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# Future approach for GEO Ground Stations Monitoring and Control (M&C) in the Mission Control Room (MCR) – the EUMETSAT Perspective

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## Abstract

With the advent of new generations of satellite systems, the harmonisation of the operations across different missions becomes a key element for cost-effective operations and for business continuity. Towards that goal, EUMETSAT has conducted several specific case studies [1] with the aim to analyse the benefits and the best possible solutions to harmonise the ground stations (GStn) infrastructure and operations between the well-established Meteosat Second Generation (MSG) programme and the Meteosat Third Generation (MTG) programme which is currently in its Satellite In-Orbit Verification (SIOV) and commissioning phase of its first satellite.

The first study explored the possibility of the using any GEO Telemetry, Tracking & Control (TT&C) Ground Station for the support of both generations of Meteosat satellites, i.e. by any EUMETSAT GEO ground segment. In this case, a transition from mission dedicated ground station assets to a multi-mission EUMETSAT ground station 'infrastructure assets' was envisaged. This approach would simplify the operations, increasing the flexibility of the overall available capacity during critical phases of the space mission in which alternate locations or dual station coverage are required.

The definition of a harmonised GEO ground stations architecture involves not only the station sites but also the centralised ground stations high-level monitoring and control systems located at EUMETSAT's headquarters in Darmstadt. Through this harmonisation, the operations in the control room of the ground station assets, initially foreseen for two separate missions, would be orchestrated in a straightforward way and with a clear view of the real time status of all the available antennas and its associated equipment.

Following this initial study and sharing this multi-mission approach [2], a second study focused on the harmonisation of the central ground stations' monitoring and control system was started with the aim to move towards a unique GEO Ground station high level Monitoring and control (M&C) system. The purpose of this paper is to describe the new GEO Ground Stations' M&C system architecture and the benefits brought by its usage in the control room.

**Keywords:** M&C, High Level M&C, HLMCS, GEO, MTG, MSG

## Nomenclature

*GEO GStn M&C system* – This term refers to the whole M&C system of the ground stations including all Low Level and High Level components.
*High Level M&C system* – The use of High Level M&C (HL M&C) system in this document refers generically to the GEO Ground Station high level M&C, located at the Mission Control Room (MCR) for centralising the ground station operations.
*Low Level M&C system* – The use of Low Level M&C (LL M&C) system refers to the GEO Ground Station low level M&C, located at the ground station site which allow the management of the operations locally at the station.
*MSG GSCON* – The GSController (GSCON) is the specific high level M&C system in the context of the MSG programme (see figure 2).
*MTG HLMCS* – The MTG High Level M&C (HLMCS) is the specific high level M&C system in the context the MTG programme (see figure 2).
*MSG CMCS* – The Fucino Centralised Monitoring and Control System (CMCS) and Cheia CMCS are the tailored low level M&C system in place for the MSG programme (see figure 2).
*MTG LLMCS* – The MTG Low Level M&C (LLMCS)- both for Telemetry Tracking Command Facility (TTCF) and Mission Data Acquisition Facility (MDAF) operations- are the tailored low level M&C systems in place for the MTG programme (see figure 2).

*MCR, MCC, Mission Operations System*- Mission Control Room is generic terminology to indicate place where operations are performed, this can be from the Mission Control Centre or from the Backup Spacecraft Control Centre. Mission Operations System resides in the Mission control room and it handles centrally all operations comprising mission control, flight dynamics and mission planning.
*MME*- The Multi Mission Elements (MME) are components used for all the systems which are not mission specific but serve more than one mission. Their functions include system monitoring of the entire ground system, dissemination, archiving and storage. In this paper, only the MME monitoring systems are considered that are pertinent to the ground station. The MME monitoring group is composed of the Telemetry Propagator (TM Prop), Analysis & Reporting (A&R), Generic Events Monitoring System (GEMS) and OP5.
*OPE* - this is the operational environment, consisting of a serious of machines dedicated to run operational activities.
*VAL* - this is the validation environment, consisting of a series of machines which are identical to the operational machines and dedicated to test changes to the system before deploying them on the operational environment (OPE). Furtherly, the VAL environment can take over operations in case of major issue with OPE.
*Northbound interface*- this is an interface provided by the M&C system to allow a higher level component to access any of the monitoring parameters, events or commands.

**Acronyms/Abbreviations**

| | |
|---|---|
| A&R | Analysis & Reporting |
| ANT | Antenna |
| BSCC | Backup Spacecraft Control Centre |
| CCSDS | Consultative Committee for Space Data Systems |
| CMCS | Centralised Monitoring and Control System |
| COTS | Commercial off-the-shelf |
| DU | Data Unit |
| FDS | Flight Dynamics System |
| GEMS | Generic Event Monitoring System |
| GSCON | Ground Station Controller |
| GStn | Ground stations |
| HCI | Human Computer Interface |
| HL M&C | High Level Monitor and Control System |
| HQ | Headquarter |
| ICD | Interface Control Document |
| LL M&C | Low Level Monitor and Control System |
| M&C | Monitor and Control System |
| MCC | Mission Control Center |
| MCR | Mission Control Room |
| MIB | Management Information Base |
| MME | EUMETSAT Multi Mission Elements |
| MOTS | Modified off-the-shelf |
| MPS | Mission Planning System |
| MSG | Meteosat second generation |
| MTG | Meteosat third generation |
| OEM | Orbital Ephemeris Message |
| OPS | Operations |
| OS | Operating System |
| RF | Radio Frequency |
| RNG | Ranging |
| SLE | Space Link Extension |
| TC | Telecommand |
| TDM | Tracking Data messages |
| TM | Telemetry |
| TM Prop | Telemetry Propagator |
| TT&C | Telemetry, Tracking and Telecommand |
| W/S | Workstation |
| XML | eXtensible Markup Language |

## 1. Introduction - Architecture Context

The EUMETSAT ground stations are monitored and controlled, locally, at the stations site via a local M&C system and, remotely, from the Mission Control Room (MCR) where all the operations for all the space and ground segments are conducted.

The figure 1 below shows the context of a station HL M&C system which connects to the station computer - LL M&C system - in several ground stations and centralises all ground station monitoring and control data within the control room.

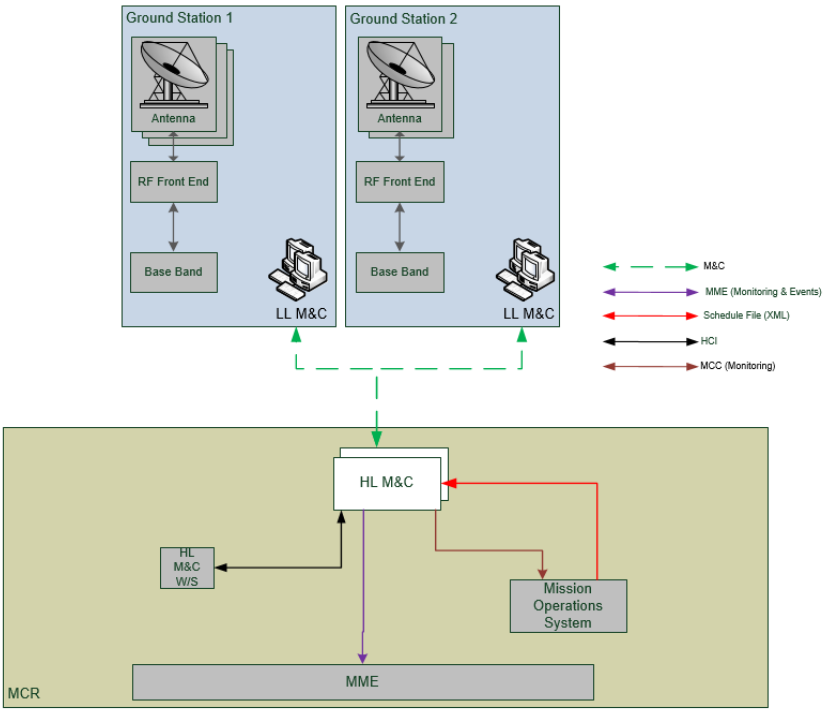


Figure 1. Overview of a generic EUMESAT GEO ground segment.

The HL M&C system is responsible for the following functions:

- Centralises all GEO ground station monitoring and control data including monitoring of alarms and events for the operators.
- Visualisation – Provides an Human Computer Interface (HCI) to the operators to visualise and interact with the GEO ground stations.
- Centralises the scheduling function for all GEO ground stations where the weekly schedule of operational tasks (e.g. station swaps, ranging calibrations and measurements, etc…) are received as an eXtensible Markup Language (XML) file from the mission planning system (part of the Mission Operations System), for the purpose of triggering macros to manage the routine operational activities.
- Provides all monitoring and event data on ‘northbound’ interfaces towards the EUMETSAT Multi Mission Elements (MME) and a subset of monitoring and event data to the mission operations system.

For completeness of information, the LL M&C system is responsible for the following functions:

- Antenna Pointing – it takes orbital prediction data received from the Flight Dynamics System (FDS- part of mission operations system) to enable the antennas to acquire and track the operational satellites.

- Ranging – it interacts with the TT&C baseband ground station equipment for orbital determination of the operational satellites and provides the data back to FDS.

- Monitoring and control locally at the stations site. For the control part, it is important to note that it is performed remotely from the MCR; keeping in mind that the token for the control capability is passed to the stations when special commanding on site from the station is required but commonly the commanding is responsibility of the HL M&C at MCR.

The rationale for the need of harmonisation effort resides in a considerable level of diversity - existing in the current mission ground segments and, in particular at ground station level - the architecture, the data flows and the interfaces are of heterogeneous nature. The figure 2 shows the current systems:

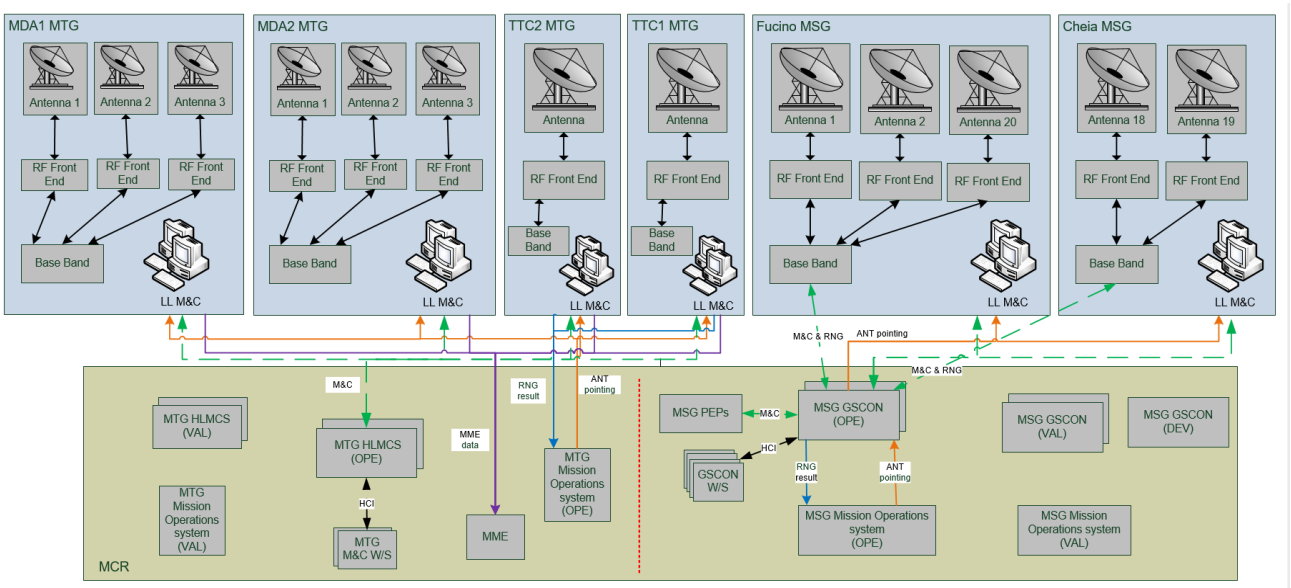


Figure 2. Overview of current MSG and MTG ground segment architecture emphasizing the ground station element.

It is fair to mention that the GEO GStn systems have been going through a general process of harmonisation for some time already before the present M&C system harmonisation work. The organisation triggered in advance some activities in order to have MTG and MSG programmes using a two-layer HL M&C - LL M&C architecture, and given that the same prime contractor was in charge of the MSG and MTG ground stations M&C system, Telespazio Italy, to adopt the same Telespazio Modified off-the-shelf (MOTS) M&C product in all low level M&C systems and finally to have both High Level M&C systems based on the same Skyline Dataminer Commercial off-the-shelf (COTS) M&C product.

## 2. Assumptions and Analysis

The assumptions made in this harmonisation approach were the following:

1. All GEO ground station operations shall be conducted from the same Mission Control Center at the EUMETSAT Headquarter in Darmstadt or at the Back-up Satellite Control Centre (BSCC).
2. The BSCC for both MTG and MSG shall be located at the Fucino Telespazio site in Italy.
3. The desire of GEO operations is to move towards a fully automated ground station operations concept.
4. The MSG Mission Planning System (MPS) is not capable to feed the Ground Stations Controller (GSCON) with the MSG ground station planning instructions in the foreseeable future. Therefore, an alternative methodology should be considered.
5. The GEO scheduling function should be performed from the HL M&C system to provide an aggregated view of all GEO ground station activities.

Several trade-off analyses were carried out during the GStn M&C system harmonisation study leading to the new system architecture presented in figure 3. A dedicated trade-off also found the balance point among all the monitoring tools used by operations team and engineers dealing with daily checks and troubleshooting.
The most important design choice comes from the vision to combine the MSG Ground Station Controller (GSCON) High Level M&C system and the MTG High Level M&C (HLMCS) system after a thorough analysis examining advantages and drawbacks of a combined GSCON / HLMCS system versus the separate configuration that is in place today.

## 3. Design choices to move towards Harmonised system- Steps taken

Several choices were made in order to move towards a harmonised and service-oriented architecture for the ground station M&C:

a. The antenna pointing and ranging interfaces to the MSG mission operations system will be migrated from the HL to the LL M&C.

b. Monitoring ground station data and event interface to the MME will be moved from LL to HL M&C. In the case of MSG, this interface will need to be established as it does not currently exist.

c. Standardise the HL to LL M&C system interface, which enforces a Management Information Base (MIB)-type concept of the M&C data available from the LL M&C. The MIB allows auto generation of the HL M&C system drivers towards each ground station. The standardisation is not restricted to the interface itself, but also deals with the different protocols implementing the data flows between the stations and the mission operations system. Harmonised Interface Control Documents (ICDs) are essential to the overall interface definition as the communication amongst M&C systems and stations is currently characterised by different protocols doing the same job but implemented in a different way.

d. Adopt a COTS approach for the GEO HL M&C system software. It paves the way to split the configuration of the M&C system into a maintenance related task (meaning drivers and low level configuration files, named Software Core Data Unit - CoreDU) and an operations related task (meaning scripts, mimics and out-of-limit definitions, named Operational Data Unit - OpsDU).

e. Increased redundancy, testing, development and simulation capabilities are foreseen to be expanded, providing the maintenance teams development environments. These can be used to perform troubleshooting with no disturbance to operations, and for the operations team to conduct operational validation and operations preparation activities respectively for the already in orbit and the to-be-launched satellites. The increased redundancy is also important to allow the stations usage with no downtime.

f. Centralised operations and scheduling are envisaged through a system centralising all the monitoring data and events, which should also be able to orchestrate operational activities by providing an overall view of the stations.
Regarding the scheduling harmonisation aspect, a staged approach has been selected:

1. Move MSG ground station operations from a manual to an automated approach where mission planning is carried out directly on the MSG GSCON.
2. After the MSG GSCON and the MTG HLMCS are integrated, update the MTG MPS to handle the mission planning needs of both MTG and MSG ground stations.

The interface to mission planning is considered as a EUMETSAT internal interface and so although a Consultative Committee for Space Data Systems (CCSDS) standard exists for scheduling [3], the cost and effort to develop this are not deemed necessary as the MTG format is already implemented and easily adaptable for MSG.

g. The adoption of CCSDS standards for all external interfaces (including baseband Space Link Extension -SLE) allows a 'service' approach to the GEO ground station utilisation - any GEO satellite can be in principle supported by any GEO station.

## 4. New Architectural Design

The new GEO ground station M&C system architecture – depicted below in figure 3 - is designed to harmonise the software systems, infrastructure, data-flows and operations methodology across the entire GEO ground segment while meeting the user needs and also complying with the latest EUMETSAT security requirements and best practices.

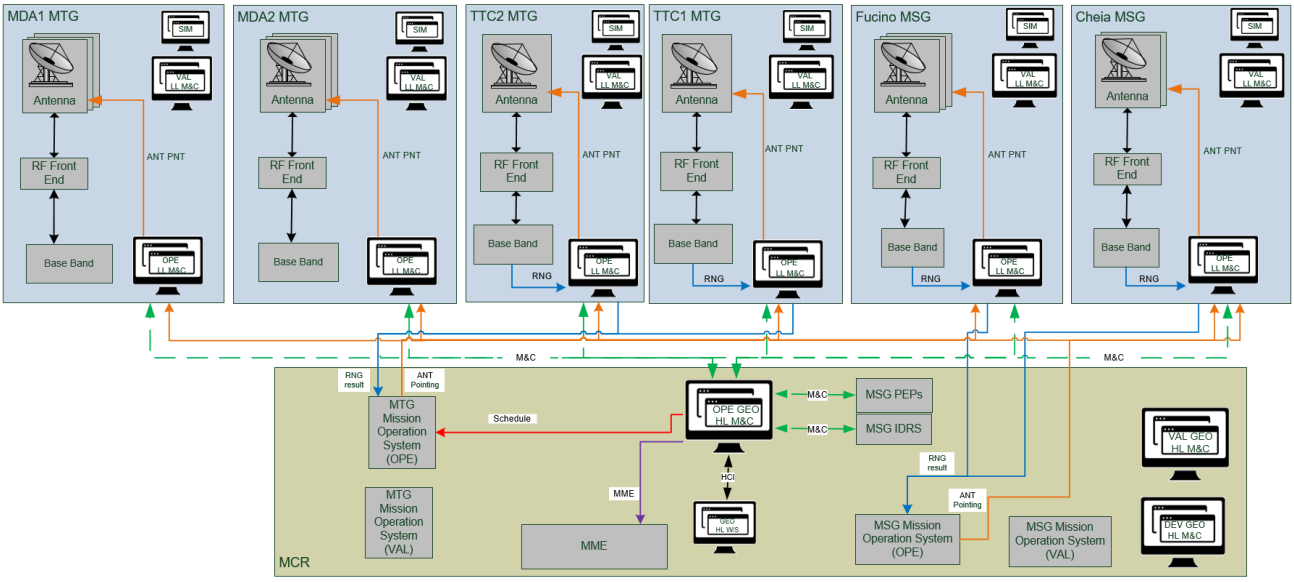


Figure 3. Overview of the harmonised GEO TT&C GStn M&C system architecture.

This system will allow a simplification of all aspects of life in the MCR as explained in section 5.

From an infrastructure point of view as represented in figure 3, the new architecture implements the virtualisation of the ground station M&C system hardware at both mission control room and station site level.

Figure 4 below shows all the interfaces of the new GEO High Level M&C system with external systems (MSG Mission Operations System, MME, MTG Mission Operations System, Ground station equipment) and within the stations M&C system itself (Low level M&C system).

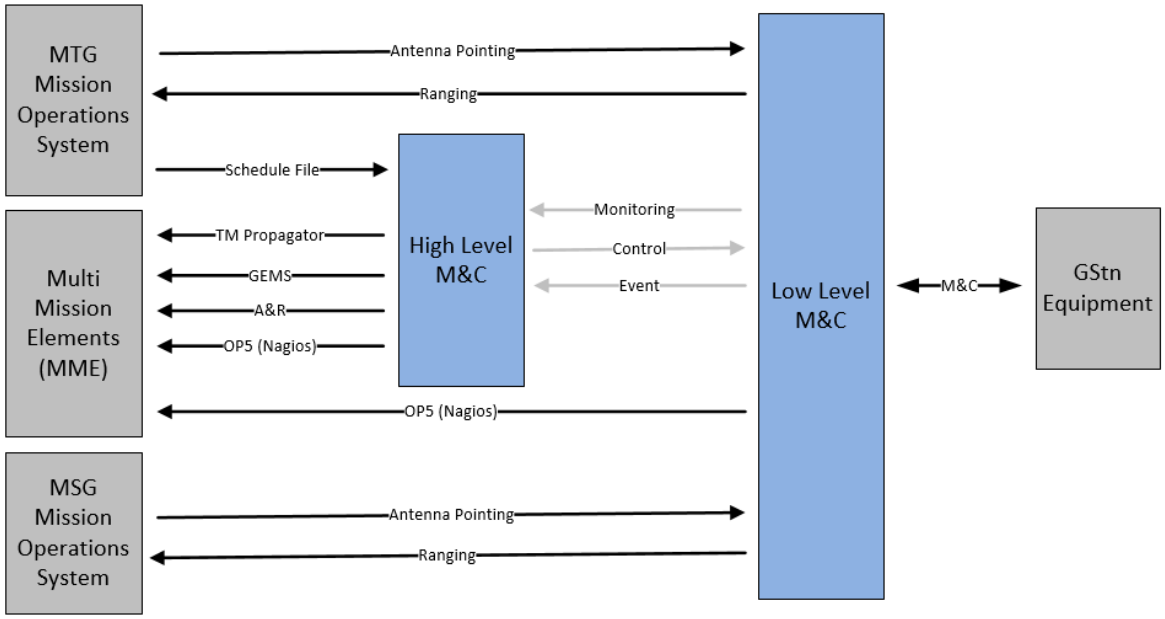


Figure 4. Ground Station M&C Interface Overview.

Specifics of the interfaces are as follows:

- Ground station
  - The Low Level M&C system interfaces with the ground station equipment for the purposes of station configuration and monitoring. The Low Level M&C system also distributes the ranging request to the TT&C baseband units and collects the resultant ranging calibration and ranging measurement data. And finally, distributes the antenna pointing data to the antenna control unit.

    All existing EUMETSAT ground stations already implement this methodology.

- MME
  - The MMEs acquire all operational monitoring data from the High Level M&C system, the majority of which it receives from the Low Level M&C system for presentation by TM Propagator, A&R and GEMS.

    Only the GEMS interface is currently supported by the MTG HLMCS and so the TM Propagator and A&R must be developed. The MTG Low Level M&C currently feeds those interfaces and hence these streams shall be disabled in the new design from LL M&C. For MSG GStn M&C system, all MME interfaces are still to be developed and integrated.

  - The OP5 data is specific to hardware monitoring and so although the High Level M&C system shall support this interface, the Low Level M&C system hardware also requires monitoring and so shall maintain this stream.

    OP5 streams are already supported by the existing High and Low Level M&C systems in MTG but will require activation in MSG.

- MTG Mission Operations System and MSG Mission Operations System
  - Ranging files shall now be transmitted from the Low Level M&C system instead of the High Level system to facilitate a service approach to the ground stations as a facility.

This is in line with the existing implementation of MTG but in MSG, the GSCON is currently generating and sending this data. Although, both MSG and MTG Tracking Data messages (TDM) are CCSDS compliant, the MSG standard shall be evolved to align it with MTG.

- Antenna Pointing files shall now be transmitted to the Low Level M&C system instead of to the High Level M&C system to facilitate a service approach to the ground stations as a facility.

  This is in line with the existing implementation of MTG but in MSG, the GSCON is currently involved in this function. MTG is already in line with the CCSDS Orbital Ephemeris Message (OEM) standard but MSG should be evolved to ensure that all MSG CMCS support OEM files for both MTG and MSG and continue to support the legacy orbit file format.

- The Scheduling interface can receive XML formatted schedule files produced by the MTG Mission Planning System (MPS) to execute routine operational activities on the ground stations.

## 5. Benefits related to the harmonisation

The following subsections present the improvements of the above mentioned design choices for Operations, Maintenance and Interoperability.

### *5.1 Benefits in Operations*

This approach will provide a significant benefit to the overall systems' operations as the ground stations' operations will be common to both EUMETSAT Meteosat missions (MSG and MTG), transitioning from mono-mission ground stations concept to ground stations 'infrastructure'.

A common software architecture used for MSG and MTG will help system operators to only require one consolidated knowledge of the system, resulting in an improved reaction to nominal ground station operations as well as for contingencies. It will also promote the knowledge retention because it will be preserved from the synergy of the two missions working, from the TT&C station point of view, as one.

The training coordination and preparation is made simpler. As the need for the previous satellite generation fades away in favour of the next generation, the possibility to have a common harmonised training for the operational team moving between the two missions helps to reduce the preparation time and speeds up the certification process.

The design solution gives the possibility to reduce the number of personnel required in the MCR because, if deemed necessary, the role of a GEO ground segment controller could be introduced to handle all stations' operations rendering obsolete the need of two mission-dedicated ground segments controllers, one for MTG and one for MSG. This would translate into cost saving in personnel.

Regarding the GStn planning, the staggered approach - shown in section 3, point f) – permits a gradual transition from the manual operation approach of MSG for scheduling ground activities to the more automated MTG scheduling. This gives the personnel accustomed to work with the MSG approach the time to adapt to the more automated MTG operations concept.

The design choice to move towards automated operations is significant, as it should reduce the mistakes related to the human factor in the MCR, being by definition less prone to error. This will allow to bring together the MTG operations concept of automating the routine operations with the MSG modus operandi, mainly based on manual operations.

The common software core for the two satellite generations will also allow to create mimics which centralise all the monitoring ground station telemetry points, displaying the information in a way that will allow a quick assessment of the overall stations status. In the event of anomalies, this should translate into improved reaction times.

This setup shows to the operations personnel all the important information on a single mimic, providing the latest overall status of the system and, in the case of ongoing investigations, offering the possibility to drill down the information for a particular element of interest.

The OpsDU concept - derived from the usage of a COTS - is an optimised way for operations that will allow creation of customised items for the controller to use. Displays can be designed to show in the MCR the information deemed necessary during routine operations and specific operational activities. As consequence, also the written procedures for the controllers can be simplified and less error prone.

As part of the OpsDU, scripts and out-of-limits can be tailored to the operational needs. The ability to create and release OpsDU independently from a CoreDU offers the Operations teams the possibility to work autonomously, meaning that the configuration is fully in line with Operations' needs while reducing the time needed for bug fixes by maintenance team or M&C provider.

Another important aspect benefitting from a harmonised system is that the automation of the system is better handled if the ground station M&C system is less mission-specific and more Meteosat programme-harmonious. This means that the operations personnel can simplify and speed up the assessment of the root cause of ground station anomalies across the complete system.

### *5.2 Benefits for Maintenance*

EUMETSAT's ground stations approach - to build the M&C system on a COTS as core software and having it tailored on the mission specific elements – also brings several advantages from the maintenance angle.

It implies the usage of a more mature and stable M&C software from the start, since the core software of Dataminer COTS M&C product is widely used in numerous application cases from the company Skyline. This ensures a robust product, and flexible enough to satisfy potential expansion needs.

A scan of the market to search for M&C systems currently available and an investigation on the systems already in use within EUMETSAT and other Organisations, it led to the identification of potential replacements for Dataminer M&C product. But a further analysis was conducted to determine if the features offered by these other M&C products satisfied the need for the new GEO HL M&C system and the outcome is that Dataminer COTS M&C product confirms itself to be the best solution under the technical and maintenance point of view.

The above mentioned approach allows the EUMETSAT ground station team to focus on the 'business layer' of the ground stations leaving the fixing of software bugs to the contracted company (Skyline). This also translates into having hundreds of new features and bug fixes coming from the standard product lifecycle of a COTS characterised by a customer-base of hundreds of other customers.
This includes the operating system (OS) obsolescence which is handled transparently by the provider as a routine maintenance item. When an OS transition is then eventually necessary, the effort on the EUMETSAT maintenance team is greatly reduced. Then, it can be said that the aforementioned M&C system has a good product momentum coming from the capability to adapt product evolutions from customers' needs but also from market's enhancements.

The separation of operations configuration items (OpsDU) from the core maintenance configuration (CoreDU) – as discussed in the previous sub-section - allows Operations and maintenance to work independently and this is an efficient way of conducting Operation (OPS), OPS preparation (OPS Prep) and Maintenance activities reducing the impacts on each other's daily business.

The design choice of having a redundant Validation environment for both the high level and low level M&C systems, results in a much more efficient deployment and testing, minimising any disturbance to operations and enhancing the system redundancy.

Another advantage resides in the possibility to go out for an open tender for the maintenance of configuration items (CoreDU) to a third party company, reducing the potential vendor locking issues.

As shown, the usage of a COTS for the M&C system benefits software deployment, maintenance efforts leading to a significant cost and man-power reduction.

*5.3 Towards the interoperability*

The new high level GStn M&C system will handle the data flows amongst the stations and the MCR in a harmonised way across the Meteosat missions. In addition, the concept to provide telemetry (TM), Telecommand (TC) and ranging as services is deemed necessary in view of the cross TT&C support to MTG within the MSG stations.

The purpose of the interoperability analysis is to explore the potential expansion of this 'service' concept to provide GEO TT&C ground station services to other future EUMETSAT missions and, potentially, even to other external entities.

The usage of CCSDS protocol for tracking data message (ranging) [4] [5] and orbital data (antenna pointing) [6] makes the system more focused to interoperability. In the wider context of supporting additional / new GEO missions, the ranging and antenna pointing interfaces are well standardised and would require only few simple modifications to also allow interoperability with another external new GEO TT&C satellites network compliant to the CCSDS standards.

Although an M&C system interface to external GEO ground station service users is described by the CCSDS standard [7], the approach for most ground station services do not foresee a ground station M&C system to be operated by the customer, leaving this in the domain of the service provider. For this reason, external M&C capabilities are not foreseen.
If monitoring access to ground station parameters is required, then a simple login to the MME systems could be provided.

In the context of interoperability, the scheduling could be handled via an internal EUMETSAT agreement so that the EUMETSAT Operations team would insert the agreed acquisitions for the satellite to support.

As demonstrated, the flexibility of the architecture design will support and serve potential collaborations with other space agencies in the GEO TT&C frame.

## 6. Conclusions

The Harmonisation of the ground stations M&C system has a significant impact in the way to conduct operations, especially for two generations of the same mission.
The future EUMETSAT GEO Ground stations architecture has the following main characteristics:

- a system which can be easily generated via MIB files and tailored to operations
- an architectural design which is robust in terms of redundancy, availability and maintenance
- a system geared towards interoperability

and this is the optimal approach to handle ground station operations.

Therefore, there are numerous benefits to Operations and maintenance by harmonising the ground station systems which are key to improve the overall system usage (for further information please, refer to section 5).

The effort of bringing harmonisation into the monitoring and control systems used in MCR is seen as of paramount importance to guarantee smooth transition to operations of new programmes. This approach helps knowledge retention for the existing operational missions with, which is especially important for long lifetime missions such as Meteosat.

Furthermore, the improvements in relation to the interoperability are beneficial when the cross- support of MSG antennas to MTG satellites is considered, in this view the MSG antennas are indeed seen as a ground stations' service to the MTG programme. Although currently there are no TM, TC services provided by any external GEO grounds stations network neither to MSG nor MTG ground segments, the adoption of the latest CCSDS standards is essential to ensure a future-proof system.

The 'GEO ground stations service concept' is not limited to the GEO antennas. There is an equivalent study in EUMETSAT to harmonise the ground station M&C system for the LEO antennas. This potentially can open up the idea to have a 'generic ground stations service concept' including GEO and LEO antennas.

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