Multi-Mission Support with WARP

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At the German Space Operations Center a new monitoring- and control-system has been developed. The concepts of a generalized and modular setup using an object oriented design were not only applied to the software itself, but also extended to the definitions of procedures and parameters used to operate DLR's ground station antennas at Weilheim in a multi-mission context. This paper describes the ideas behind this new software and the consequences for operations using it. In case studies the benefits of this software design for fast and safe operations as well as for an easy configuration management are highlighted. The effort needed to run the station using the new M&C-system in daily routine-operations is compared to what would have been needed to achieve the same with the tools previously in use.

Nomenclature

Antenna	=	The sum of a physical antenna dish, its driving controls, and all the RF- and IF-equipment connect to it
Station	=	A site running one or more antennas, including their equipment, to support spacecraft operations
M&C	=	A system to remotely monitor and control a given hardware equipment
WARP	=	Weilheim Antenna Remote Processing, the M&C used at Weilheim ground station as antenna control

I. The Weilheim Antenna Remote Processing Software WARP

WARP, the software used at Weilheim ground station to remotely configure the ground station hardware, consists of applications derived from a new software framework recently developed at the German Space Operations Center (GSOC) to generically support any monitoring and control task. This generic approach was deliberately chosen not only to benefit from common developments but also to establish in the near future a connection between several systems, being put into place locally at first. The vision at GSOC is to finally provide, based on those common software tools, a service-oriented end-to-end monitoring and control from the space-link all the way down to the interface to the external costumer.

Starting up with this goal in mind, the resulting antenna control software ended up to be very different in design and capabilities compared to its predecessor. While a specialized system, dedicated to run an antenna M&C, might represent the whole antenna hardware as one, the generic approach requires a modular and scalable setup. This modularity yields potentials as well as perils, but after all, it was generalization and abstraction which lead to the biggest successes of this new software.

DLR's ground station at Weilheim consists, among several others, of six antennas capable to provide up- and down-link in various frequency ranges. There are 3 antennas for receiving and transmitting signals in S-band, two of them with 15 m in diameter, the third one with 9 m. A fourth antenna, 11 m in diameter, is prepared to receive and transmit signals in Ku-band, and a fifth of size 13 m is currently under construction and will work in Ka-band. All of them are full-motion antennas optimized to follow quickly moving targets, they are capable of receiving and transmitting signals, and all can be operated in autotrack-mode. The sixth antenna, a dish with 30 m in diameter, is designed to operate in L-, S- and X-band. Due to a very easy access to its feed system, this antenna can be equipped with specialized RF-devices and hence is used for a large variety of tasks and tests.

All these antennas are operated in multi-mission context. This ranges from routine TT&C-operations for scientific LEO-satellites to emergency support of commercial geostationary satellites. Currently, Weilheim ground station is prepared to support 47 different missions on one or several antennas mentioned above. In addition, DLR provides support to further missions on dedicated antennas located in Weilheim, but not discussed in this paper.
The multi-mission context sets boundary conditions for operations: The antenna equipment must be configured fast but safely for any mission, and this very frequent. Typically, the preparation phase prior to acquisition of signal lasts

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twenty minutes. During this time period the antenna has to be configured – keeping in mind that the actual state of the antenna hardware at the beginning is kind of random, defined by the previous support – and tested, including some time margin to react to problems. In addition, some work on the antenna hardware necessary for tests or maintenance might be done by system engineers in case there is a sufficient time-slot between two scheduled supports. Providing stable operations under these conditions is a tough requirement to scheduling, operations management and last not least the tools and software in use.

II. Software-Design

The basic and generic task of an M&C-system can be defined as mediation between some hardware to be controlled and a controlling instance, be it a human operator or some automated scheduling device. In any case, the M&C-system needs to collect information about and from the hardware and provide this information to the control instance. Based on this (and maybe other context-) information, the control instance in turn may issue commands which are to be delivered to the hardware by the M&C. Following this logic, the WARP software is structured in a classical three tier architecture, with *generators* as interfaces to the hardware, *consumers* as interface to the control instance (e.g. a GUI) and a backbone in between providing the exchange of information between generators and consumers. The backbone basically can be seen as two parameter channels: a monitoring channel collecting data from the generators and sending it to the consumers; and a command channel distributing directives from a consumer to the appropriate generator. (See Fig. 1.)

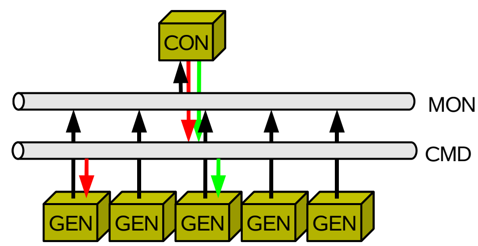

Figure 1. The three tier architecture of WARP. *Generators provide the necessary interfaces to the hardware to be controlled, while consumers are the interface to the command instance. The connection in between is given by parameter exchange channels for monitoring and commands.*

In reality, the structure of WARP is not as simple as shown in Fig. 1. The need of hierarchically structured monitoring for instance requires a processor that receives all the monitoring from the generators like a consumer does, derives high-level information depending on the states of several hardware devices and sends the results as monitoring data, acting now as a generator itself. Similar cases occur for many applications developed within the software framework to provide special functionality like a state-machine, dynamic resource management and so on. However all processes within this software receive and send data either as generator or consumer and the data exchange mechanism, precisely how the data is propagated through the internal parameter channels, is only defined by those two roles. Consequently, all consumers get the same monitoring data, and all generators react to commands independent from which consumer they originate.

A. Predefined Command Sequences

As any other M&C-system, WARP provides a possibility to run predefined sequences of commands to safely configure the station. Within WARP, these sequences are called *workflows*, and they are coded and executed using the script language LUA. Running workflows can either be triggered manually by an operator or automatically utilizing queues or daemons to start certain workflows under certain conditions. Regardless which kind of application finally executes a workflow, they all are consumers within the software framework. Therefore all these applications are not only capable of sending commands, they have access to the complete monitoring provided by the station hardware.

This, together with all the logical components a script language like LUA provides, allows to test each command issued against the reaction of the hardware and verify all desired settings. Moreover, commands can be conditioned depending on the actual state of the hardware. Such conditions can originate from safety reasons, e.g. avoid switching RF equipment on load, but also from operational considerations, e.g. do not configure the up-link chain at all in case a pass is scheduled as down-link only.

The possibility to evaluate all station settings during run-time combined with the potential of a full featured script language empowers WARP to handle the features and specialties of different antenna hardware and different missions internally, providing a unified appearance to the operator. The course of a single support can be structured in logical steps like setup, testing, pass, start and stop up-link and so on, and they do look the same regardless if a certain mission requires some special treatment like, for instance, a compensation of the Doppler shift prior to the sweep, or if a certain antenna uses a different tracking method.

B. Replicate Hardware Structures with WARP

At Weilheim ground station, a number of identical baseband devices can be connected to any antenna by IF-switch-matrices. Although there is a standard assignment of two dedicated devices per antenna, this gives a wide flexibility to comply with special requests, for instance, during LEOP supports. The modular structure of WARP in turn is perfectly suited to replicate this setup within the M&C-system. There is one software instance for each antenna plus one additional, a central station instance, controlling the pool of baseband devices and the IF-switches. All antenna instances are connected to this central instance by a proxy-application. That way the central instance can hand over the control on a given baseband device to a certain antenna, manage the pool and make sure the IF-switches are set correctly.

A nice by-product of this central station instance is the fact that, without any effort, this instance keeps track on all activities at the different antennas. It's just been told, which antenna is configured for which mission and in which stage of a support it is by now. Thus, one gets an overview on all the activities at Weilheim ground station at a single display, a feature especially welcomed by the operations management. This is a first example for the desired coupling of several components to a system-wide monitoring.

III. Generic Descriptions of Antennas, Missions and Actions

Before actually coding workflows for WARP, the existing scripts used by the old legacy system were analyzed. The very first observation was, there was a flood of more than 4400 files per antenna existing and used (or maybe not used anymore) to configure the antenna. Properly organizing those files clearly is kind of a Sisyphean struggle, if possible at all. Furthermore the existence of those files gives room for human errors during operations, by just accidentally picking a wrong one. Therefore one of the primary goals of WARP was, to achieve a clean and comprehensible way to define the required station configuration and limit the number of actions accessible for the operator.

As a first step towards this goal, three major groups of different command types were identified: Firstly settings required by the antenna hardware, like angular limits or attenuations, secondly settings required by the mission, like frequencies and bit-rates, and finally functional switches to control signal paths and outputs (See Fig. 2). The first two groups are static in the sense that they are to be set only once for a support. In turn, the subset of command parameters changed several times during the course of a support is small.

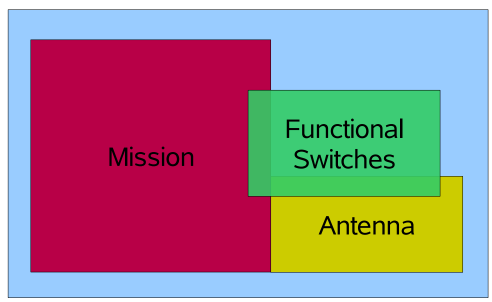

Figure 2. Separation of the command-parameter-space into several regimes. *The different areas indicate, that certain commands are used to configure a station for a given mission, while others reflect settings required by the antenna hardware specifics.*

The second step towards the goal of simplicity was to define the mission requirements in terms of unified and hardware independent parameters. As already can be sensed from the examples above, a mission – precisely the required settings to support a mission – should be specified in an abstract way. In other words, a customer specifying how to establish a space link does not need to know any details about antenna hardware specifics. At Weilheim, we ended up with a set of 90 parameters[*] completely describing any mission.

Although a mission is defined abstractly, setting up a given antenna hardware still requires to translate the abstract definition into concrete commands. However, this translation needs to be done only once per antenna and does not depend on the actual values, therefore the translations are called *mission-functions*. These functions take the (abstract) value as argument and deduce the (concrete) commands finally sent to the devices. Let's demonstrate this by an example: The base-band equipment at Weilheim synchronizes the demodulated telemetry data to the TM transfer frames according to CCSDS.[1] To do this, the base-band device needs to be configured with the total frame length including synch-word and (optional) coding symbols etc. The on-line data-interface at the station also needs to be configured with the TM frame-length, but dealing with decoded data, the net frame-length as defined by the CCSDS standard is relevant here. Now the mission functions handle the difference by sending the net frame-length to the data-interface and the total frame-length to the base-band device. Meanwhile the abstract mission definition contains just one single frame-size, the coding type and the synch-word, from which both relevant values can be derived.

In some cases, the final value sent to a device depends on both, mission and antenna specifics. For instance, the

[*]In fact, not all of them are applicable to each mission. As an example, specifying the modulation differs in case of direct modulation or stepwise using a sub-carrier.

tracking loop needs to be configured with the mission dependent down-link frequency and the antenna dependent phase calibration for this frequency. Again, the concept of mission-functions is perfectly suited to handle this. The function takes the down-link frequency as an argument, looks up the antenna specific calibration value (centrally stored only once) and sends the corresponding commands.

The third step on the way to generalized operations was to standardize the actions, carried out during a support. Afresh, an abstract definition of the activities did the job and the separation between antenna description and mission specification was very helpful. The first action of a support is a global reset. Its intention is to bring all the available hardware into a well defined and safe state, regardless what has happened before. Beside serving as a basis for all following actions, reaching this reset-state is a first functional test of the system. Potential problems preventing a successful support might be detected already at this point. Since the workflows in WARP themselves check the monitoring to report the expected values, the operator does not need to take care on actual values here. This way the reset-state becomes abstract but common for all antennas. If the reset-workflow was executed successfully, the antenna hardware corresponds to this reset-state and the preparation may continue, if it reports an error, the device showing a malfunction is identified and the upcoming activities can take this into account, e.g. by using redundant hardware.

Following the reset, the next action is to configure the antenna for the mission in question, which means executing all the mission-functions defined above. After that, the configuration of the antenna remains the same and only functional changes are carried out like switching carriers on and off, start and stop data recordings, and so on – actions as generic as their names already suggest.

Although this generalized approach works for most of the missions, there just are some special cases that do not fit into this concept. However, inspired by the technique of overloading methods in object oriented programming, those special cases are handled by creating dedicated workflows, but these workflows, applicable only to a given mission, replace the generic ones used for all the other mission, instead of exist in addition. That way, for one task there is still only one workflow visible and executable to the operator. The key for doing this is, that the system needs to know which mission is supported at the moment. This has to be declared once prior to the support, and overridden with the release of the station at the end.

Now, hiding options might be useful in operations to avoid selecting a wrong one, but they still have to be managed. Therefore it is interesting to compare the number of data files to be managed within WARP with the situation we had before. As mentioned above, the predecessor of WARP had collected a total of more than 4400 configuration files for just one antenna. Within WARP, the number of files needed (workflow definitions and parameterizations of all 47 missions currently supported by Weilheim) is 442. Even taking into account that this number will increase with time and upcoming missions, it is – due to the generalizations discussed above – unlikely to explode by a factor ten. Even better, only 66 out of the 442 files are specific for a the considered antenna, thus the number of configuration files needed to operate all three S-band antennas at Weilheim is not tripled in WARP, it is moderately increasing from 448 to 568.

The benefits of WARP for the daily configuration management will be further displayed in the following two case studies.

Case Study I: Replacing Antenna Hardware

At one of the S-band antennas the primary HPA used for most of the routine operations was broken and had to be replaced. With the new amplifier in place, the level of the input signal provided by the up-converter needed to be adjusted to fit the characteristics of the new hardware. Logically, just one number – the attenuation set at the up-converter – should be a subject to change, and in fact, within WARP only a single parameter, part of the antenna description, had to be touched, thanks to the separation between antenna and mission specifics.

Compared to that, a simple count of how often the command sequence "set the attenuation at the up-converter to 7 dB" was explicitly contained in the configuration files of the old system resulted in 50. It might be, that some of these appearances were obsolete, e.g. used for missions no longer supported, but potentially all of these places would have to be checked for relevance.

Case Study II: Implementing New Features to an Antenna

An interesting scenario studied at Weilheim is the common operation of two satellites with just one antenna at a time. To achieve this, the signal-path in the down-link of the two 15 m S-band antennas at Weilheim was slightly modified. (For details see Ref. 2.) A consequence of this modification was an additional signal loss of 3 dB in the down-link. This could be compensated by adjusting the attenuators at the down-converters accordingly, but contrary to the example above, the actual value set at the down-converter is defined by a combination of antenna specifics and mission specifics.

Now the separation between antenna- and mission-descriptions reveals its power. The antenna description contains default values for typical signal levels, basically determined by the orbit type of the spacecraft. For example, a typical spacecraft in a low-earth-orbit transmits a signal which needs to be decreased by 10 dB at the down-converter to provide the IF-signal with the desired level, while a satellite in a geosynchronous orbit usually requires an attenuation of 5 dB. Those two numbers are stored as antenna-specific values, but in addition each mission has its specific definition of the signal strength, which is applied relative to the antenna default. Most of these mission dependent values are just zero, because the mission works well with the standard setting. But in case a spacecraft transmits a much stronger or weaker signal, an additional or reduced attenuation can be specified in order not to overdrive the base-band device.

At first glance it might look odd to define the value of a single hardware-parameter at two different places. However, only this provides the possibility to apply all changes in the configuration at the points where they belong to. In this example, a change in the hardware affected the signals of all missions and such a global correction was applied by changing the antenna description for LEO and GEO from 10 dB and 5 dB to 7 dB and 2 dB respectively. Nevertheless the attenuator setting can be tuned separately for the needs of each mission. And if this was done for a mission once, this specific value stays valid, even if a hardware change like discussed takes place. Again the comparison to the previous M&C-system demonstrates the benefit: While within WARP only two numbers are subject to change, the setting of the down-converter attenuation appears 55 times[†] explicitly in the old scripts.

IV. Operational Benefits of WARP

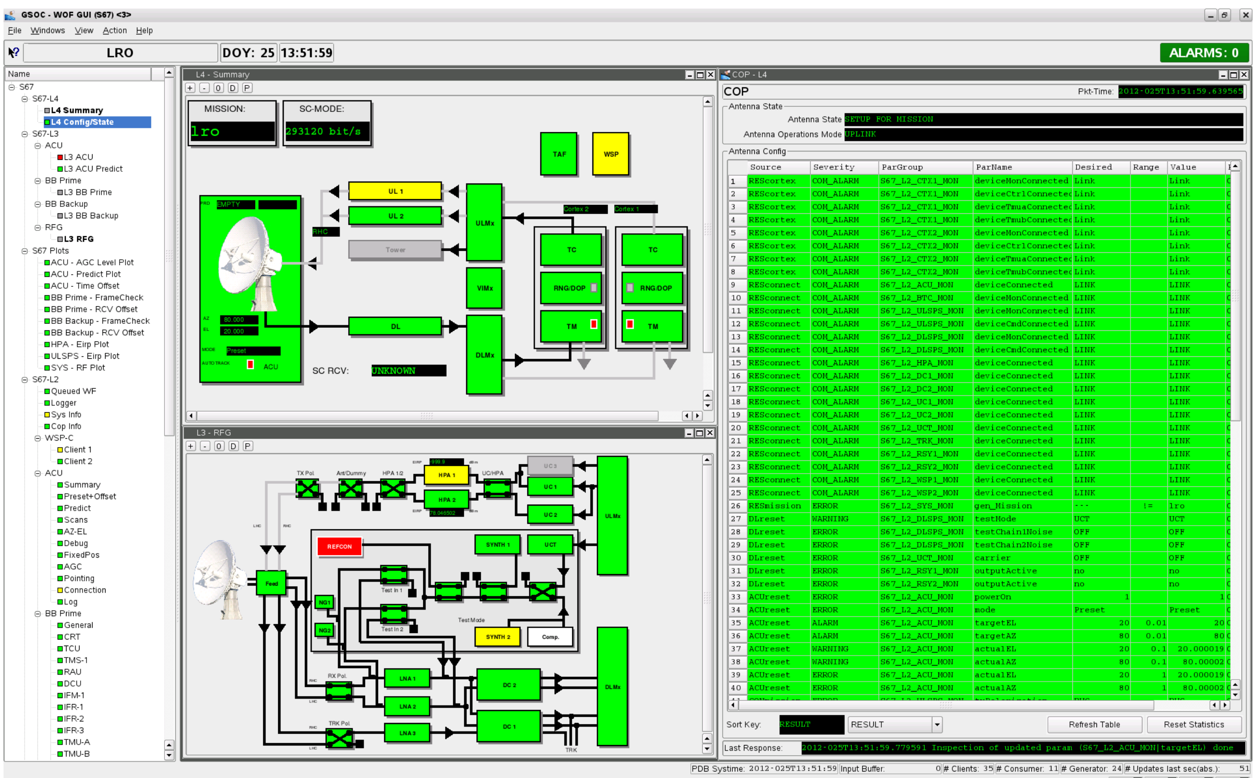

Figure 3. Example for an antenna display in WARP. *Displayed is the antenna overview and a detailed view of the radio-frequency group, together with the monitoring of the configuration observation processor.*

A. Antenna Display

The separation between antenna hardware at one hand side, mission configuration on the other and a functional description of the desired action during a support at third can also be found in the graphical representation provided by WARP. Clearly, some box representing a piece of hardware will be colored in red if the corresponding hardware reports an alarm. However, a collection of "green" devices does not necessarily work together the way they are

[†]This number is of the order of the supported missions, but does not exactly match. Therefore changes like the discussed one need to be implemented very carefully since the command setting appears not exactly once per mission but some few times more.

expected to. For instance, to run an antenna in autotrack-mode the whole tracking loop consisting of down-converter, tracking-receiver and antenna-control-unit has to be consistently configured, and a misconfiguration may not be connected to just one of the devices. Even worse, the symptom – ACU did not switch to autotrack – is usually not reported by the device(s) actually causing the problem.

To master such dependencies, one part of WARP is the so called *configuration observation processor* (COP). This tool consists of a state-machine, keeping track of the state of an antenna as a whole. Internally this global state breaks down to several functional groups, e.g. up-link is off, configured or radiating (clean carrier, idling, transmitting data), tracking is disabled, configured, active etc. To each of these parts, a table containing the relevant settings is connected and those settings are permanently checked as long as the corresponding antenna state is valid. Figure 3 demonstrates the two views of an antenna as they are realized within WARP. The block diagram is colored by the pure hardware state of the devices, indicating *if* the devices can be operated, while the table on the right indicates the list of parameters checked by the COP to assure the correct configuration, that is *how* the devices are operated.

Obviously, the actual values to be checked vary with the different antennas and missions. But here again, we benefit from the abstract definition of antennas and missions and the mission-functions translating this definitions into device parameters, because these are exactly the inputs needed to fill the COP-tables with actual values. In other words, having identified once the hardware settings relevant for a certain activity, these settings can be checked against their mission- and antenna-dependent values without further work, once the mission description is given in terms of the abstract mission parameters.

To the operator, the antennas do look alike, reporting the state of the hardware in one picture and the configuration next to it. From both displays the operator can navigate through the different layers of monitoring down to the basic display format where a single device can be controlled directly. Therefore the starting point for trouble shooting is the same on all antennas and for all missions and WARP guides the operator to the point where a malfunction might be investigated or corrected manually.

B. Setting up a New Mission

With all the above said, it is clear that setting up WARP for another mission is straightforward. What is needed to be done is filling out a table with 90 (or less) values, specifying frequencies, bit-rates, coding-types and so on. If the new mission does not require any special types of actions, this is it – and the new mission can be supported by any antenna operated with WARP.

Having the mission descriptions reduced to a simple table also simplifies to compare several missions and doing some analysis on them. As discussed already, the tracking loop needs some phase-calibration constants, which depend on the down-link frequency. A simple list of frequencies in use will help the system-engineer to provide these calibration constants. Of course, keeping a list with frequencies up to date is not a big issue, but instead of updating the M&C configurations and a list containing the frequencies, with WARP such a list is directly provided by the M&C-system. The system-engineer and operations are actually using the same database.

Although most of the missions supported currently at Weilheim fit well into the generic description of parameters and activities, WARP still provides the possibility to re-define all workflows for a given mission. That way, the introduced generalization does not limit the flexibility. However, it is a lesson learned, that most often, if something seems to require a dedicated workflow, in fact a hidden assumptions within the definition of the generic workflow is revealed. The correct and complete separation between antenna description, mission definition and generalized activities is, although simple in theory, sometimes hard to achieve.

C. Controlling Operations and Automation

The largest impact on operations by WARP is due to the generalized definition of activities. Together with the common workflows for all antennas and missions, the procedure for the operators have become common. Furthermore, the state-machine within the COP-tool can prevent human errors during operation. The sequence of activities is largely fixed since the different workflows are designed to work on top of each other. For example, as discussed in the previous section, the execution of the mission-function rely to some extend on the fact, that the antenna was brought into the reset state before. Other restrictions result from operations and safety considerations, such as to inhibit test procedures once a pass has begun or prevent radiation.

A support can roughly be divided into four phases: Setup, Testing, Pass and Cleanup. While the setup and the cleanup strictly follow fixed rules concerning the order of workflows, the testing phase and the pass itself yield a variety of options. An end-to-end data flow test with an external counterpart might be done prior to the pass or skipped. Order to do so reaches the operator at Weilheim via a voice-connection. Similar, managing the activities during a pass – set up-link, start and stop ranging and so on – is communicated to Weilheim via voice. Because of this, the extend to which WARP can operate an antenna automated, by now is limited.

Nevertheless, the workflows themselves are a first step towards automation, as they can be executed either by a human operator or by some scheduling system. The fact, that workflows verify the correct execution of the issued commands, allows for automated error-correction, and this already is applied within WARP. Some well-known problems with the station hardware are explicitly checked at critical points and if an error was caused by one of those known features, it is immediately corrected by the workflow.

Another area where WARP demonstrates its capabilities for automation is the processing of the data products gathered during a support. The raw data is first stored locally, but whenever such a local file is closed, its content is automatically processed, steered by a mission dependent product specification. Such a specification can contain things like format conversion, compression, renaming, and of course delivery to some FTP-server.

Beside WARP, there are other applications derived from the same generic M&C-framework invented at GSOC, controlling other tasks at GSOC and Weilheim ground station. Some of them are operated purely manual on purpose, others work almost completely autonomously. For WARP the strategy is to include automated operations step by step, changing the role of the shift personal slowly from an actively commanding operator to a monitoring expert and trouble-shooter.

V. Procedures - Completeness, Effectiveness and Cunningness

In the previous sections, the workflows used to run operations with WARP were discussed in a general way, based on arguments and ideas, guiding the development. Now the resulting command sequences shall be checked, if the ideas driving WARP really have lead to significant changes. To do this in a quantified way, several statistical quantities are introduced based on hypotheses, what the characteristics of a "good" sequence of commands[‡] shall be. These quantities are then calculated based on the logs of regular passes of the TanDEM-X satellite supported by Weilheim ground station, one run with WARP and as comparison another one run with TIGRIS, the M&C-system previously used at Weilheim.

The first measure looked at is *completeness*. To ensure a safe operation of the antenna system, it's best not to rely on settings not explicitly commanded, but assumed to be correct. This leads to the check which fraction of the existing command parameters within the system is actually used. That fraction will never become 100%, since there are always some parameters in a system with no need to touch them during routine operations. Obvious cases like parameters defining the TCP/IP address for the devices are removed from the statistics here, but there are still some parameters connected to functionality just not used. As an example, the frequency sweep to establish the up-link can be done by the baseband devices in the IF-regime as well as by the up-converter in the RF-regime. Using the sweep in the IF-regime only at Weilheim, the command to initiate a sweep at the up-converter will never be sent.

Therefore the absolute number of command parameters available and actually used is not as important, but choosing the same parameter-space in both cases, the comparison between WARP and TIGRIS gives an indication if one of the two allows more parameters to be set wrongly without being corrected. In fact, the strategy of WARP, to bring the antenna into a well defined state prior to any mission configuration, results in a significantly higher coverage in the command-parameter-space than for TIGRIS.

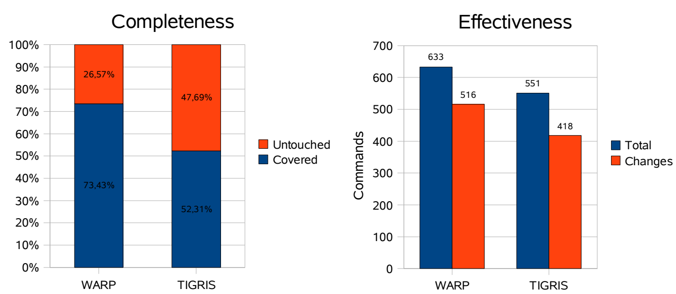

Figure 4. Comparison of completeness and effectiveness at WARP and TIGRIS.

A second measure is *effectiveness*, describing if commands send through the system do actually alter the current setting or not. The effectiveness is measured by the number of commands with a different value than the previous command on the same parameter in relation to the total number of commands sent. Again, there are cases where sending the same value several times is unavoidable, e.g. parameters triggering a certain action, such as "start recording", which carry no meaningful value at all. Nevertheless, such cases are due to the implementation of the interfaces of the devices, and with the same hardware equipment, this effect should be the same to any M&C-system. In this quantity, the stringent sequence of workflows to be executed within WARP and its benefits are confirmed. The efficiency of the command sequence in WARP is slightly above 80 %. In comparison, about every forth command in TIGRIS repeats the value already set, giving a efficiency of about 75 %.

[‡]Of course, those quantities are somewhat arbitrary, but they are intended as an indication if a given command sequence complies to well defined criteria and must not be misunderstood as an absolute measure for quality.

This is in parts an explanation why WARP is easier to manage for multi-mission support than TIGRIS. The values, defined by a mission, do not show up multiple times within the course of a support. And only because WARP controls the current antenna state and thus knows if the actual settings allow a given operation, it can proceed without making sure the most important preconditions are met by explicitly commanding them again.

Even a high effectiveness does not imply, that the executed sequence of commands was smartly composed. In fact, a random sequence of sufficient length will converge to 1 in both, completeness and effectiveness. Therefore the third measure introduced here is called *cunningness*. It's based on the fact that command sequences are targeted to bring the antenna hardware into a certain state. Four such states are defined as the following:

1. *Setup* All relevant configurations defined by the mission are set.
2. *Prepass* The antenna is pointed to the ascending point of the satellite, data recordings are started and the up-link is ready to be set.
3. *Uplink* The up-link to the satellite is set, the antenna is "green" for commanding the spacecraft.
4. *Stop* The support is completed, all data recordings are stopped, the antenna is brought back into a safe configuration with the up-link down, ACU in park and so on.

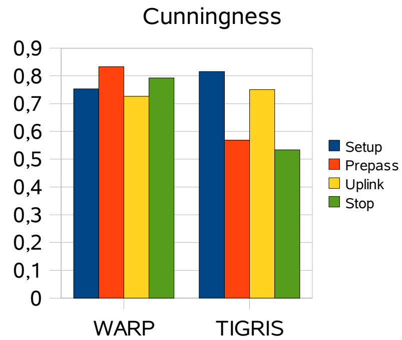

Figure 5. Cunningness of command sequences in WARP and TIGRIS.

For each of the transitions into these four states, the cunningness is defined as the number of the command parameters changed from one state to the other, divided by the total number of commands issued. In other words, if the setting of some parameter needs to be changed from A to B, it is more cunning to just command B than first commanding A again or C or something else and reach B only with the second or third command. It is impossible to reach perfect cunningness in a real world since there are many counterexamples where something is needed to be commanded for given period of time only, but again, comparing command sequences on the same hardware will at least give a fair estimate.

As shown in Fig. 5, WARP reaches a cunningness of 0,7 to 0,8 while the corresponding activities in TIGRIS yield a larger spread between 0,5 and 0,8. In case of the transition to setup, WARP is in disadvantage to TIGRIS because of the strategy to do a reset first and take care of the mission settings only afterwards. This clearly contradicts the concept of cunningness (and demonstrates that all the measures discussed here must be interpreted with care). For setting the up-link, both systems reach similar values, while for the transitions to prepass and stop the workflows of WARP are significantly more cunning than the procedures of TIGRIS.

VI. Conclusion

Weilheim ground station is successfully supporting spaceflight since 1968, configuring the hardware using switches and dials at the front-panels at first, later on using remote interfaces. From this point of view, the comparison between a new M&C-system and its predecessor (developed about twenty years ago) is somewhat unfair – it would be a pity if a new system with all the new technologies available would not be superior. Therefore the intention of the comparisons discussed in this paper is not to prove the old legacy system was bad – it definitely was not – this letter is supposed to present a censorious test, if the new system really is good and exploits the new possibilities.

It was shown in several case studies that WARP is much more easy to manage in the given multi-mission environment than the legacy system previously in use at Weilheim ground station was. Furthermore, a comparison of the command sequences of the two systems proved, that the goals of WARP, to provide secure operation of the Weilheim antennas in a multi-mission context, robust against errors caused by operators and system engineers, were met. The key to these achievements is to distinguish between the description of an antenna hardware to be operated, the definition of a mission to be supported, and link those two by unified procedures.

However, beside all statistical analyses, the successful operation of Weilheim ground station using WARP is after all the best argument for this new tool.

Appendix A
Acronym List

ACU	Antenna Control Unit
COP	Configuration Observation Processor
DLR	German Aerospace Center
FTP	File Transfer Protocol
GSOC	German Space Operations Center
GUI	Graphical User Interface
HPA	High Power Amplifier
IF	Intermediate Frequency
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase
RF	Radio Frequency
TCP/IP	Transmission Control Protocol/Internet Protocol
TIGRIS	M&C-system in operation at Weilheim before WARP
TM	Telemetry
TT&C	Telemetry, Tracking and Command
WARP	Weilheim Antenna Remote Processing, Weilheim's new M&C-system

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A high quality software, taking care of the needs of all of us, can only emerge from a fruitful collaboration of software developers, hardware experts and experienced operators. The success of WARP is the success of all of us.

References

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