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THE SKA TELESCOPE CONTROL SYSTEM GUIDELINES AND ARCHITECTURE

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Abstract

The Square Kilometre Array (SKA) [1] project is an international collaboration aimed at building the world's largest radio telescope, with eventually over a square kilometre of collecting area, co-hosted by South Africa, for the mid-frequency arrays, and Australia for the low-frequency array. Since 2015 the SKA Consortia joined in a global effort to identify, investigate and select a single control system framework suitable for providing the functionalities required by the SKA telescope monitoring and control. The TANGO Controls [2] framework has been selected and comprehensive work has started to provide telescope-wide detailed guidelines, design patterns and architectural views to build Element and Central monitoring and control systems exploiting the TANGO Controls framework capabilities.

INTRODUCTION

Spring 2015 representatives from eight SKA Consortia met in Trieste, Italy, for the SKA Local Monitoring and Control (LMC) Standardisation Workshop, with the purpose to explore some open source control system frameworks and define a procedure to select the best suited for SKA. The main criteria adopted for the final evaluation were:

- technical applicability, with particular respect to:
  - scalability
  - industry standards support and bespoke developments
  - modernity and roadmap
  - user support and documentation
- integration of precursors
- risk mitigation

The TANGO Controls framework turned out to be the best suited to fulfil the above criteria, especially with respect to it's modern architecture and strong roadmap for future developments. TANGO Controls has been selected as SKA monitoring and control common framework. A series of workshops have been scheduled in 2016, with the aim to improve commonality across the main sub-systems[1] control systems architecture. The TANGO LMC Harmonisation through telescopes workshops targeted at analysing the existing designs made by the Elements Consortia, identify commonalities, defining best practices and provide a path to LMC harmonisation beyond the selection of TANGO as control system framework. Building on the outcome of the harmonisation effort, the SKA Control System Guidelines document summarises generic design patterns and common approaches for monitoring and control harmonisation across SKA Elements, to maximise the benefit of the TANGO control system framework.

TERMINOLOGY

In a scenario where a worldwide community is involved in the Elements, and thus telescope, control system design, some clarifications about the adopted terminology helped better understanding. In particular, the SKA control system guidelines use the following definitions:

- **monitoring**: is used in the context of a higher-level component subscribing to updates of a TANGO Attribute with the purpose of evaluate its value/quality factor for a specific reason;
- **archiving**: is used in the context of gathering monitoring. information, e.g Attributes, from a TANGO device to save it to a monitoring archive;
- **logging**: is used in the context of additional information that may be emitted by components to support fault finding and engineering activities. No information that is expected to be used for operations or expected to be monitored by another component may be included only in logs. Logs can also be stored; this is referred as *log storage*;
- **failure**: occurs when an item is unable to provide the correct service and is unable to perform its required function according to its specification. Either hardware or software can fail, and the failure must be reported together with all the details required for a prompt and effective identification of the failed component;
- **fault**: is the cause of an error, or the condition that causes software to fail to perform its required function;
- **error**: refers to difference between actual autput and expected output;
- **state**: refers to the TANGO device State attribute;
- **health state**: represents the overall health of the component with respect to a set of monitoring points/reported failures applying a predefined metric;
- **alarm**: an audible and/or visible means of indicating to the operator an equipment malfunction, process deviation, or abnormal condition requiring a timely response, as per the IEC 62682 standard.

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[1] Referred as *Elements* in the SKA project.

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ELEMENT LMC

The mid-frequency and low-frequency telescope arrays comprise a number of Elements that map into TANGO facilities, as depicted in Table 1 and 2. The role and responsibilities of each Element in the control system of the telescopes have been identified and summarised. Each instance of each Element shall implement a single standalone TANGO facility[2]. This allows for each Element to build a self-contained control system that can be deployed and tested in advance.

Table 1: SKA-MID TANGO Facilities

Facility	Description
SKA-MID	Telescope Manager
MID-CSP	Central Signal Processing
MID-SDP	Science Data Processor
MID-D*nnnn*	One for each dish (170 SKA1, ~2500 SKA2)
MID-SAT	Synchronisation and timing
MID-SADT	Signal and Data Transport
MID-INSA	Infrastructure (South Africa)
MID-M*nn*	MeerKAT precursor receptors (64)
MID-MKAT	MeerKAT precursor ancillary

Table 2: SKA-LOW TANGO Facilities

Facility	Description
SKA-LOW	Telescope Manager
LOW-CSP	Central Signal Processing
LOW-SDP	Scieince Data Processor
LOW-LFAA	Low Frequency Aperture Array
LOW-SAT	Synchronisation and timing
LOW-SADT	Signal and Data Transport
LOW-INAU	Infrastructure (Australia)
LOW-ASKAP	ASKAP precursor ancillary

To guarantee consistency between facilities, a set of standard "Element level" TANGO devices provide a common interface to the telescope manager (TM). Moreover, a number of SKA base classes for TANGO devices are foreseen, to be adopted overall the telescope monitoring and control, that will provide common functionalities and consistent behavior.

The *Element Master* TANGO device is the entry point that TM, or other Elements, will connect to to retrieve some high level information for general operations, and provides the control and coordination of an Element for general operations. The *Element Master* is responsible to distribute and coordinate the control within the Element hierarchy for operations such as start-up, shut-down, power management, overall state transitions, etc. The *Element Master* provide monitoring information for the overall Element state as well.

[2] With the exception of DISH there will be a single instance of an Element per Telescope.

The SKA Telescope will require a significant amount of logging messages. The *Element Logger* TANGO device provides log aggregation functionality for the Element, and allows TM to modify the log level of remote telescope logging for selected devices. A robust log forwarding channel will be used for log storage.

All Elements will adhere to the common SKA design pattern for standardised alarms reporting. Elements are in charge to evaluate and build all the appropriate alert rules and expose them in the *Element AlarmHandler* TANGO device.

TM and the Elements are involved in defining and implementing the Telescope Model. The Telescope Model (TelMod) is defined as that part of the Telescope Manager (TM) software that uses computational models and parameter data to configure signal reception and processing, so as to produce the required data products. Computational models are likely to be implemented by TM or SDP, whilst all the Elements provide an *Element TelState* device to enable discovery and retrieval of LMC device attributes that provide telescope state items.

SKA DESIGN PATTERNS

Common TANGO patterns and implementation decisions try to coordinate and integrate the Elements distributed stand-alone TANGO facilities and the Telescope TANGO facility into a single instrument. To take advantage of the TANGO framework and provide a better integration Elements and TM are supposed to adhere to the design patterns.

SKA TANGO Developers Guideline

Specifically targeted to the developers, this part highlights TANGO-specific SKA patterns and best practices. SKA developers will adhere to and contribute to improve the developers guidelines, as it is expected to be an evolving document. Various aspects are included, but not limited to, TANGO device and SKA Element modelling, TANGO device implementation aspects, e.g. device States and Modes, polling, events, quality factor, alarms. Patterns for configuration and control commands and unsolicited information reporting are provided. The naming convention for commands, attributes, properties and enums is proposed. The standard interface for Element level SKA devices is also defined, including commands, attributes and properties.

Device Naming Convention

Device naming convention addresses TANGO device naming across all TANGO facilities for the full SKA project. The main rules are:

- TANGO device names will be globally unique within the observatory
- SKA TANGO device names are managed centrally by the SKA device naming convention
- SKA facilities will be referred to with uppercase and dash as separator

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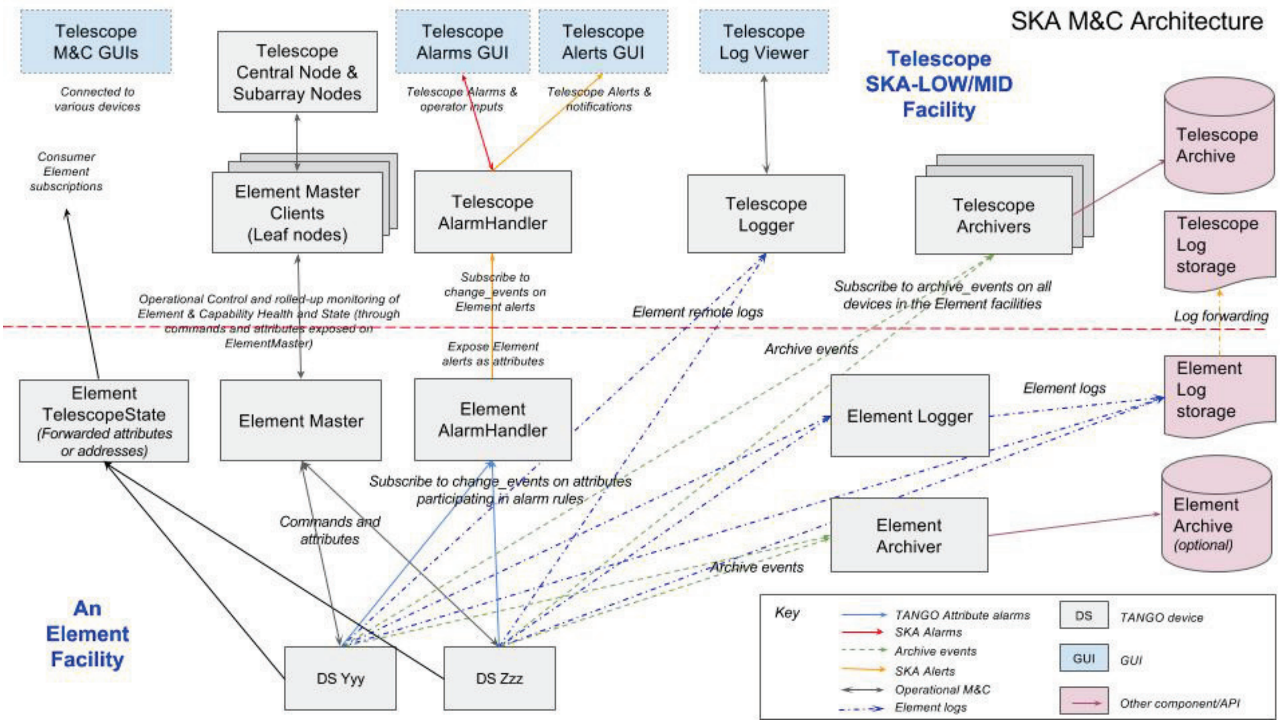

Figure 1: Proposed monitoring and control architecture.

- there will be a limited number of SKA TANGO facilities, including two telescope facilities for SKA-MID and SKA-LOW
- SKA TANGO device names will be denoted in lowercase with underscore as separator
- there will be a limited set of TANGO device domains allowed per Element.

Distributed TANGO Facilities

As noted, the SKA telescope comprises a number of Elements, each implementing a standalone TANGO facility, as well as two "central" TANGO facilities for the SKA-MID and SKA-LOW telescope management. Element facilities need to be integrated with the telescope facilities to build a working instrument. To minimise configuration and synchronisation errors, integration of different facilities is based on discovery and introspection. TM access to other elements is via a set of well known TANGO devices, identified as Element level devices. The *Element Master* device provides the shortcuts, populating this information from the Elements TANGO database to guarantee consistency. However, TM may connect to each Element TANGO database for detailed analysis, diagnostics and drill-down. In the case one of the Elements provides input for the other Element, TM may act as a broker and provide the relevant information, such as the Fully Qualified Device Name (FQDN) of the required TANGO devices. The proposed monitoring and control architecture, which does not highlight all the possible layers in the control hierarchy, is depicted in Fig. 1; some of the components shown will be described in the next subsections.

Element Telescope State

In the context of the TM, the concept of *Telescope Model* has been introduced to denote that part of TM software that uses computational models and parameter data to configure signal reception and processing so as to produce the required data products. It includes, but not limited to, models for:

- propagation of signals from an astronomical target to the telescope, including light bending, earth rotation and tropospheric/ionospheric effects;
- the behavior of the array elements, such as dish pointing and beam steering;
- the effects of interference on the recorded signals.

The computational model calculations are to be repeated at various time intervals, ranging from once per observation to approximately ten times per second. The parameters involved in the computations are to be modeled in the TelState TANGO device, at Element and TM levels, making them easily available to other consumer Elements. The TelState TANGO device, however, does not implement the actual algorithms and calculations required by the Telescope Model, as these will be implemented by appropriate TANGO devices.

SKA Control Model

Since the wide range of equipment that the SKA Telescope comprise, the need arises to identify and define a comprehensive set of states and modes that have to be implemented by all TANGO devices, at all levels of hierarchy, in order to simplify the device interactions and reduce the effort required to develop the control system software. The SKA Control Model (SCM) defines a set

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of standard TANGO attributes and commands that apply to SKA TANGO devices, and the possible/allowed state transitions; it also specifies which SCM attributes are mandatory and which optional. One of the major benefits for defining a telescope-wide control model is to align the SKA Control Model with the built-in TANGO device state, such that TANGO state can report the *operational status*. Moreover, a common subset of attributes is used to report the status of a wide variety of entities in a consistent way, defining possible/allowed state transitions, commands used to trigger transitions, and how the progress is reported. The SKA Control Model attributes are summarised below:

- **state**: TANGO state
- **healthState**: indicates the availability of an entity to produce the desired functionality;
- **obsState**: indicates the state of an entity with respect to the ongoing observation;
- **obsMode**: specifies which observing mode is currently active;
- **adminMode**: administrative mode, indicating whether an entity is used or not;
- **controlMode**: indicates whether control is local to Element or remote;
- **simulationMode**: indicates whether a simulated functionality is provided;
- **testMode**: specifies whether an entity supports specific testing behavior;
- **configurationProgress**: reports completion percentage on ongoing configuration.

SKA mandates a subset of the 14 TANGO state values; the proposed TANGO device state machine, taking into account the interactions with some of the SCM states and modes, is depicted in Fig. 2. As an additional example of the SCM attributes, the state machine for subarray level devices, that apply to the obsState attribute, participating into observations, is depicted in Fig. 3.

Engineering Data Archive

TM has a requirement to archive all the engineering data and control parameters in a central telescope archive, referred as Engineering Data Archive (EDA). Thus, SKA-MID and SKA-LOW telescope facilities are in charge of archiving all the attributes provided by the devices in the Element facilities. Elements may deploy Element level archiving for internal use, if required; one use case addresses Element standalone operation. The Element archives are completely separate from the Telescope archive and can be managed by the Element with no regards for the EDA.

SKA archiving will be based on the TANGO HDB++ archiving system [3]. For local element archiving the architecture comprises:

- TANGO archiving setup with a MariaDB backend [4]
- one HDB++ ConfigurationManager device
- a number of HDB++ EventSubscriber devices

For central Telescope archiving a Cassandra [5] backend is foreseen, with at least:

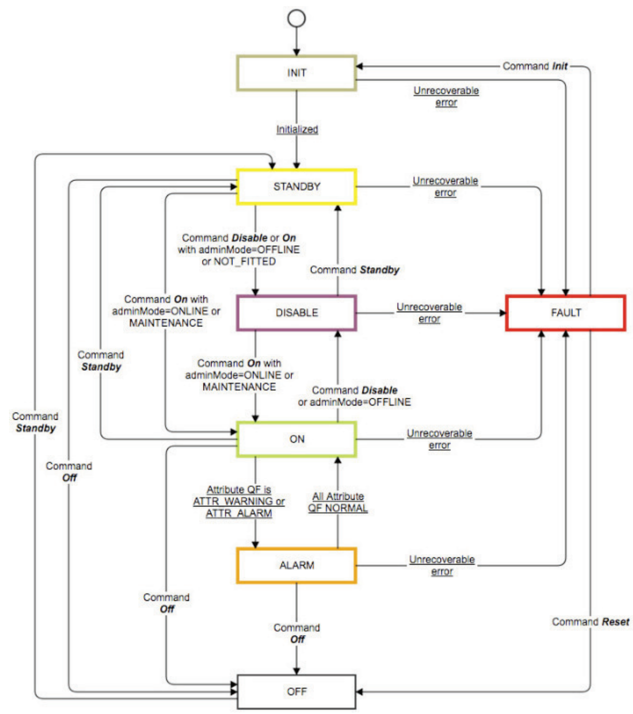

Figure 2: TANGO device state machine. Internally triggered transitions underlined.

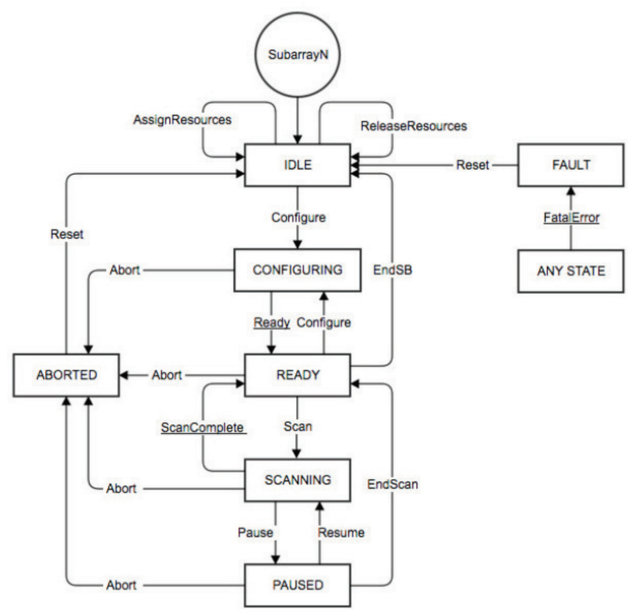

Figure 3: Subarray device state machine, apply to obsState SCM attribute. Internally triggered transitions underlined.

- one dedicated HDB++ ConfigurationManager device; more than one ConfigurationManager device can be deployed whenever complexity, architectural or practical reasons require it;
- at least one dedicated EventSubscriber device for each Element; additional EventSubscribers may be deployed for telescope central archiving of each Element

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whenever performance, architectural or operational reasons require it.

This is a case where TM access, as a subscriber, Element TANGO devices at lower levels of the Element hierarchy: scalability and performance reasons suggest to avoid the bottleneck of a single point of contact, exploiting point-to-point TANGO capabilities, in the specific case publish/subscribe pattern.

Logging

A significant amount of logging messages is foreseen in the SKA Telescope control and monitoring system. More in detail, the SKA logging system has to support runtime viewing and persistent storage of device logging streams. Two services have been identified to fulfil the requirement:

- the TANGO Logging Service (TLS), to support runtime viewing of logs in an Element as well as centrally in the telescope facilities for logs across Elements
- rsyslog with an Elasticsearch/Logstash/Kibana (ELK) backend to support log storage

Log aggregation is foreseen at Element and Telescope level by means of dedicated LogConsumer TANGO devices for aggregated viewing. The SKA TANGO device logging base class provides support for three logging targets, namely Element, Telescope and Storage, with distinct logging levels, adhering to the RFC 5424 [6] format.

Alarm Handling

SKA adopted the IEC 62682:2014 standard [7], entitled "Management of alarms systems for the process industries". The standard defines an alarm as *"An audible and/or visible means of indicating to the operator an equipment malfunction, process deviation, or abnormal condition requiring timely response"*. SKA telescope alarm handling exploits a hierarchical approach, based on the AlarmHandler device. Since the strict definition of "alarm", the intermediate concept of "alert" has been introduced to deal with non IEC 62682 compliant alarms. Each Element is in charge of implementing the appropriate Element Alerts as rule-based formulæ using a combination of attribute values, attribute quality factors and device states. Each Element Alert is exposed as a specifically named and formatted attribute on an Element AlarmHandler device. Building on the Element Alerts, the Telescope AlarmHandler is tasked with the responsibility to implement rule-based formulæ to define the Telescope alarms, which are compliant to the IEC 62682 standard, thus requiring operator timely response.

CONCLUSION

The SKA Telescope Control System Guidelines strives to define generic design and common approaches for LMC harmonisation across SKA Elements to maximise the benefit of the TANGO control system framework, as well as what is available from the wider TANGO community, within the SKA project. This will become the definitive guideline for the control system in all SKA Elements, to coordinate common monitoring and control functionalities, interfaces and behaviors.

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