TOWARDS A EUROPEAN SST/STM SYSTEM – THE EUROPEAN OPTICAL NETWORK PROJECT

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ABSTRACT

We present the European Optical Network (EON) project, an activity being conducted as a part of the ESA Space Safety Programme. EON is a technology demonstrator of an automated network of sensors which can provide optical observations and data products in order to improve spacecraft safety, assure mission success, maintain the awareness of the population of man-made space objects and eventually protect the space environment.

The project combines existing and newly deployed sensors into an optical network and provides software services for handling data requests, observations scheduling, processing of the acquired data, and delivering a number of data products with high level of process automation.

1 GENERAL PROJECT AND SYSTEM DESCRIPTION

In recent years several European Union initiatives focused on increasing European autonomy in space situational awareness (SSA) and space surveillance and tracking (SST). ESA has also put substantial effort into developing software and hardware solutions paving the way towards creation of European SSA/SST systems.

Aiming at addressing this need, the European Optical Network (EON) project started in January 2022 and is planned for 24 months. It is carried out by an international consortium composed of experienced entities from different countries that together possess a complementary set of tools, knowledge, skills, and goals: Sybilla Technologies Sp. z o.o. (prime contractor, ST) and partners: Okapi:Orbits GmbH (OO), Cilium Engineering Sp. z o.o. (CE), Vyoma GmbH (VY), NTT DATA Romania S.A. (NTT), Aristotle University of Thessaloniki (AUTh), Libre Space Foundation (LSF), AstroTech KFT (AT) and Astros Solutions (AS).

The EON system has been designed to provide data for satellite operators, service providers, and public or private entities interested in space traffic management (STM) and in SST. The system can also be used by sensor operators to provide data and use EON support services in their daily operations. The EON system will be able to provide information on position, velocity and brightness of objects orbiting the Earth on high-LEO, MEO and GEO regimes and on orbits crossing these regions.

From the technical point of view, the consortium focuses on three main system streams: sensors upgrades and deployment; development of software services; system integration and operations.

Regarding sensors upgrades, the project aims to at further development of the existing Panoptes-Solaris network and integration of the existing or deployment of additional sensors to improve the resiliency and redundancy of the network. The entities involved in this stream (ST, CE, AT, AUTh and AS) are upgrading or adding 22 sensors.

The user accesses the functionalities of the system through the interfaces of its software components and is isolated from the hardware components used for acquisition, processing, storage, and data transfer.

Over 20 software services are being developed within the project in order to support data requests, processing, and data products delivery.

To assure that the entire system works smoothly integration of the hardware components with the software services is required, followed by thorough testing phase, leading to the system operational phase.

Prior to system definition and establishment of sensor upgrade plan the Consortium consulted various

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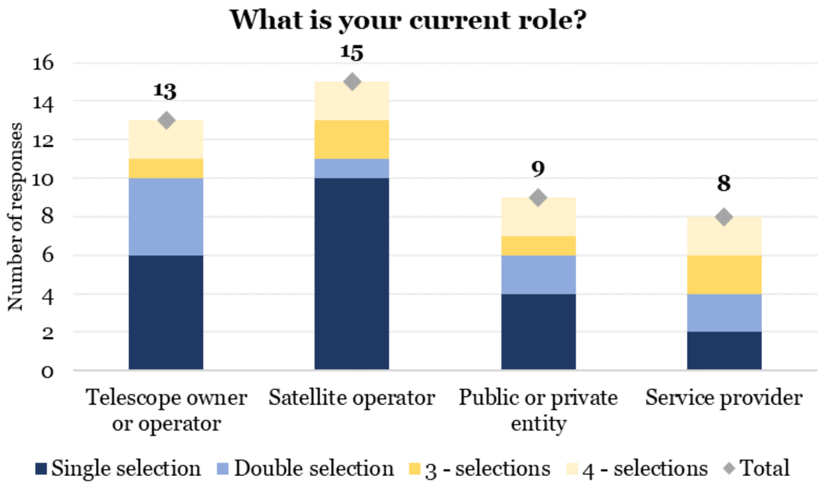

Figure 1. Survey results - the number of responses and the current role of the interviewees (colour-coded) .

stakeholders in the form of a survey, to better understand user needs. The survey was divided into four parts (general questions, section for sensor owners/operators, section for service providers, section for satellite operators). A total of 31 interviewees participated in the survey. 18 answers were generated by the Consortium members/consultants and ESA as they have significant experience in the areas listed above. At least 14 answers were provided by external users. The survey link was shared with more than 50 entities, which means that the response rate exceeded 25%.The largest group of users were satellite operators, followed by telescope owners, as presented in Figure 1 (more than one answer was possible per user).

2 SENSORS UPGRADES AND DEPLOYMENT

Within the main objectives of the project are: firstly a selection of suitable set of sensors in order to ensure uninterrupted service provision and high-quality data products; secondly the installation of additional sensors to complement the existing network effectively.

Existing sensors can also be upgraded or relocated. Relocation is also an important form of upgrading sensor performance by allowing it to gather more data (locations with better weather), data with better precision (better seeing), improve reliability (better local support) and cover missing parts of GEO region or increase region redundancy of the observatories (different geographical location). Sensors are qualified through functional, endurance and robustness tests.

The Consortium discussed the optimal distribution of sensors with satellite operators, sensor owners and operators, as well as key stakeholders from the consortium to select best upgrade scenarios for EON.

2.1 Sensors' network – selection of sites and total number of sensors

The baseline network selected for upgrades and further development is Panoptes-Solaris network of sensors. The network is characterized by the usage of uniform software provided by Sybilla Technologies running ABOT automation software with scheduling by WebPlan and where the SST data is processed by Astrometry24.NET. The existing network, of 14 sensors, is shown on Figure 2. (BlackGEM project in Chile consists of 3 separate sensors).

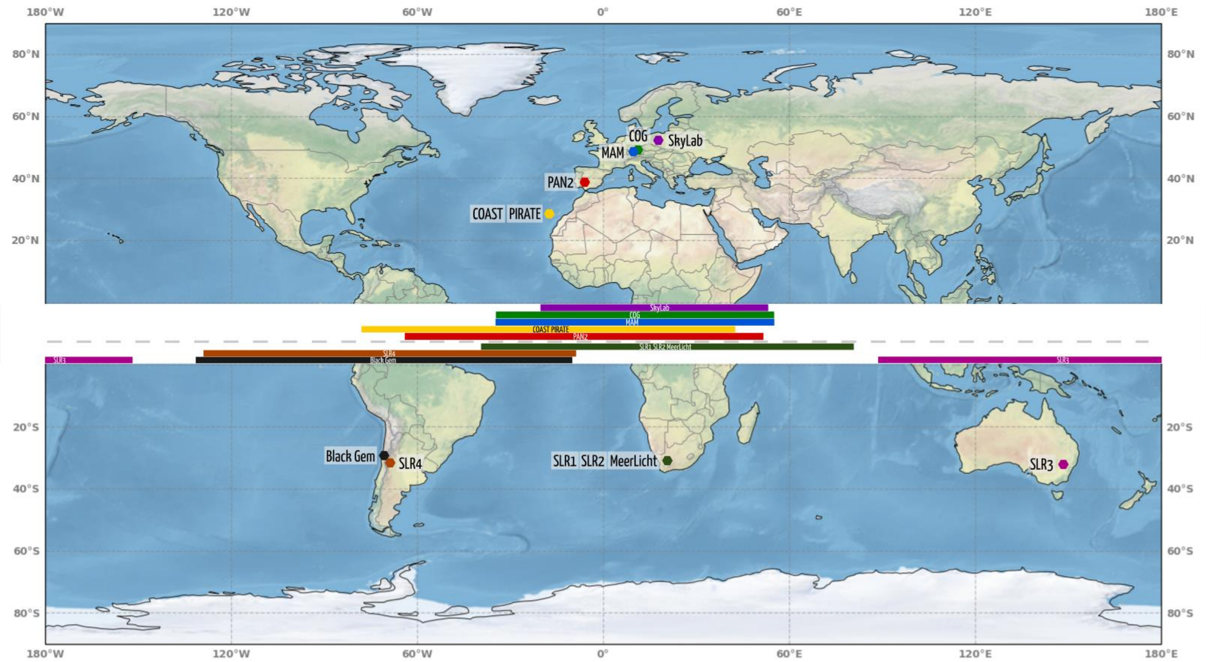

Figure 2. Panoptes-Solaris network – baseline network of sensors for EON. Map shows GEO belt coverage 20° above the horizon for the locations of presented sites.

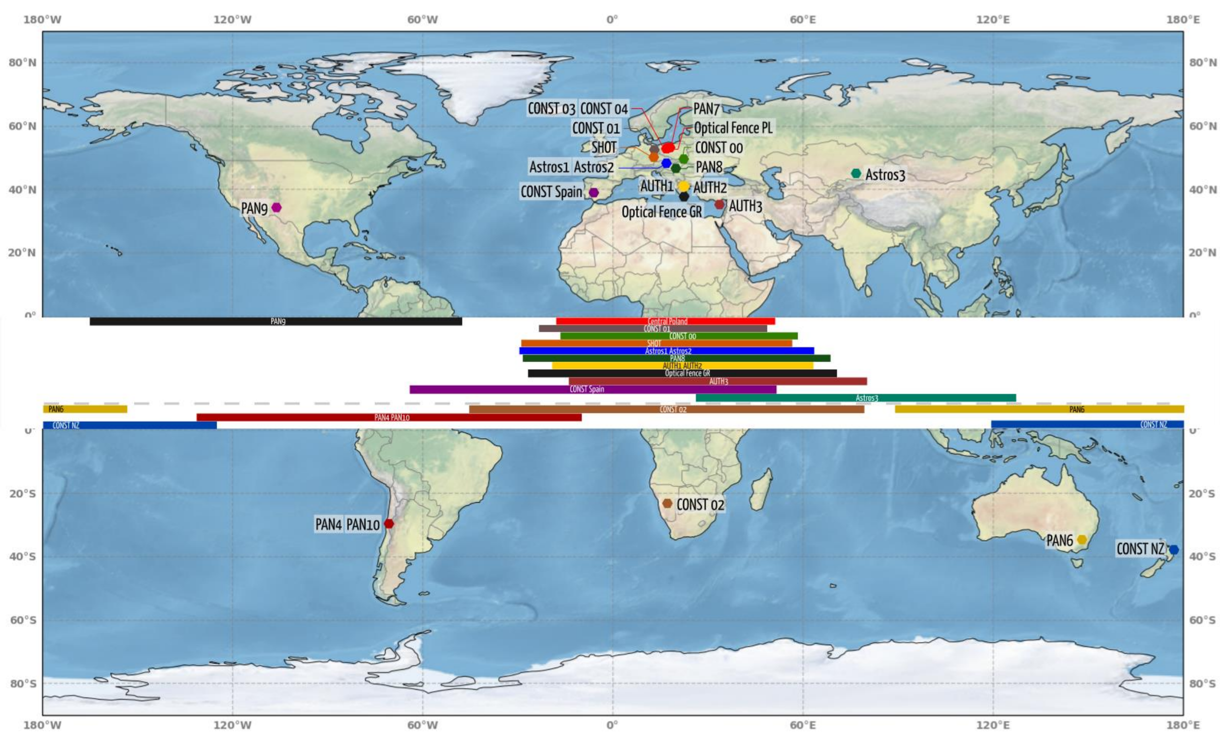

Figure 3. Sensor upgrades network – additional sensors for EON, status for January 2023. Map shows GEO belt coverage 20° above the horizon for the locations of presented sites.

By designing the network of sensors, the consortium evaluated multiple upgrade scenarios keeping in mind the following criteria:

- Quality and usability of the equipment to SST (class and cost of the equipment which would be added to the network).

- Geographical location contribution to the whole GEO coverage and selected GEO regions optimal for supported satellite operators.
- Cost optimization (best added value with largest possible number of hours contributed to the project for minimal price).
- Increasing SST/STM community participation with new entities, providing better resilience for European Optical Network and in the long term better political financial support for operation.
- Synergies with existing and future projects conducted by the sensors or entities owning them.

Taking into consideration the described criteria, the Consortium finally came to an agreement on 22 additional proposed upgrades as presented in Figure 3 and Table 1.

During the project run, the initial deployment plan was reviewed and updated. Due to various reasons (political, financial, technical etc.) the Consortium had to resign from several sites and compensate them by another deployment. While selecting alternative sites various conditions were taken under the consideration (weather, costs, political situation).

The following upgrades are ongoing or completed:

- Three Astros sensors - two Astros (Slovakia) sensors are connected to the EON network, perform necessary interface adjustment and tests. Relocation of one of the Astros sensors from Slovakia to Kazakhstan. Key benefits: better GEO coverage, better weather conditions, redundancy of GEO region, uncorrelated weather with other sensors.
- Panoptes 4 - UZG sensor (University of Zielona Gora, Poland) relocated from Spain to Chile and connected to the network. Key benefits: one new sensor in the network, good weather conditions, uncorrelated with other sensors, faculty with very experienced astrodynamics personnel.
- Panoptes 7 - UNC integration (connection to the network) – sensor owner: University of Nicolaus Copernicus in Torun. Key benefits: one new sensor in the network; faculty with very experienced personnel willing to further invest in the SST capabilities.
- SHOT integration (see Figure 6) - sensor from Czech Republic is connected to the EON services and provides data as external sensor. Key benefits: one new sensor in the network, strategic partner from Czech Republic, integration of non-ABOT system.
- Panoptes 9 – new sensor located in North America. Sybilla and Cilium deployed a sensor in North America dedicated for GEO observations and connected it to the network. Being a site with a far west location the sensor will be a valuable addition to the network and an important milestone for Sybilla’s and Cilium’s development.
- Aristotle University of Thessaloniki (AUTH) - 3 sensors in Thessaloniki, Cyprus and Holomon – upgrade, relocation and integration with the network. Partnership with entity from Greece.
- Panoptes 10 (see Figure 5) - Baader Planetarium 1-m telescope in Chile. Thanks to the large aperture and particularly suitable location (high-altitude observatory in Chile) the sensor can be seen as a multi-purpose instrument – for surveys of GEO pushing the limits of detection of small objects, ad-hoc follow-up observations of objects detected by smaller sensors on all orbital regimes. In the future the sensor can be equipped with instruments extending its capabilities to spectroscopy and polarimetry.
- Panoptes 8 – Hungary sensor in Baja Observatory. AstroTech with Baja observatory will actively contribute to system testing, evaluation and optimization of operational procedures developed in the project. Their feedback and contribution significantly improved CONOPS and quality of software used in the project.
- Panoptes 6 (see Figure 4) – Australia Sensor – setup installed in east Australia in October 2022 for improved coverage of that GEO region. Key benefits: 1 new sensor in the network, new location in Australia, good weather conditions, uncorrelated with other sensors, faculty with very experienced astrodynamics personnel.
- Constellation type of sensors (CONST). Base source of large amounts of optical data for the project. Constant monitoring of selected GEO regions. Six sites will host RASA 8” and CMOS camera (QHY163M or similar). Sensors are deployed or being in the process of deployment in: Spain/Europe (E-Eye hosting centre), Rzeszów/Poland, Berlin/Germany, Rooisand/Namibia, New Zealand, Tahiti, Hawaii or Reunion. (Final locations are discussed with potential hosting entities)

Table 1 presents the current status of all sensors upgrades as per the end of January 2023 and describes the stage at which the sensor is. The first stage is the “Hardware completion” which means gathering the equipment and installation of the equipment on site. The second stage is “Connection to EON”, installation of software on the sensor which allows to gather first data from the sensor. The following stage is “Calibration’, when the quality of the data is checked and adjustments are made if necessary. The last stage is “Operational”, when a sensor is connected to the network, checked, and produces data of good quality.

Table 1. Sensors upgrades status (sensor name, site and sensor's current status).

#	Sensor name	Target Site	Status
1	**Panoptes-3 (AUTH1)**	Greece, Thessaloniki	Calibration
2	**Panoptes-11 (AUTH2)**	Greece, Holomon	Hardware completion
3	**Panoptes-5 (AUTH3)**	Cyprus	Calibration on test site (before relocation to Cyprus)
4	**Panoptes-4 (UZG2)**	Chile	Operational
5	**Panoptes-6 (ST)**	Australia	Operational
6	**Panoptes-7 (UNC)**	Poland, Torun	Connection to EON
7	**Panoptes-9 (PAN9)**	New Mexico, USA	Calibration
8	**Panoptes-10 (PAN10)**	Chile	Connection to EON
9	**Astros-1 (AST1)**	Slovakia	Operational
10	**Astros-2 (AST2)**	Slovakia	Operational
11	**Astros-3 (AST3)**	Kazakhstan	Hardware completion
12	**CONST00**	Rzeszów, Poland	Calibration
13	**CONST01**	Berlin, Germany	Calibration
14	**CONST02**	Namibia	Connection to EON
15	**CONST03**	Test site - Poland, target site - TBD	Calibration on test site
16	**CONST04**	Test site - Poland, target site - TBD	Calibration on test site
17	**CONST05**	New Zealand	Hardware completion
18	**CONST SPAIN**	Spain	Hardware completion
19	**Optical Fence (PL)**	Poland	Calibration
20	**Optical Fence (GR)**	Greece	Calibration
21	**Panoptes – 8 (PAN8)**	Hungary	Operational
22	**Panoptes-SHOT**	Czech Republic	Operational

2.2 Type of sensors – hardware

The network of sensors consists of three types of sensors:

a. tracking sensors with the mount built from: wide field astrographs, industrial computer for control, CMOS camera, time monitoring unit.
b. survey sensors optimized for selected GEO region monitoring. The goal is to cover the GEO belt with at least double or triple redundancy (depending on the customer needs and available budget). Sensors are delivering data and providing necessary experience for next generations of stations.
c. Optical Fence sensors.

The Optical Fence system is an innovative system based on modern CMOS technology working on the triangulation network principle intended for LEO and high-LEO satellite surveying.

The system can detect and identify hundreds of LEO objects during single night. The limiting size is 0.4 m at the height of 500 km and is better than 1m for 2000 km altitude. The system is operating on principles similar to fireball networks, i.e., stations observe the same volume of space from different locations. With much larger altitudes of target objects, the system is much more extended than a typical fireball network, optimal distances between the stations can be larger than 1500 kilometres.

Due to required observing conditions (satellites must be illuminated by the sun, visible during the night, with similar observing conditions for both stations) the network elements are placed close to the same meridian and the observations occurs mostly (but not only) after the sunset and before sunrise. For low latitudes typically two observing windows are available - evening window and morning window. For medium latitudes two windows are available half of the year while all night observations are possible from spring to autumn.

The main principle of the network is a simultaneous observation of the same object from two distant locations. The object is visible in various parts of the sky, simple triangulation can be used to calculate the position at specific time. With the set of few positions the state vector can be determined, and the orbital elements can be calculated. With known position and orbit the object can be checked against the existing catalogues for identification.
The distance between the stations is set according to expected altitudes of the observed objects. With higher LEO orbits (altitudes higher than 1000 kilometres) an optimal system can be composed of two stations with distances between 1500 and 2000 kilometres. Such configuration ensures the proper observation geometry for high altitude objects. In the case of low LEO orbits the distance should be decreased. More than 2 stations can be placed along the same meridian with various distances for low and high LEO observations.
Examples of upgrades sensors are presented in Figure 4, Figure 5, Figure 6.

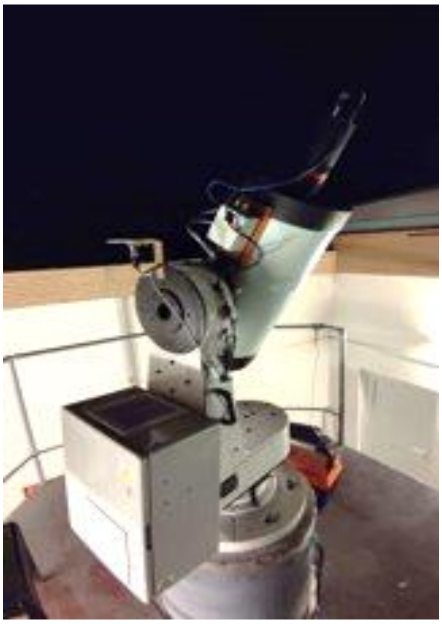

Figure 4. PAN 6 sensor (site: east Australia, Rasa 11'', aperture: 279 mm).

Figure 5. PAN 10 sensor (site: Deep Sky Chile, CDK1000, aperture: 1000 mm).

Figure 6. The SHOT sensor (site: Teplice, Czech Republic, CDK17, aperture: 432 mm) .

3 SOFTWARE SERVICES

The EON software services can be characterized by their functions (see Figure 7). The simplified version of the system architecture is presented in Figure 8, which does not include auxiliary services. Overall, 25 services have been planned [2] and are being developed by 6 entities (ST, OO, VY, AUTh, NTT, LSF). The following description presents the system flow and user interaction and based on the functional approach introduces all the EON software services, focusing on their main functionalities and problems that they solve.

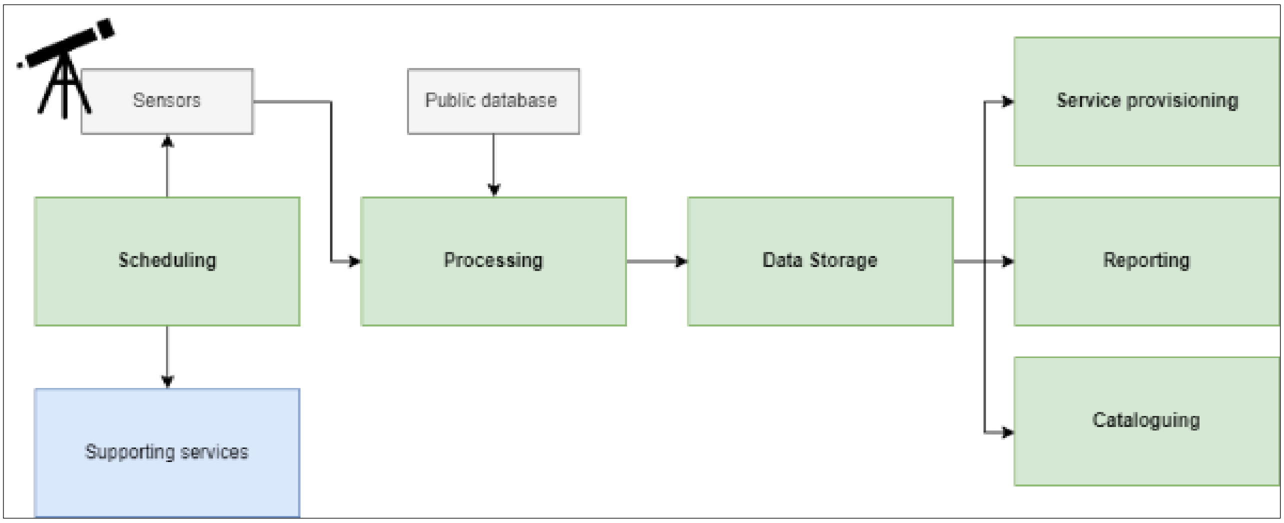

Figure 7. EON software functions.

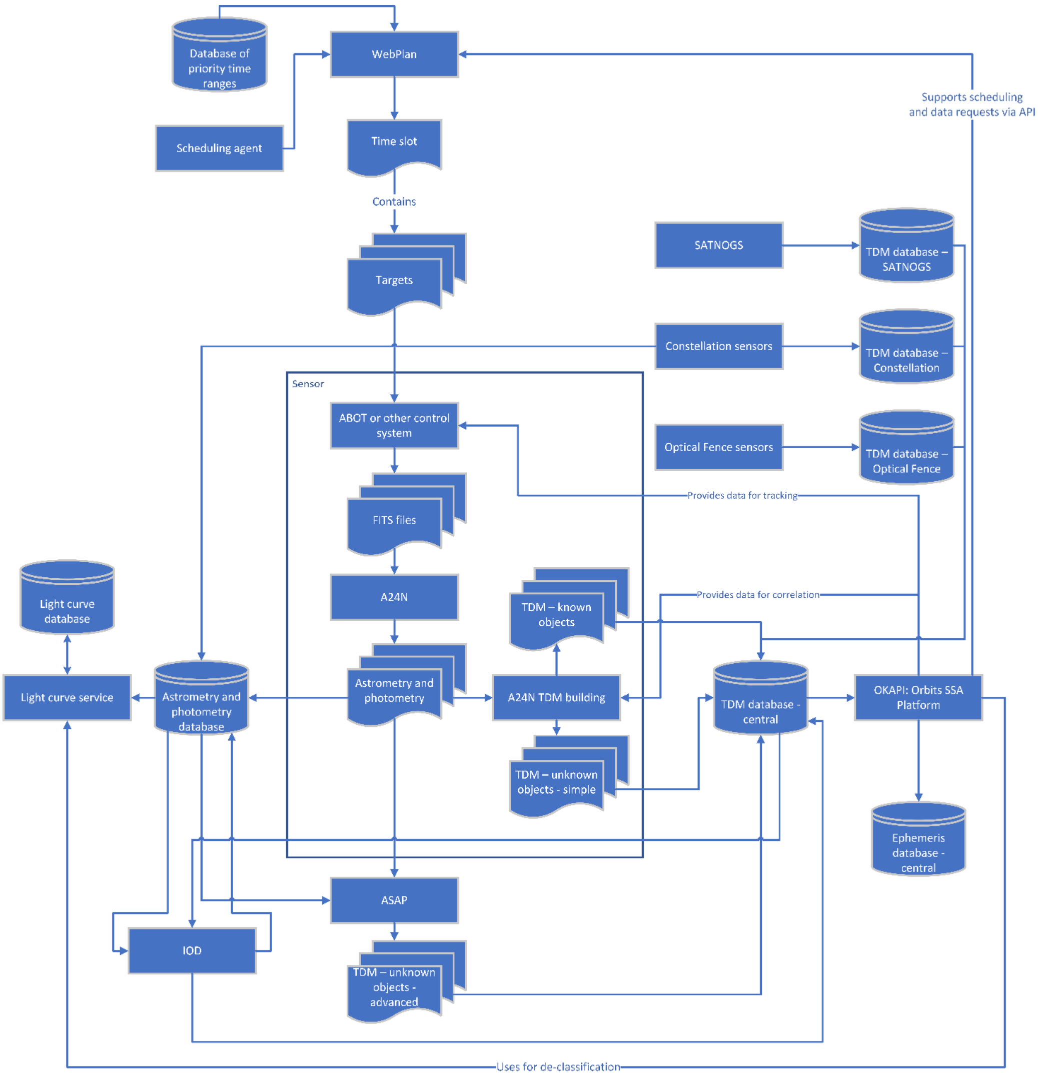

Figure 8. EON system architecture - simplified scheme (without auxiliary services).

3.1 Scheduling

The user's interaction with the system starts with the **Scheduling Agents Service** (SAS), a service that supports observations planning. The service reads the configuration defined by the user.

SAS can receive a list of targets defined via the auxiliary **Target List Service**. The Target List Service is a CRUD (create, read, update, delete) service serving as a storage for user's target lists where specified lists of prioritized objects for observations can be created along with defined observational parameters such as number of measurements, number of tracks, separation between tracks. An example user interface (UI) is presented in **Błąd! Nie można odnaleźć źródła odwołania.** . The user creating such list can also select allowed and not allowed sensors lists choosing from the sensors available for him/her. The list of sensors is exported from the **Sensor Book Service** which allows to maintain updated information on the sensors properties. An example of the Sensor Book (UI) is presented in Figure 9. The Sensor Book is a REST service with the following operations available: Create (creates new sensor entry in the service), Read (reads the sensor's properties), Update (updates the sensor's properties), Delete (deletes the sensor entry), Export (export the sensor details in the ESA Interface Control Document (ICD) format).

Once the observations are planned with the Scheduling Agents, the selected sensors are scheduled via **WebPlan**

(ST platform for sensors networking, delivery of schedules, gathering data in its AstroDrive component) where time slots are booked and populated with the target's description (coordinates or ephemeris) and sensor setup details. Within the EON project, necessary WebPlan upgrades are being implemented aiming at simplifying its structure, creating a typical REST API, improving the efficiency while using the WebPlan calendar etc., as well as at providing the needed UI adjustments. Moreover, migration of users to Azure Active Directory is ongoing.

Apart from the Sensor Book and the Target List, the observation planning process is supported by the following services:

Almanach Service which gathers publicly available ephemeris data in TLE, SP3 and CPF formats for the purpose of internal use and caching.

Weather Service which provides current weather forecast for a given site based on a third party forecast and calculates the probability of observations.

Object Brightness Service which provides information of object brightness and its statistics (such as average, median, minimum, maximum brightness, and standard deviation) helping to select exposure time and adequate sensors, the brightness statistics are calculated by an

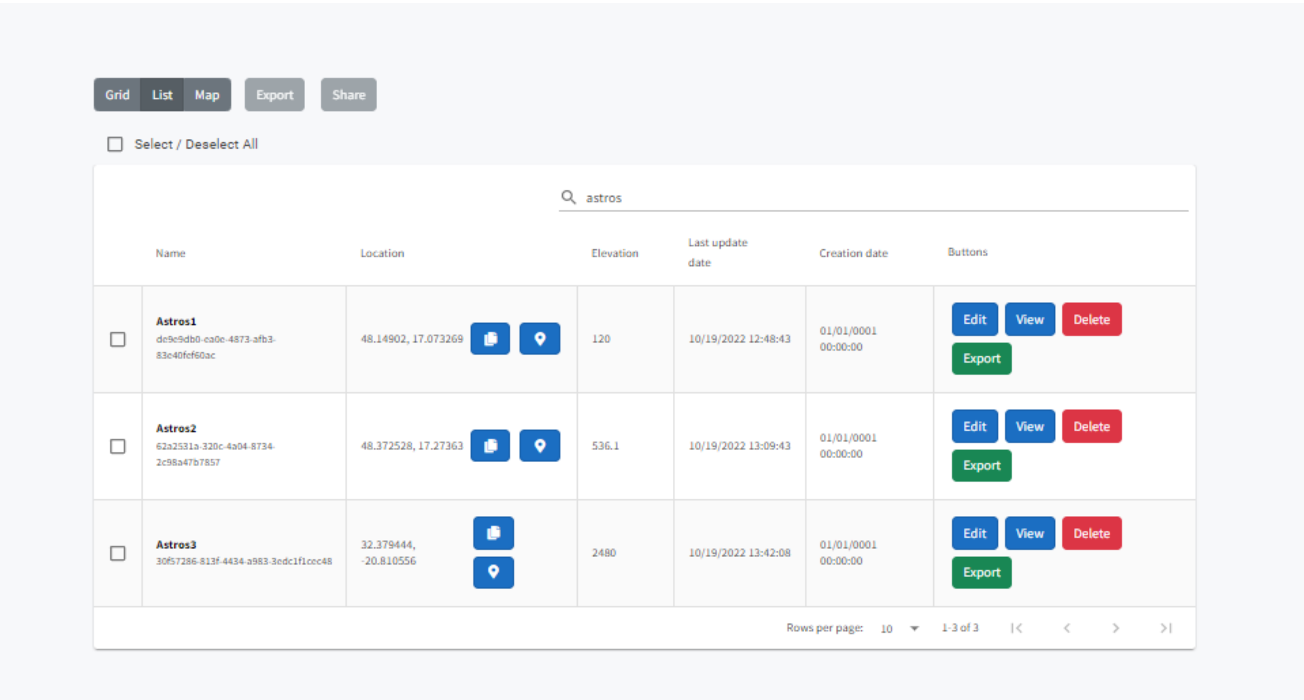

Figure 9. The Sensor Book service – UI (presenting the lists of sensors with their location and action buttons available for a user).

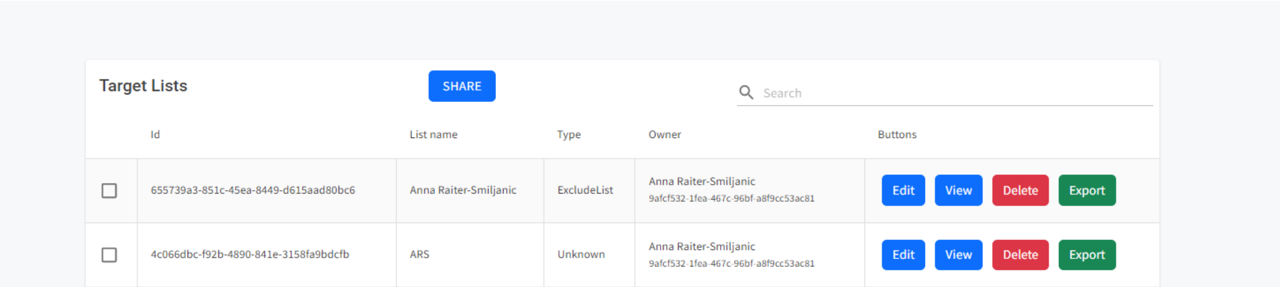

Figure 10. The Target List Service – UI (user's target lists and action buttons available for a user).

external script, which uses data from the DISCOS catalogue (if own measurements are not available), provides orbital regime for each target and populates the data tables within the service.

Whitelisting Service which allows to limit the distribution of the information about the classified objects.

3.2 Processing

Scheduled observations are executed automatically with the help of the system controlling a sensor (for example ST's ABOT, Astronomical roBOT). Raw FITS files (frames) produced from executed observations are then processed by the **Astrometry24.NET Service,** which produces JSON files with astrometric and photometric measurements, as well as correlates measurements with catalogues and produces TDMs. The following services are related to the system's processing function:

Correlation Service which after receiving astrometric data for detections found on images identifies moving objects (potential satellites) and builds tracklets from the set of moving objects; found tracklets are listed in TDM format for further processing.

Time Bias Service which calculates time bias and its statistics (average, median, min, max, standard deviation, error) for a batch of TDMs containing observations for which high precision ephemeris is available, the service is able to provide time bias report for a chosen sensor and time.

TDM conversion Service (Public Databases) which gathers data from public databases of RF and optical observations, converts them to TDM format and submits them to the main service.

Light Curve Service which receives brightness measurements together with astrometric information (TDMs), returns magnitude vs time (a light curve) in IADC format (.CSV) and the results of light curve time-series analysis (an example is presented in Figure 11). Figure 11 presents the analysis of a 23-sec tracklet of ID 36525. Diagnostic plots (top- to-bottom) are the light curve, Lomb-Scargle periodogram (LSP), amplitude of the stronger peak detected in LSP, and amplitude of the stronger peak, as found by phase-dispersion minimization (PDM). The left column shows the analysis of the 'RAW' light curve, while the right column shows the analysis of the de-trended light curve (DT), which reveals a period of 11 sec, not seen in the raw data. A moving-polynomial filter detects a trend in the raw light curve (top-left, red line) that may be the signature of a long periodicity, but is strong enough to 'hide' the short-periodic component (green) and render the LSP inconclusive -- both LSP and PDM suggest a zero-amplitude 'dominant period', i.e. an aperiodic signal. Subtracting the trend from the raw signal, the DT curve is obtained and analysed (right column). LSP detects a peak at 11 sec, which is confirmed as the dominant period, by PDM. This sequence of operations automatically classifies the tracklet as "Statistical Class #7" which, after a false-positives filter, classifies the object as 'Periodic variable' but with 'possible additional periodicity longer than tracklet length'.

Initial Orbit Determination and Orbit Determination Service which provides object's trajectory; the service helps to perform follow-up observations of newly detected objects by retrieving its ephemeris based on provided optical observations in TDM format (initial orbit determination) and of objects with bad ephemeris based on new ephemeris (orbit determination).

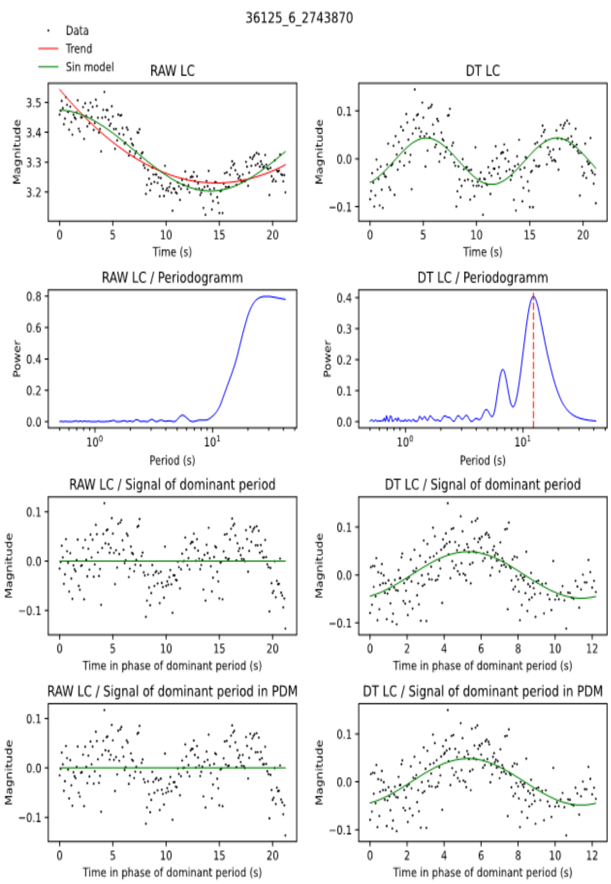

Figure 11. Light Curve analysis - example. See text for details (section 3.2).

3.3 Data storage

Data files (FITS, JSON, TDM) from observations are generated and provided to **AstroDrive** (data storage platform allowing to download and upload files) or to the **Data Cubes Service**. The Data Cubes Service is a subsystem of the AstroDrive component and allows for quick creation of directories with specified quota, permissions and duration.

3.4 Cataloguing

A number of features allowing to build-up and maintain the object catalogue is provided by the **Catalogue Service** and subservices: Catalogue access, Scheduler interface, Sensor-centric data requests, Close approach support. In case of a fragmentation event, the **Fragmentation Cataloguing Service** is used to catalogue objects involved and resulting from the fragmentation according to the inputs provided by a data requester.

3.5 Reporting

Reports and appropriate visualizations concerning sensor performance, processing pipeline performance, user services performance and used resources can be provided by the following services:

Reporting Service which generates reports on the data gathered, general sensors statistics, resources used and summary for specialized agents as well as events like fragmentation, manoeuvre, payload separation.

Telemetry Service which logs information on the sensors status (Can observe or Cannot observe) and provides reason for not performing observations (for example maintenance, software/hardware failure, weather, other), logs information on the processing pipeline performance and can provide statistical information (for example number of FITS files produced, number of TDM files produced) for a selected sensor and selected time period; allows to follow other services health check. The service uses Grafana dashboards as visualization tool.

3.6 Services provisioning – services supporting events confirmation

The services described below along with the SAS are designed to confirm and catalogue observations of events:

Payload Separation Service: which confirms payload(s) deployment in-orbit. The following operations are available: Create (creates new payload separation confirmation request), Read (reads the request status), Update (updates the request details), Delete (deletes the payload separation confirmation request).

Manoeuvre Confirmation Service: which confirms a manoeuvre and its performance. A user supplies the service with the target state data which are then compared with the actual data found in the object catalogue post event execution. A manoeuvre execution analysis report is generated and can be retrieved.

Fragmentation Cataloguing Service: which allows to perform CRUD operations on fragmentation cataloguing request, manually provided or based on FDR (fragmentation data report) provider monitoring, as well as runs automated fragmentation cataloguing process. The service helps to increase safety of operations possibly affected by fragmentation events.

Cluster Monitoring Service: which allows to correlate measurements of closely spaced objects with the catalogue and recognizes which observations collected via tracking belong to certain satellite(s) flying close to other objects.

3.7 Other services

The remaining supporting services are described below:

Ticket System: which allows to report issues (tickets) to the support team in a consistent way and keeps track of them.

Authentication Service: which provides authentication compatible with OpenID 2.0 standard. To fulfil this role the Azure Active Directory has been selected.

3.8 Services – status summary

The status summary for all the software services developed within the project is as described below:

- MVP (minimum viable product, understood as at least one of the use cases defined in [2] is addressed) - done: 21 services.
- MVP - ongoing: 2 services.
- MVP - to do: 2 services.
- Demo version (defined as all the use cases defined in [2] are addressed)- done: 8 services;
- Demo version – ongoing: 11 services.
- Demo version – to do: 2 services.

4 INTEGRATION AND OPERATIONS

The EON project aims to develop a comprehensive and redundant sensor network that will ensure coverage of the GEO belt. Simultaneously, the EON team develops appropriate software allowing to address the end user needs and stakeholders' requirements.

At the moment of preparing this publication, sensors connected to the system prototype started to deliver data. Table 2 summarises the volume of delivered data compared to the Consortium commitment.

Table 2. Summary of delivered hours vs committed hours, divided between consortium partners and sensors.

Partner	Sensor	Hours planned	Hours used	Hours left	TDMs	Obs points
ST	1m	165		165,0		
ST	UZG relocation (PAN4)	400	4,3	395,8	0,0	0,0
ST	**Panoptes-Solaris**	**990**	**671,5**	318,5	**13 134,0**	**608 918,0**
ST	COG	-	98,3	-	694,0	11 180,0
ST	MAM	-	9,8	-	83,0	2 739,0
ST	PAN2	-	424,0	-	11 832,0	583 719,0
ST	PAN4 (b.r.)	-	36,3	-	525,0	11 280,0
ST	PAN6	-	103,3	-	1 074,0	62 660,0
CE	1m	165		165,0		
CE	UNC Integration	100		100,0		
CE	PAN9	690	84,5	605,5	1 150,0	136 466,0
CE	Astros	600		600,0		
AUTh	AUTH	600		600,0		
IGU	SHOT integration	133	19,5	113,5	183,0	6 893,0
AT	New sensor Hungary (PAN8)	500		500,0		
Total		**4 343**	**779,75**	**3 563,25**	**14 467,00**	**752 277,00**
ST	**CONST**	**9000**	**455,75**	**8544,25**	**9337**	**1 181 076**
ST	CONST001	-	144		2978	254625
ST	CONST002	-	34		565	68096
ST	CONST003	-	277,75		5794	858355
CE	Optical Fence	1700		1700		

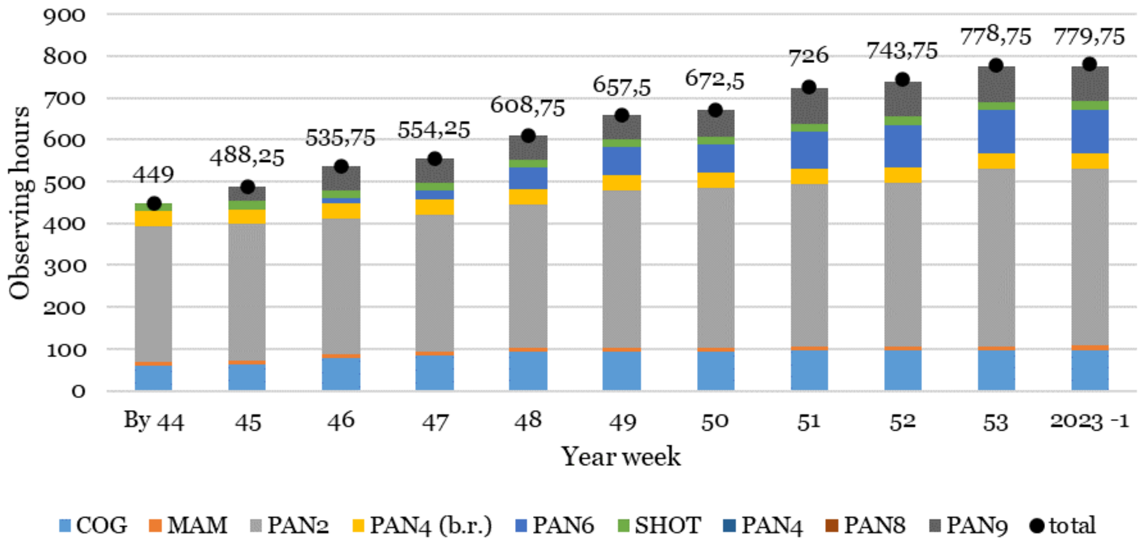

Figure 12. Summary of gathered data in 2022 in the EON project presenting the number of observing hours per sensor and by year week (incrementally).

The integration of hardware and software components is planned once the software services are deployed and all the sensors upgraded and deployed. The workflow from data request to data products delivery will be automatic. Initial demonstration cases include payload separation confirmation mode and manoeuvre execution confirmation mode. Integration process shall be regarded from a single sensor perspective. The following main stages can be distinguished:

- sensor connection,
- sensor calibration,
- normal operation:
  - catalogue build-up.
  - service provisioning (demonstration).

Sensor connection

Sensor connection to the EON system shall be initialised upon completion of hardware deployment and achievement of "first light". This phase consists of adding the sensor to the WebPlan, installation of processing software and opening data flow. In parallel, key sensor characteristics are entered into the Sensor Book. Depending on the sensor owner preferences, the sensor may have a special software for remote sensor management (ABOT) installed. Consequently, the sensor is visible to the WebPlan-user and can be scheduled throughout the EON services (Scheduling Agent with/without Target List support). The observational data are processed at the sensor side (e.g. Astrometry24.NET) and delivered to the AstroDrive and/or Data Cubes. Successful observation (observation, which ended with TDM creation) and data ingestion signifies the end of this phase.

Sensor calibration

Sensor calibration is an essential process that aims at estimation of sensor time bias and validation of sensor data. The calibration procedure assumes conduction of an observational campaign dedicated to GNSS objects (these objects have precise ephemeris). A sample of observational data is selected according to certain given criteria and a comparison of RA-DEC values provided in TDMs versus RA-DEC values coming from ephemeris (e.g., SP3) for a particular epoch is performed. This analysis allows Time Bias estimation. Once the time is calculated and applied, O-C (observed vs computed) residuals should be concentrated around the "0" line, as it is illustrated in Figure 13.

Normal operations

Automatic data flow from the fully connected and calibrated sensor shall be continuous and uninterrupted. Each maintenance issue is logged, while overall sensor and software performance is visualised (Telemetry Service). The processed data is used for further catalogue build-up and end user service provisioning.

Catalogue build-up and maintenance

The data received from the sensors is catalogued and used for ephemeris and service provisioning. Data of poor quality (e.g. from public databases) will be refused for catalogue building purposes. From this perspective, sensor calibration is crucial to ensure high quality of data and maintenance of the catalogues. The Catalogue Service will provide the user with ephemeris for a new (IOD) and existing (OD) object. Sample OD results performed for PAN2-SP3 data is presented in Figure 14.

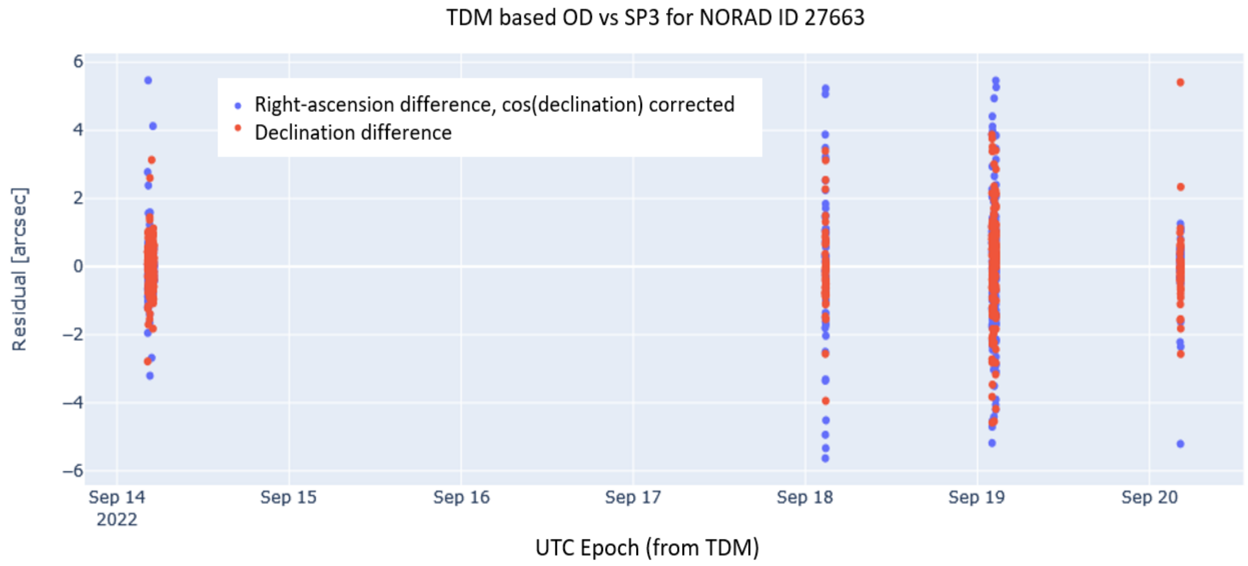

Figure 13. O-C residuals in arcsec vs UTC epoch for object 27663 observed by PAN2 sensor, with applied time bias of 141 ms. Even distribution of residuals around zero mean with no observable trends shows appropriate modelling of relevant effects and good orbit determination quality.

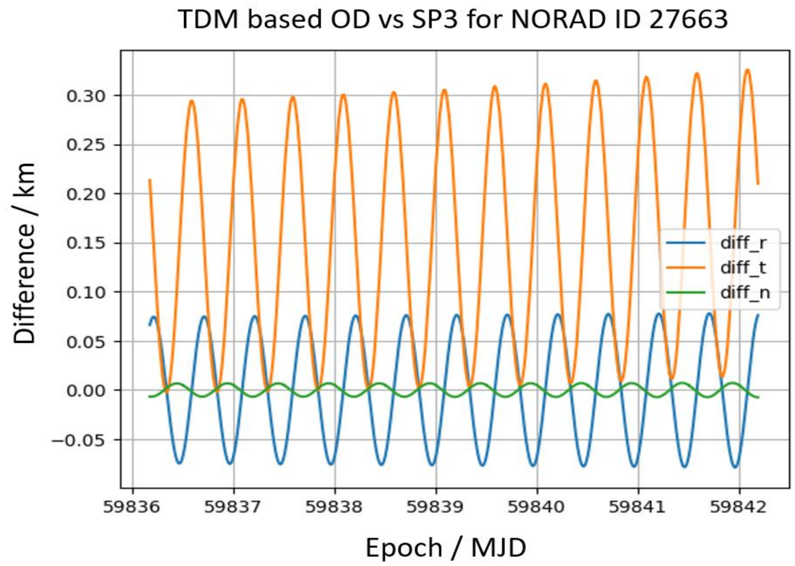

Figure 14. Orbit determination results for object 27663 based on TDMs from sensor PAN2, where the RA-DEC values were substituted with SP3 values. Overall difference within expected range with zero mean for radial and normal differences. Along-track offset is under investigation.

Service provisioning (demonstration)

The EON project will demonstrate the network capabilities to monitor high impact events, including:

- Fragmentation,
- Payload separation,
- Manoeuvre,
- Cluster.

The demonstration will cover full operational process, starting from sensor scheduling, through data processing and ending at reporting. Successful execution of this exercise will confirm the system maturity and readability for delivery of the mentioned services.

5 REFERENCES

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