Three Integration Architectures for Satellite and Ground Operations Automation

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In recent years, satellite operators worldwide have identified the need to address their satellite and ground station M&C infrastructure as a whole in order to efficiently support their operations and reduce the total cost of ownership. Typically, satellite operators base their operations upon specialized SCC and MAC COTS solutions, often from different suppliers, which while they can efficiently support operations in their specific domain, it makes it difficult to integrate operations and unify the automation strategy. GMV commercializes both SCC products (*hifly*) and MAC products (*magnet*) and has had the opportunity to delivery ground systems based on these two products as well as integrating one of them with a third party product. The paper provides a comprehensive analysis of the pros and cons of three integration architectures, which GMV has worked with, at different levels (integration complexity and effort, achieved automation capabilities, maintainability aspects). The first architecture addresses the operations of a large fleet of satellites and ground resources by coordinating the SCC and the MAC systems through a high-level ground resource management protocol hiding the complexity of ground operations to SCC system. A second architecture is based on a limited integration of the SCC and the MAC systems taking advantage of the available public provided by each system, but low level ground operations are still performed from the MAC system. This is a typical architecture that can be found in many satellite operators requiring a limited level of ground station and satellite operations integration. A third architecture is based on a single system capable of providing all the required capabilities to monitor and control both the ground station and the satellite. In this case all the operations are performed and automated from the same system, providing the satellite operator with a unique environment that simplifies the monitoring and control of the resources and the SW maintenance. GMV's *hifly* and *magnet* products are built upon the same software, as is also described in the paper, so they can support any of the above architectures.

I. Introduction

WHEN one has a look at the ground systems architecture deployed by commercial satellite operators and in particular at how they integrate the operations of their ground and space segments it is possible to identify many integration architectures, each one providing different levels of integration and centralized operation capabilities.

In this paper we analyze, based on our experience as a ground segment integrator, three integration architectures that can be commonly found and we compare their pros and cons. The analysis is made from a high level perspective since when one look at the lower level implementation details, what is found is that there are almost as many approaches as satellite operators exist, due to a number of reasons:

1) Satellite operators typically base their operations upon specialized Satellite Control systems (SCC) and Ground Station M&C systems (MAC) commercial solutions, often from different suppliers. Each solution in the market offers different integration capabilities and mechanisms.

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2) Different integration requirements. For instance large operators require sharing the use of their ground segment resources between satellites, maximizing their use and manage back-up resources to be ready to support communications with any satellite in the fleet.
3) In some cases, the independent evolution of the SCC and the MAC systems deployed by the satellite operator, not addressing a clear integration strategy at an early stage. To complicate the scenario, it is not rare that different systems are used, for instance to operate each satellite platform. If a clear integration strategy was not addressed at an early stage, it becomes increasingly difficult to set it up when the fleet and the number of ground systems grows.

II. Background

GMV develops, commercializes and integrates a wide range of COTS products for satellite operations. In particular two products are relevant to this paper:

1) *hifly:* a satellite control system which was developed based upon ESA's SCOS-2000 satellite control kernel and adapted by GMV to support the operations of GEO satellites and the particularities of each commercial bus.
2) *magnet:* a ground station and network M&C system fully integrated with *hifly* thanks to both systems share most of the core software modules, including those supporting the telemetry/monitoring data processing, telecommand/control data processing, data archiving, data visualization as well as the tools to automate operations.

III. A High-Level Integration Architecture

The first integration architecture to be analyzed was designed to support operations of a large fleet of satellites and ground resources that could be shared and were compatible with several satellites in the fleet. Satellite operations were supported by *hifly* while the ground station operations were supported by a MAC system from a third-party supplier.

The main design driver was to hide as much as possible to the SCC all the low level ground station equipment configuration tasks so that the SCC system and their users (satellite engineers and operators) only need to take care of the satellite operations leaving all the complexity of the ground station control encapsulated within the MAC (and only to be known by the ground station engineers and operators).

A. Implementation Details

Four types of ground stations resources (they can also be seen as services to be provided by the MAC to the SCC) that need to be coordinately managed between *hifly* and the MAC systems were identified. They are briefly described:

1) *Telemetry Resource:* it consists on all of the TT&C ground station equipment (from the antenna to the BBU) properly configured to receive telemetry for a given satellite and transmit it to *hifly*.
2) *Telecommand Resource*: it consists on all of the TT&C ground station equipment (from the BBU to the antenna) properly configured to uplink telecommands sent by *hifly* to a given satellite.
3) *Ranging Resource*: it consists on all of the TT&C ground station equipment (from the BBU to the antenna) properly configured to perform ranging measurement sessions for a given satellite and transmit the measurements to *hifly*.
4) *Antenna Pointing Data Provision Resource*: it consists on all of the TT&C ground station equipment (antenna and antenna control equipment) properly configured to perform antenna angular measurement sessions for a given satellite and transmit the measurements to *hifly*.

On the other hand, a protocol to manage the resources at high-level was also defined. The Table 1 lists the messages that were identified and provides a short description of each one. Additionally the messages can contain attributes that provide *hifly* with some control over the MAC configuration activities (for instance a telemetry type Resource Request can identify the site where an available station shall be configured to receive telemetry).

Table 1. High-level Resource Management Protocol messages between the MAC and the SCC.

Message	Description
Resource Request	Allows the SCC to request the allocation of a resource to the MAC
Resource Modify	Allows the SCC to request the modification of a resource attribute
Resource Release	Notifies the MAC that the SCC no longer needs to resource
Resource Reset Command	Notifies the MAC that all the resource allocated to the SCC can be released
Resource Primary Response	Acknowledge to the SCC that the MAC has received a request from the SCC
Resource Status Request	Requests an update of the resource current status
Resource Status Response	Notifies the allocation of a resource to the SCC and provides resource status data
Resource Status Update	Notifies the SCC there is a change in the status of an allocated resource
Resource Reset Notification	Notifies the SCC that a resource that was allocated needs to be released

As an example of how the protocol works, the Fig. 1 shows a typical sequence of operations for a satellite ranging session:

1) *hifly* sends a *Resource Request* for a ranging type resource to the MAC. The request in addition to the mandatory attributes (such as the satellite) can contain optional attributes such as the site and the antenna to be used for the ranging session.
2) The MAC checks the message contents and sends back to *hifly* a *Resource Primary Response* confirming that the request is going to be processed.
3) The MAC checks if there is a station available to be configured to perform the ranging session. If found, it starts configuring all the station equipment required to perform the ranging measurement.

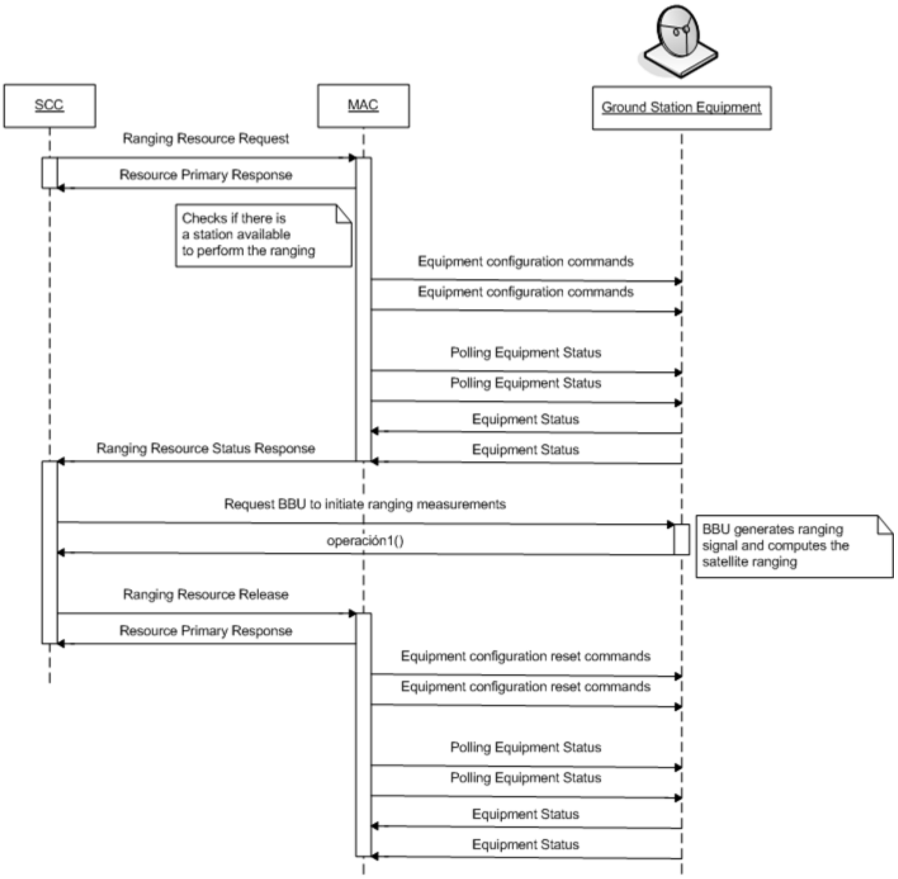


Figure 1. Sequence diagram describing the allocation of a ranging resource to the SCC.

4) Once the configuration is completed the MAC sends a Resource Status Response to hifly notifying that a ranging type resource has been allocated to it and provides the relevant resource details (such as the baseband unit hifly needs to connect to).
5) hifly establishes a connection with the baseband unit and collects the ranging measurements. Once all the ranging data has been received, hifly instructs the SCC to release the ranging type resource by sending a Resource Release message.
6) The MAC checks the message contents and sends back to hifly a Resource Primary Response confirming that the request is going to be processed.
7) The MAC starts commanding the equipment to reset the station configuration.

B. Advantages and Disadvantages

This integration approach has some clear advantages:

1) Each system has full control on the operations of its domain (satellite or ground), thus a modification, in the MAC (for instance as a result of modifications in the ground equipment or changes in the procedures automating the equipment configuration) has no impact on the other system.
2) Both, the SCC and the MAC system remain fully specialized in each activity domain. An evolution of one of the system needs to consider the requirements specific to its domain only.
3) Satellite engineers and operators are not bothered with ground station details or issues. The SCC sees the MAC system just as a “satellite communication service” provider.
4) Development and maintenance of satellite operational procedures are simplified, since only contains satellite operations and “satellite communication service” requests.
5) The MAC system does not need to deliver ground station monitoring data to the SCC. This simplifies the configuration and maintenance of the both systems. On the other hand, the SCC user has no access to station monitoring data from the SCC workstation.
6) Allows the automation of the SCC connections to the baseband units. The SCC just requests resources to the MAC, which, in the response, provides the connection details of the baseband units configured for the relevant satellite. Then the SCC automatically establishes the connection based on the MAC’s response.

The main drawbacks of this approach are:

1) The resource management protocol needs to be carefully designed. All the required coordination activities to be supported by the protocol need to be carefully identified and analyzed during the requirements phase.
2) It requires a significant implementation effort. It implies to implement a new and specific protocol in both, the SCC and the MAC systems and internally implement support for the resource management concept.
3) The level of integration that can be achieved depends on the flexibility provided by the resource management protocol and can be limited by an incomplete implementation in one of the systems.
4) If a change is required to improve the integration capabilities, changes in the software in both systems are required.
5) The SCC user has no access to station monitoring data from his workstation.
6) Two different procedure automation tools are required, once in the SCC for satellite procedures and one in the MAC for equipment configuration procedures.

A final section in this paper summarized the above advantages and disadvantages and compares them with the other integration architectures described below.

IV. A Low-Level Integration Architecture

The second integration architecture which is analyzed is likely the most common one among commercial operators, although with variations depending on the capabilities provided by the involved SCC and MAC systems and the actual customer integration requirements. It represents the case where it is required to achieve a maximum integration but with a minimum costs.

The design drivers for this architecture typically are:

1) Minimize the implementation costs by using external interfaces and integration capabilities already available in the products.
2) Centralize the routine ground station low level operations from the SCC.
3) Use the SCC automation capabilities to automate both the ground station operations and the satellite operations.

4) Keep all the ground station equipment commanding and equipment status acquisition under MAC control. The MAC supports the communications with the equipment and implements the equipment communications drivers.

C. Implementation Details

The existing SCC and MAC commercial solutions typically provide public interfaces allowing the dissemination of monitoring/telemetry data as well as the injection of commands from external systems. These interfaces make possible with a limited effort the dissemination of ground station equipment monitoring data from the MAC to the SCC, as well as sending from the SCC equipment commanding requests for execution by the MAC. As a result an exchange of low level monitoring data and equipment configuration requests take place, thus this architecture can be identified as the low level integration architecture.

Ideally the goal of this architecture is to be able to process in the SCC the ground station monitoring data like the satellite telemetry is processed, including application of out-of-limits thresholds, generation of alarms, display and archiving of the received data or access to these data from an automated procedure. Likewise it is required to have ground station commanding capabilities from the same SCC tools used for satellite commanding and in particular from the SCC procedure automation tool.

The following figure shows an example of this architecture and of the data flows between systems. It is based on a real system where GMV provided a *hifly* SCC and we were requested to integrate it with a third-party MAC system following this integration architecture.

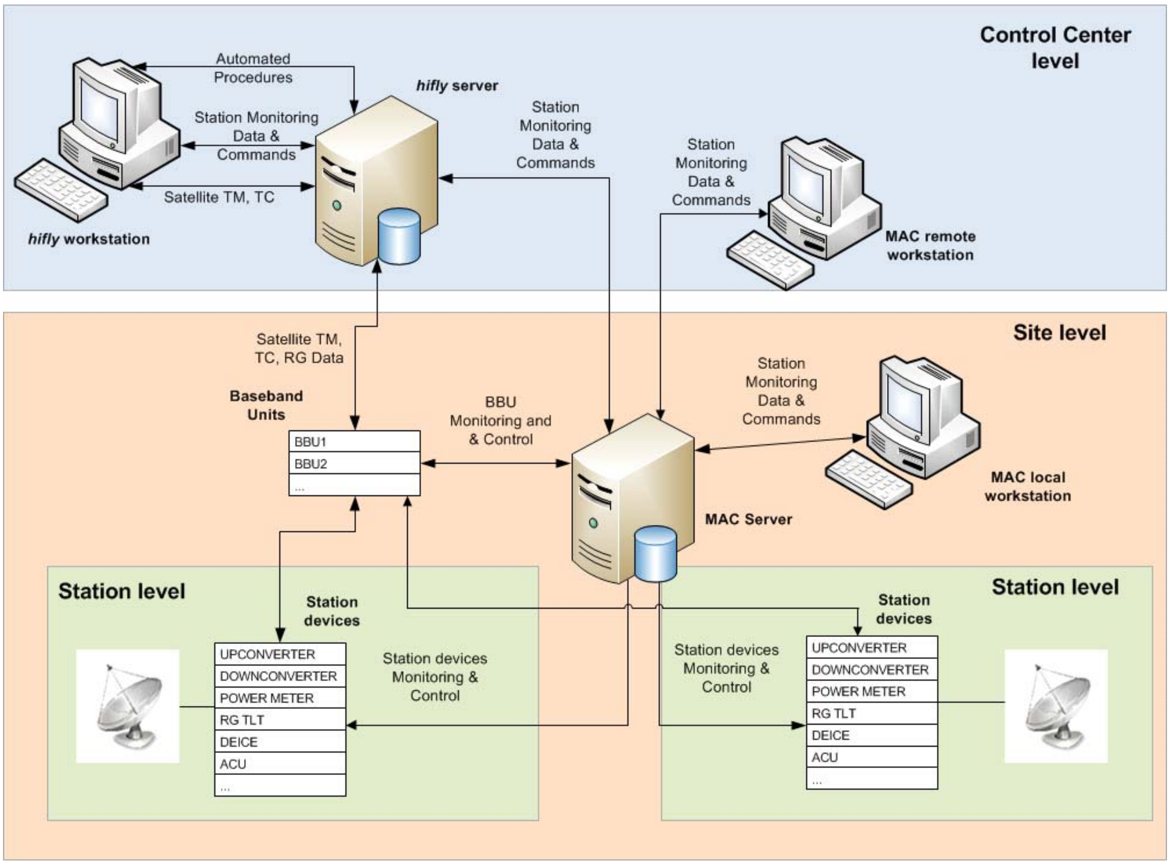


Figure 2. Example of a low-level integration architecture.

D. Advantages and Disadvantages

This integration approach has the following advantages:

1) Low integration costs, since this is achieved through already available public external interfaces. Only the "remote" or "client" side needs to be implemented in one of the systems. The decision of what system is adapted to act as "client" of the other system, is normally based on implementation costs and the integration capabilities made available by each system through its external interfaces.

2) Allows centralizing the operations of both, the satellite and the ground station, in the SCC. Depending on the SCC capabilities, operations of both systems can also be automated and centralized in the SCC, so only one automation tool is required.
3) As in the High-Level Integration Architecture, both systems remain fully specialized in each activity domain. An evolution of one of the system needs to consider the requirements specific to its domain only.
4) If a change is required to improve the integration capabilities, it normally can be supported by configuration with no need for software changes.
5) The SCC operator may have full visibility of the ground station status from his workstation.
6) Homogeneous way to operate the systems since there is only one entry point to the system.

The main drawbacks of this approach are:

1) The ground station monitoring and control data need to be loaded in the SCC as well as in the MAC system. Additionally monitoring and control tools (such as data displays) need to be configured in the SCC in addition to the configuration done in the MAC system.
2) A modification in the ground station architecture or changes in the equipment implies changes in the configuration of two systems.
3) Satellite engineers needs to know the ground station details when they prepare the automated procedures or be supported by ground stations engineers.
4) The maintenance of the operational procedures is complicated since they mix satellite telemetry and telecommands with ground station monitoring data and commanding.

V. A Single System – Full Integration Architecture

A third integration approach is to support both the satellite and the ground station operations from a single system, providing the user with a unique operational environment with full control of the satellite segment and ground segment.

The main design drivers for this architecture are:

1) Support with a single system, both satellite and ground station equipment operations in order to provide a maximum operations integration. In particular operations are automated through a single tool.
2) Provide as a minimum the capabilities and tools that the customers expect from a specialized SCC system and from a specialized MAC system, but now from a single system.
3) Minimize the procurement and maintenance costs by reducing the size of the software and the number of systems to be deployed.
4) Provides only-MAC functions or only-SCC functions from some workstations. For instance an only-MAC workstation is required at the station for equipment maintenance purposes.

A. Implementation Details – From *hifly* to *magnet*

The Fig. 3 shows an example of a high-level architecture based on this approach and on *hifly* and *magnet* products.

As described above, using a single system capable of supporting the operations of the satellite fleet and of the ground stations provides significant advantages to the customer. From a point of view of the software developer it represents a major challenge. In this section we outline the process that GMV followed in the development of the *magnet* product, which is based on *hifly,* and the major changes that were carried out.

magnet was born as the natural evolution of *hifly* to provide support for ground station M&C taking advantage of the flexibility of the *hifly* architecture to integrate existing proven elements for ground station M&C. The goal was to combine these existing ground station management components with all the functionality and versatility available in *hifly*: database driven system, telemetry/telecommand/events history files, definition of user roles and privileges, powerful telemetry visualization tool, customizable displays, advanced automated procedure tools, etc.

The existing low level components that were initially integrated into *hifly* to become *magnet* were:

1) FIP. Subsystem that handles the communication of the antenna RFT equipment (Up and Down-converters, ACUs…). One FIP is typically implemented for each antenna at the ground site.
2) EACS. Process in charge of equipment communication of the equipment typically linked to a site (Base Band Units, RF Matrixes…) and the FIPs. It also provides an interface for ground monitoring and ground commanding at site level.

It is worth mentioning that the above components were selected following only an availability criteria and that the *magnet* architecture allows for a smooth replacement of these components by a different ones as long as they provide similar functionality.

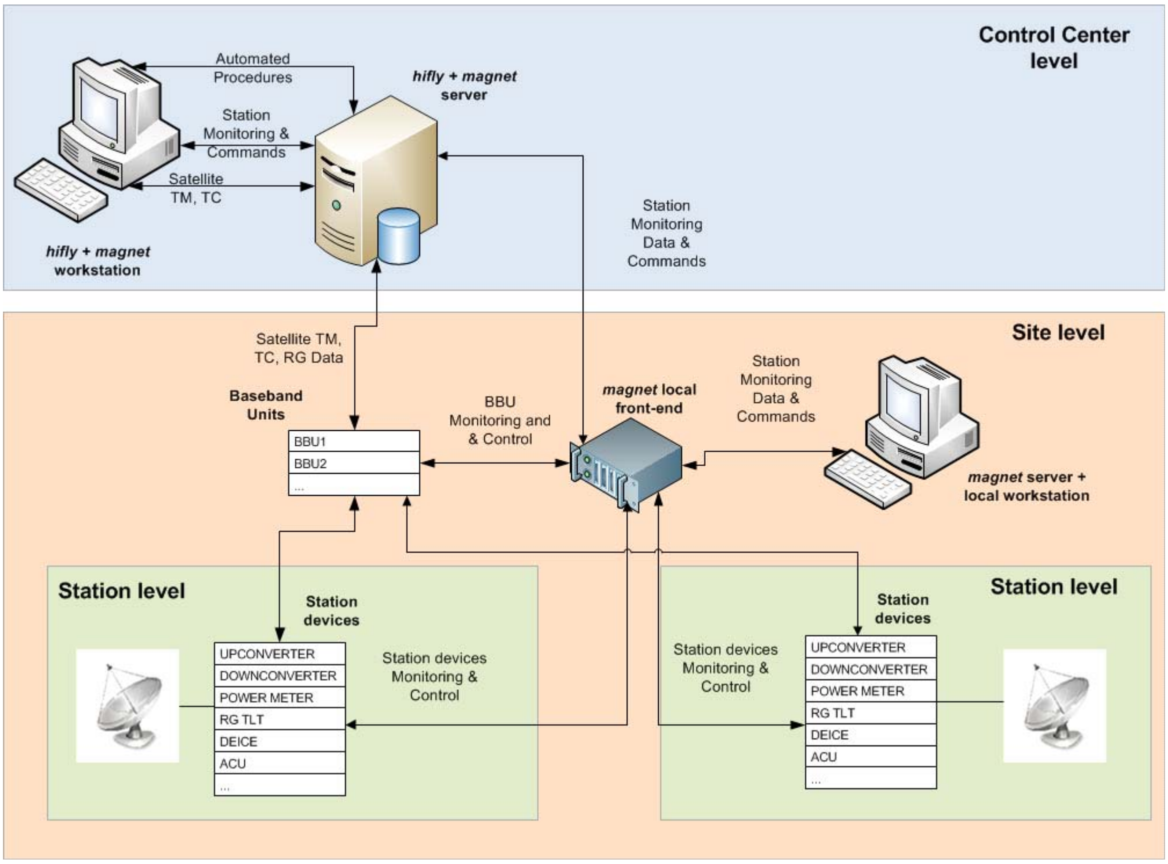


Figure 3. Example of a single system supporting a full integration architecture.

A major challenge was to keep in *magnet+hifly* the same easiness of configurability and adaptability provided by *hifly* and this required a non-negligible design and development work. This effort was mainly focused on making simpler the configuration of EACS and FIP and extending the static and quite fixed architecture of FIP telemetry.

In order to communicate *magnet+hifly* with ground equipment the concepts of Ground Monitoring (GM) and Ground Control (GC) came up. *hifly* was enabled with new links providing TCP/IP communications to EACS. As a result *magnet+hifly* interfaces with the ground equipment through the EACS in the same way it interfaces with the satellite through a Baseband Unit.

For station monitoring data, *magnet+hifly* receives station monitoring data through fixed packet stream. The stream is managed by *magnet+hifly* like any other satellite stream. The station stream is handled by a devoted packetizer in charge of decommuting the station monitoring data based on the station equipment configuration in the database. Internally, different packets are generated, allowing distinguishing between ground monitoring data and satellite telemetry. The Fig. 3 describes this architecture.

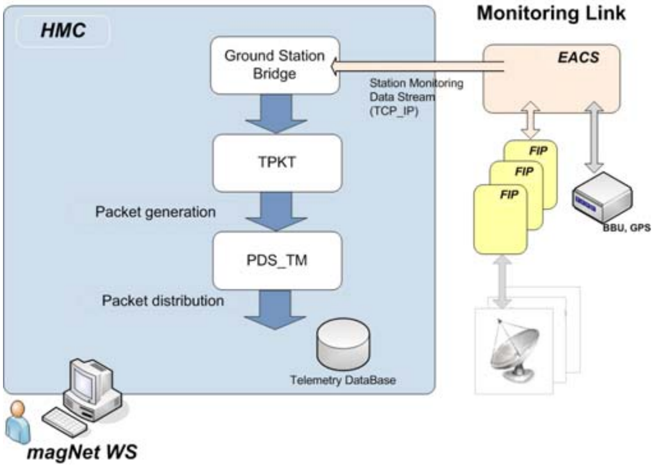


Figure 3. Ground station monitoring data processing architecture.

For sending station equipment commands a specialized releaser was implemented. The commanding link is managed from *magnet+hifly* in the same way the satellite TC link with the Baseband Unit is managed, including support in the applications managing the links through predefined configurations or the BUI. This approach allows to easily manage the link from operational procedures.

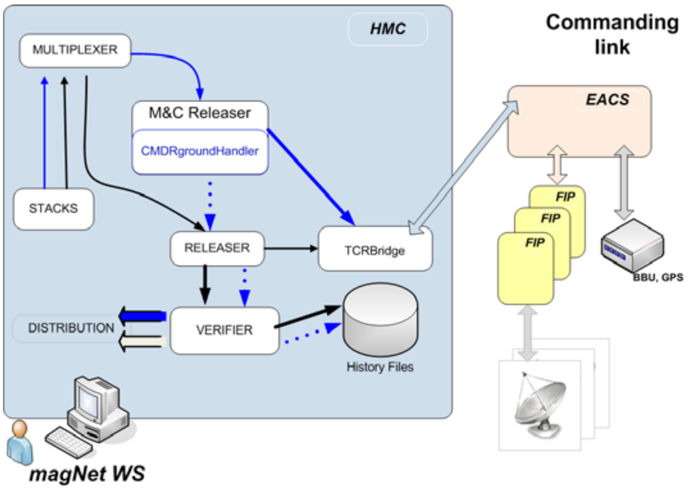


Figure 3. Ground station control architecture.

In order to support the ground equipment data definition, in principle no modification to the existing *hifly* database scheme was considered necessary. However, two additional tables were finally added, although they are just used to customize the Equipment Views (described below) in the GUI.

In order to load the ground equipment data into the database it was first required to specify an ICD defining as .xml files the equipment data and then to develop a loader capable of reading the equipment data files and automatically loading these data into the *hifly* database.

No specific historical ground monitoring data storage or tools needed to be implemented either. Ground monitoring data is stored in the existing *hifly* archives also used for spacecraft data storage. Integration of the new data was largely facilitated by the use in *hifly* of relational databases.

Once information from equipment was fully integrated into by extending the database *hifly* ICD, next step was to enrich *hifly* capabilities at GUI level. *magnetviews* is a new application providing all the tools required for an efficient M&C of the ground station equipment by means of specific displays.

The *magnetviews* M&C displays are configured based on a three-level hierarchical structure:

1) A site level mimic, representing a summary status of the whole ground system. The site level mimic is automatically presented when the *magnetviews* application is started. It shows a multisite deployment that allows the operator to have a quick overview on the status of the equipment in the site.

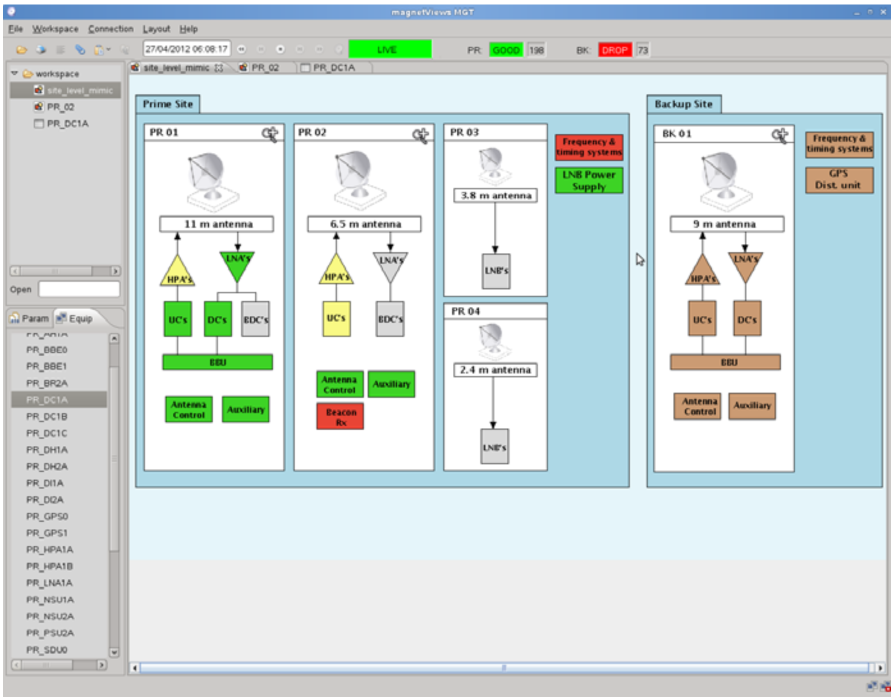


Figure 4. Site level mimic

2) Several station level mimics, showing the status of the equipment comprising an station (from the antenna to the baseband unit).

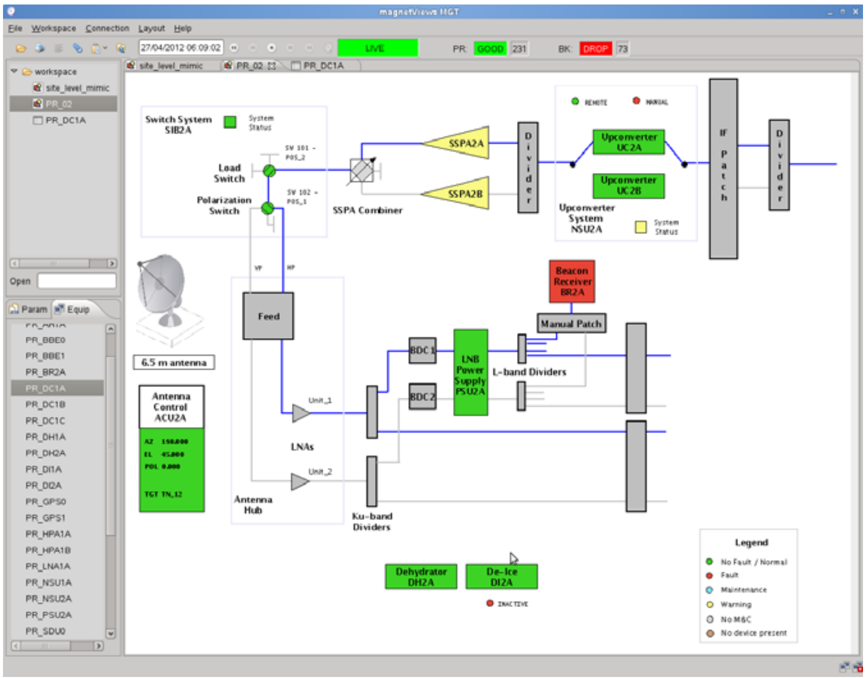
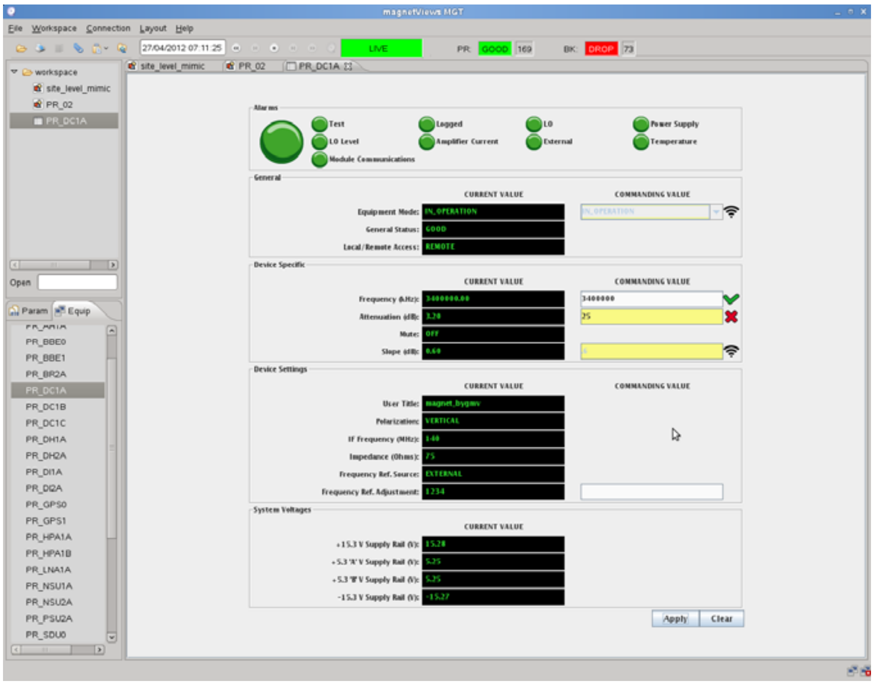


Figure 4. Station level mimic

3) Equipment Views, showing the status of single pieces of equipment and also providing command capabilities for a particular device. This view is automatically generated from the equipment configuration data as stored in the database.



General

	CURRENT VALUE	COMMANDING VALUE
Equipment Mode:	IN_OPERATION	IN_OPERATION
General Status:	GOOD	
Local/Remote Access:	REMOTE	

Device Specific

	CURRENT VALUE	COMMANDING VALUE
Frequency (kHz):	3400000.00	3400000 ✓
Attenuation (dB):	3.20	25 ✗
Mute:	OFF	
Slope (dB):	0.60	

Device Settings

	CURRENT VALUE	COMMANDING VALUE
User Title:	magnet_bygmv	
Polarization:	VERTICAL	
IF Frequency (MHz):	140	
Impedance (Ohms):	75	
Frequency Ref. Source:	EXTERNAL	
Frequency Ref. Adjustment:	1234	

System Voltages

	CURRENT VALUE
+15.3 V Supply Rail (V):	15.28
+5.3 'A' V Supply Rail (V):	5.25
+5.3 'B' V Supply Rail (V):	5.25
-15.3 V Supply Rail (V):	-15.27

Figure 4. Site level mimic

The following features were needed to be developed in *magnetviews* MIMICs

1) Hierarchical Mimics. Clicking on an area of a higher level Mimic display pops up a more detailed Mimic display for the GS equipment selected within the area.
2) Access to the device status window from any Mimic display where the device is being represented.
3) Path highlighting

Visual object dynamics on Mimics is defined with .xml files that can be easily edited with a specific mimic editor inside *magnetviews*.

B. Advantages and Disadvantages

This integration approach has the following advantages:

1) Allows centralizing the operations of both, the satellite and the ground station, in the SCC. Only one automation tool is required.
2) The SCC operator may have full visibility of the ground station status and full control the of the ground equipment from his workstation.
3) Homogeneous way to operate the systems since there is only one entry point to the system.
4) Only one system needs to be configured. This minimizes the drastically the procurement and maintenance costs.
5) No integration costs. A fully integrated system is provided.
6) Speeds up the deployment of the changes. Only one system needs to be updated. Validation is required for only one system.

The main drawbacks of this approach are:

1) The evolution needs to consider a wider set of requirements. This affects however to the product manufacturer but not to the customer.
2) A system upgrade needs to be coordinated with both satellite and ground operation teams.

Although the automated procedures may mix satellite and ground operations, making their development and maintenance more complicated and requiring coordination of the satellite and ground station engineers, a correct structuration of the automated procedure contents and the use of sub-procedures can facilitate the task to a large extent.

VI. Integration Architectures Comparison

Table 1. Comparison of the three integration architectures

	High-level integration architecture	Low-level integration architecture	Single system - Full integration
Implementation Effort	Significant. At the SCC and at the MAC a specific module to support Resource Management Protocol has to be developed. Internally both systems software needs changes to support the Resource Management Concept.	Limited. Since normally it is based on existing public interfaces only the “client” side needs to be implemented in one of the systems.	No integration effort is required.
I/F Complexity	A specific protocol needed to be agreed and an ICD specified by all the parties supporting all the coordination requirements.	Simple, since normally it is based on existing public interfaces.	No interfaces between systems are required.
Achieved Integrated Functionality	Enough thanks to a thoughtful design of the Resource Management Protocol. Reaching a higher level of integration requires extending that protocol.	Good, although it is highly dependable on the capabilities of each system.	Maximum.
Achieved Automated Operations	Automation needs to be supported by both the MAC and the SCC. Each system provides automated operations for its particular domain. Activities can only be coordinated at high level.	Full centralized automated operations are eventually possible, but it is highly dependable on the capabilities of each system.	Maximum.
System Configuration Effort	Ground station equipment information is only loaded into the MAC. Operational procedures specific to each domain need to be defined and validated at the MAC and at the SCC.	Many data regarding the station equipment needs to be loaded and configured in both the MAC and the SCC. Operational procedures may be defined and validated only at the SCC.	Minimum since the ground station information is loaded into the system once. Operational procedures are defined and validated from the same system.
Operations Maintainability (changes in ground operational procedures, replacement of ground equipment by a different model, etc.)	A change in one system typically does not affect to the other. Changes in the SCC may be required in case of new stations are added.	A change in the ground station equipment affects to both the MAC and the SCC.	Only one system needs to be maintained.
SW Maintainability	A change in one system SW does not affect to the other. Two systems need to be maintained.	A change in one system SW does not affect to the other. Two systems need to be maintained.	Only one system needs to be maintained.

Appendix A
Acronym List

ICD	Interface Control Document
GUI	Graphical User Interface
MAC	Monitoring and Control
M&C	Monitoring and Control
SCC	Satellite Control Center
TT&C	Telemetry, Tracking and Commanding