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THE SKA DISH LOCAL MONITORING AND CONTROL SYSTEM

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Abstract

The Square Kilometre Array (SKA) will be the world's largest and most sensitive radio observatory ever built. SKA is currently completing the pre-construction phase before initiating mass construction phase 1, in which two arrays of radio antennas - SKA1-Mid and SKA1-Low - will be installed in the South Africa's Karoo region and Western Australia's Murchinson Shire, each covering a different range of radio frequencies. The SKA1-Mid array comprises 130 15-m diameter dish antennas observing in the 350 MHz-14 GHz range and will be remotely orchestrated by the SKA Telescope Manager (TM) system. To enable onsite and remote operations each dish will be equipped with a Local Monitoring and Control (LMC) system responsible to directly manage and coordinate antenna instrumentation and subsystems, providing a rolled-up monitoring view and high-level control to TM. This paper gives a status update of the antenna instrumentation and control software design and provides details on the LMC software prototype being developed.

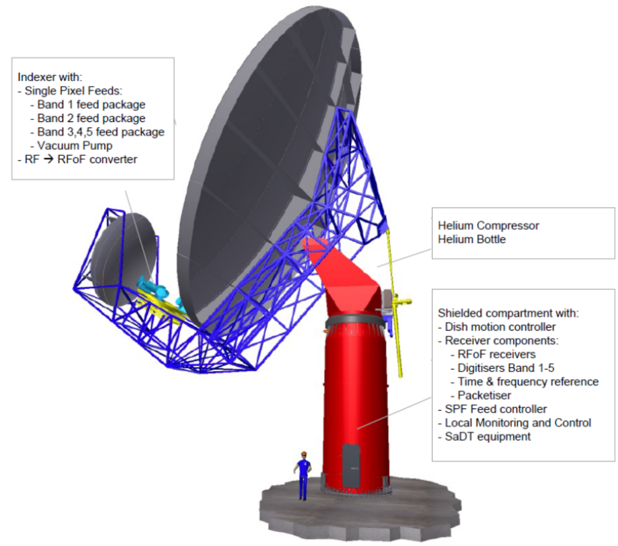

Figure 1: Schematic overview of SKA Dish design and instrumentation.

SKA DISH OVERVIEW

The SKA1-Mid Dish array will consist of 130 15-m Gregorian offset antennas with a feed-down configuration equipped with wide-band single pixel feeds (SPFs) for the SKA frequency bands 1 (0.35-1.05 GHz), 2 (0.95-1.76 GHz) and 5 (4.6-13.8 GHz) [1–3]. Band 5 will be installed in a subset (67 dishes) of the available antennas and splitted into two sub-bands - 5a (4.6-8.5 GHz) and 5b (8.3 to 15.3 GHz) - to improve the feed sensitivity and reduce the digitizer complexity and cost [4].
A sketch of the antenna is shown in Fig. 1 with the instrumentation distributed in three major locations: feed indexer, yoke and pedestal compartment.

Each feed package is mechanically mounted at the subreflector focus on the indexer which allows feed precision positioning and frequency band switching. The band 1 feed package is completely at ambient temperature. The band 2 feed package uses an ambient temperature horn, and cryogenic orthomode transducers (OMTs) and low noise amplifiers (LNAs). Bands 5 OMTs and feed horns will be cooled. All LNAs are followed by a second stage amplifier in the same package. The two cryogenic feed packages employ Gifford McMahon (GM) cryocoolers requiring high pressure helium. The helium compressor is mounted at the antenna yoke, with helium supply lines routed to the indexer. The cryogenic components inside the cryostat are thermally insulated by high vacuum. A vacuum pump is placed at the indexer with vacuum lines to all connected cryostats. Feed components can be monitored and controlled by low-speed serial lines.

The receiver sampler enclosure, located on the indexer, hosts the circuitry components and the ADC devices for feed signal amplification, filtering and sampling. ADC sampled and control data are trasmitted to/from the receiver FPGA components, located in the pedestal unit, by Optical Digital Links consisting of optical/digital transceivers connected with optical fibres. The digitiser packetizes and transmits the signal over a high-speed Ethernet link to the central signal processor. A master clock timer unit receives time and frequency reference inputs externally (provided by the SKA Signal and Data Transportation (SaDT) element) and generates timing and frequency references where needed, including the control of the calibration noise source that is transmitted over fibre to the feed packages.

A RFI-shielded cabinet is present in the antenna pedestal to house digital electronics and hardware for antenna movement and monitoring and control purposes. Among these the Antenna Control Unit (ACU), the single pixel feed and receiver controllers, the computing equipment hosting the Local Monitoring and Control (LMC) system and the networking equipment providing the Ethernet link among subelements. No active cooling is provided for equipments inside the cabinet, only a ventilation mechanism.

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The design and prototyping of SKA Dish hardware and software components is managed by four major working groups within the Dish Consortium:

- *Dish Structure (DS)*: responsible for the antenna design (mechanical structure, optics, reflectors, feed indexer), servo systems for antenna and indexer positioning, power distribution supplied to all Dish equipments, safety systems (i.e. fire/intrusion sensors, limit switches);
- *Single Pixel Feed (SPF)*: designing the feed packages and helium/vacuum services;
- *Single Pixel Feed Receiver and Digitizer (SPFRx)*: designing the digitizer system;
- *Local Monitoring and Control (LMC)*: responsible for the design of the Dish monitoring and control system.

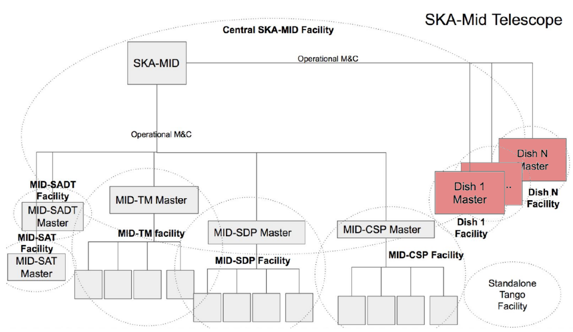

Figure 2: High level SKA1-Mid M&C system hierarchy.

THE DISH LMC SYSTEM

Dish LMC Role in SKA

Given the scale and complexity of SKA in terms of number of instrumentation to be controlled and spread of collaboration members, the SKA Monitoring and Control (M&C) system is being designed using a unique M&C reference framework and a standardized set of design patterns across the SKA Elements, including the Dish. The Tango Control System [5] was selected as the SKA framework in March 2015. Since then, an extensive work was carried out in the Collaboration to define a series of design guidelines and a common set of standards to be adopted by each Elements, including:

- overall SKA system hierarchy organized in terms of Tango domains
- common messaging, naming conventions and architectural patterns, particularly for archiving, monitoring, logging and Element master control
- a base Tango device with common SKA functionalities and a mandatory set of Tango devices to be provided per Element
- a standardized control model abstraction, e.g. a predefined set of operating modes and states, each mapped to Tango attributes
- standardized programming language, OS and hardware platforms (whenever possible)
- common software development and deployment methodologies and relevant technologies

The standardization process is still in progress for some of the above cited areas and will be completed before construction phase.

The high-level architecture for the SKA1-Mid M&C system arising from the standardization process is shown in Fig. 2. Each Element (e.g. the Dish) has a Local Monitoring and Control (LMC) system directly interfacing with instrumentation and providing Element master control and rolled-up monitoring data to a central Telescope Manager (TM) Element. TM, at the top of the hierarchy, orchestrates the scientific observations, centrally coordinating all the involved telescopes on the basis of the information provided by LMCs. In this context Dish LMC performs local fast control, diagnostics, life-cycle and safety operations on Dish components, collecting and aggregating their monitoring information (logging, monitoring parameters, events and alarms) and presenting it to TM in an abstracted and standardized way. Dish LMC performs M&C operations via the sub-element controllers, through a local Ethernet link, enabled by a network switch provided by the SKA Signal and Data Transport (SaDT) element, responsible also for the external connectivity of the antenna (e.g. transport of science and M&C data).

Each Element in SKA will have a dedicated Tango facility, identified by the Tango DB, hosting the Tango device server configuration for that Element. This corresponds for the Dish to a Tango facility instance for each of the 133 antennas present in the SKA1-Mid array. From the monitoring and control perspective each Dish facility has a moderate size when compared to other SKA Elements in terms of expected data flow to TM (of the order of 100-200 kbps), number of Tango devices present (<20), fastest control loop (~100 ms for the antenna pointing monitoring and control), archived data and log storage requirements (12 h at minimum, few days or a week at maximum).

Dish LMC architecture is described in the following section.

Dish LMC Design

The high-level architecture of Dish LMC system is shown in Fig. 3 (top panel) together with relevant monitoring and control components in the Dish and in Telescope Manager. Each rounded box in the figure represents a software module with one associated Tango device server. The connectors (dashed lines) indicate the major monitoring and control data flows among the depicted modules, in form of Tango commands and attribute events. Other data flows (e.g. logging, archiving) are represented separately in the bottom

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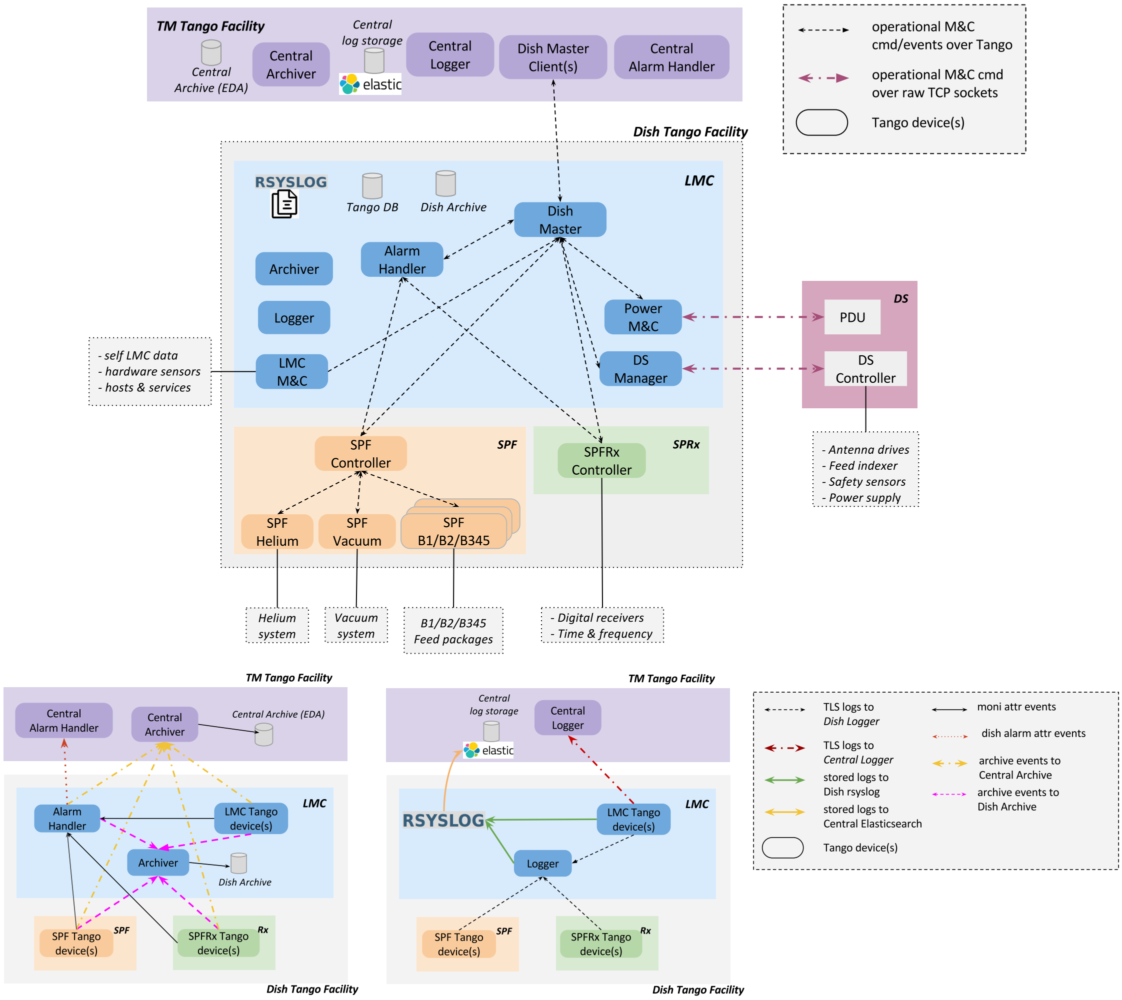

Figure 3: Top panel: Dish LMC high-level software architecture; Bottom panel: Alarm and archiving data flow view (left panel), logging data flow view (right panel).

panels. The gray box represents the Dish Tango facility grouping all Tango devices present in LMC, SPF and SPFRx sub-elements, while the upper violet box represents the TM Tango facility. The Dish Tango DB is physically residing in the LMC computing server.

A number of Tango devices are present in the Dish and reported in the figure, each interacting via the Tango channel (i.e., CORBA [6] and ØMQ [7] for command- and event-based communication respectively.

Dish Master Providing high-level control (via low-level LMC and sub-element devices) and rolled-up monitoring status to TM

Alarm Handler The Dish Alarm system, detecting and reporting alarms in the Dish on the basis of monitoring data collected by other Tango devices

Logger Collecting logs generated from other Tango devices in the same Dish facility at configurable level via the Tango Logging Service (TLS) channel

Archiver Collecting and archiving monitoring data and alarms from other Tango devices at configurable level and persistency

DSManager A Tango device server interfacing with the Dish Structure sub-element for antenna and power monitoring and control operations. The interface uses a TCP socket channel and an established messaging protocol with the DS antenna Beckoff system.

Power M&C A Tango device server interfacing with the Dish Power Distribution Unit (PDU)

LMC M&C Responsible for life-cycle operations on LMC Tango servers and for detection of LMC health status on the basis of collected self-monitoring data (e.g. hardware, Tango server and service status)

SPFController A Tango device providing SPF master control and aggregated monitoring status to LMC on the basis of monitoring data reported by low-level SPF devices.

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The latter's interface with the feed package, helium and vacuum service instrumentation via serial line links. These devices are provided by the SPF working group.

SPFRxController A Tango device, designed by the SPFRx working group, interfacing with receiver digitizer system to provide SPFRx master control and aggregated monitoring status to LMC, similarly to the SPFController.

The expected interactions among dish and TM Tango devices are depicted in Fig. 3 (bottom panel) for different views. Alarm and archiving data flows are represented in the left panel while logging data flows in the right panel.

Each Dish device will have three different logging targets at configurable log levels: a *DishLogger* device, a *CentralLogger* device in TM and a local rsyslog server. The first two devices are standard Tango devices implementing the Tango Log Consumer interface. Their main purpose is to aggregate all facility logs and support log viewing applications at the single facility or sub-array level. Logs generated by Dish devices are stored locally to files with limited time persistency and centrally to a long-term Elasticsearch storage using a syslog forwarding mechanism set up by LMC.

Alarms and archiving is naturally provided by the Tango Core and provided components, such as the Tango Archiver and Alarm system. Each Dish device can generate specific archive events on its Tango attributes that can be subscribed by both a local and a central archiver device, which archive them to a database backend (e.g., MySQL or Cassandra). Dish monitoring archive will have a limited time persistency. Similarly Tango attribute events can be subscribed by the *AlarmHandler* device which detects Dish alarm on the basis of configurable rules. A Central *AlarmHandler* device uses the Dish AlarmHandler to form higher-level alarms (e.g. at array level).

Dish LMC Prototype

A software prototype is being implemented following the architecture presented in the previous section. The scope of the prototype is to validate the design and carry out end-to-end dish qualification at the end of the SKA pre-construction phase with all the designed dish systems mounted on the first SKA antenna deployed in the Karoo area.

A number of technological choices has been made for the prototype after a preliminary evaluation phase. We list them in Table 1. Some of the assumptions are already considered as SKA standards, such as the Tango framework and its components, the software version system and supporting OS, while other technologies specified (e.g. Ansible, Nagios, Jenkins) are under evaluation being adopted also by other SKA Element LMCs.

Given the scale of Dish LMC a deliberately simple development and continuous integration approach was adopted for the prototype. A standardized and more robust development and testing methodology for SKA software is under study and will be available for the construction phase.

Table 1: List of Dish LMC Prototype Employed Technologies

Type	Technology
Progr. language(s)	C++ (control system), python (configuration & testing)
M&C framework	Tango 9
Tango tools	PyTango, yat4tango, Elettra Alarm System, HDB++ Archiver, Taurus GUI
Libraries & tools	boost, jsoncpp, pugixml, Exprtk, Nagios 4
Build system	cmake
Version control	git (GitLab)
Testing	Google Test, python behave + nose
Configuration management	Ansible
Continuous integration	Jenkins
Documentation	Doxygen + Sphinx/breathe
Virtualization & OS	VirtualBox, Ubuntu 14/16

The hardware virtualization and deployment strategy represents another area where a detailed analysis is expected at SKA level. For the prototype development and testing we have employed a full virtualization environment with Virtualbox as virtualization software. However, it was noted that some LMC components (e.g. the archiving, log storage, the GUI applications, the Dish Tango DB) would be suitable for containerization. The potential benefits will be analyzed in detail after the qualification stage.

While some of the LMC components (e.g. the *Archiver* and *AlarmHandler* devices) can fully re-use existing Tango components, others require a fresh development to meet the SKA requirements and guidelines. We have grouped such required functionalities in a base LMC Tango device so that all other LMC devices shown in Fig. 3 can use them. We list the implemented features as follows:

- Logging to syslog target, besides Tango builtin targets, and custom logging macros
- Dynamical generation of Tango attributes in devices from formatted (XML) configuration files

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- Tango attribute transition rules and command state machine based on attributes other than the builtin Tango state
- Definition and configuration of formula attributes in devices
- Tango device proxy utilities, e.g. proxy, event and handler registration via properties or macros
- Definition of sequence of commands or tasks
- Software exception and event rate attribute counters

Similarly, other SKA Element LMCs (e.g., CSP and LFAA) have implemented similar or additional functionalities in their prototypes. A SKA working group is currently analyzing each of these functionalities to produce a unique SKA base device and enforce standardization in the construction phase.

Some of the above listed features were introduced to ease LMC software update due to continuous interfaces and guidelines changes but also to support LMC component configuration with CM tools such as Ansible. The LMC device configuration can infact be specified in template configuration files easily managed by Ansible at configuration time. At runtime the device configuration is kept in the TangoDB as usual.

Formula attributes and the extended state machine support the Dish and SKA Control model requirements and the main LMC functional requirement which is aggregating and rolling up the monitoring status from a collection of device attributes. Formula attributes can be used also as pre-alarm attributes in combination with the Alarm system.

Finally, Tango does not allow at present to define and execute a sequence of commands, with potential mutual task dependencies and long running times. This is particularly required for the Dish in some operational scenarios, like setting the antenna in a safe mode in response to given events (e.g. a power cut) or setting the feeds to operational mode. The last functionality listed above covers these needs.

Additional Tango devices developed from scratch include:

- a device to collect LMC self-monitoring data (hardware sensors, service status, etc) from a Nagios server using the *Nagios Event Radio Dispatcher (NERD)* and import them as dynamical Tango attributes
- an interface device to Dish Structure antenna positioning Beckoff system using a custom protocol developed by the MT Mechatronics DS group. A similar protocol is in use also in other single-dish antennas such as the Sardinia Radio Telescope (SRT).

SUMMARY

The SKA project has recently entered Critical Design Review stage of pre-construction in which final software design and qualification are expected in mid 2018 before proceeding to construction phase. Implementation of Dish LMC prototype started after the detailed design review when no SKA guidelines and standards were released. Software implementation is in advanced status for some LMC components (LMC base device, Dish logger, master, alarm system, LMC M&C) while others responsible for the antenna structure and power control are awaiting for progresses in DS design and interface consolidation. For testing purposes device emulators have been developed for SPF and SPFRx sub-elements and early tests of the LMC-SPF interface were carried out in June 2017. Considerable efforts are currently dedicated to LMC software and dish interfaces update after the major SKA guidelines release in March 2017 to ensure a high-degree of compliancy with the still-evolving SKA standards.

ACKNOWLEDGMENT

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