquisition of the sensor segment necessary for acquisition of detailed information relative to space objects, for space weather quantitative forecasts and prediction of threats based on the available information.

CONCLUSIONS

As shown in this analysis, the ESSAS is a System of Systems which is defined as a network of autonomous systems providing a common mission:

- Some elements are operationally autonomous (i.e. collateral / contributing elements).
- Some elements have an autonomous management (i.e. contributing elements).
- Due to the mission, elements must be geographically distributed (all around Earth-based, space-based).
- The development will be incremental (i.e. existing building blocks, new required assets).

Moreover, the ESSAS is a dual system which will be used either by civil or defence Users and will have to protect sensitive data and work with shared resources. The agreed definitions of data policy rules and resources sharing principles are now crucial for further system design.

These characteristics represent great challenges for the ESSAS design and this explains why, the ground data segment is so important for this system.

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