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SKA SYNCHRONIZATION AND TIMING LOCAL MONITOR CONTROL - PROJECT STATUS

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Abstract

The Square Kilometre Array (SKA) project aims to build a large radio telescope consisting of multiple dishes and dipoles, in South Africa (SKA1-Mid) and Australia (SKA1-Low) respectively. The Synchronization and Timing (SAT) system of SKA provides frequency and clock signals from a central clock ensemble to all elements of the radio telescope, critical to the functionality of SKA acting as a unified large telescope using interferometry. The local monitor and control system for SAT (SAT.LMC) will monitor and control the working of the SAT system consisting of the timescale generation system, the frequency distribution system and the timing distribution system. SAT.LMC will also enable Telescope Manager (TM) to perform any SAT maintenance and operations. As part of Critical Design Review, SAT.LMC is getting close to submitting its final architecture and design. This paper discusses the architecture, technology, and the outcomes of prototyping activities.

SAT SYSTEM OVERVIEW

The SAT system of SKA Telescope project [1], designed by the Signal and Data Transport (SaDT) [2] Consortium of the SKA, provides frequency and clock reference signals from a central clock ensemble that are distributed in a phase-coherent manner to each antenna across the telescope's fibre network. The SAT system is divided into 4 modules – SAT.CLOCKS (CLK), SAT.STFR.FRQ (FRQ), SAT.STFR.UTC (UTC) and SAT.LMC.

The CLK module provides the timescales for the SKA Telescope and uses an ensemble of three hydrogen masers as the reference clocks, providing a 10 MHz reference and PPS signal. The timescales will be tied to coordinated Universal Time (UTC) as their time and frequency reference. Global Navigation Satellite System (GNSS) time transfer will be used as the primary time transfer method and the time transfers will be computed by the Bureau International des Poids et Mesures (BIPM). A steering mechanism has been designed to keep the time and frequency of the SKA Timescale within 5 ns of UTC.

The FRQ module distributes phase coherent frequency signals, using a custom design consisting of the Transmitter Module (Tx), Receiver Module (Rx) and a Communication Control Module, to all the receptors of the SKA1-Mid and SKA1-Low telescopes. The excess phase noise, induced by the various noise sources in the fibre-optic cables that degrade the quality (the coherence) of the transmitted signals by perturbing the phase, is detected and compensated in order to transfer reference signals with sufficient coherence over the longer link lengths.

The UTC module, uses the White Rabbit (WR) system to distribute the absolute time (from the timescale designed by CLK) to the receptors in SKA1-Mid and SKA1-Low. The WR signal is generated and distributed by WR switches that are synchronized to the SAT Clock ensemble. They each receive a 10 MHz reference and PPS signal, and use the Network Time Protocol (NTP) to determine the UTC time of a PPS edge. Their output is transmitted via a single fibre to a WR end point. The end point measures and compensates for the optical and system delays, and outputs a replica of the PPS pulse, which is delivered to the receptor equipment.

The SAT.LMC module monitors the health and controls the various pieces of equipment of the SAT system. It presents a rolled-up view of the health of the SAT system to TM.

SKA MONITOR AND CONTROL

The Monitor and Control system of SKA adopts a hierarchical approach. The SKA Telescope consists of a number of elements based on the functions that the telescope will perform. The TM element orchestrates, monitors and controls all the other elements of the telescope via Local Monitor and Control (LMC) systems, local to each element. These Element LMCs in-turn orchestrate, monitor and control the respective elements. The LMCs receive control commands from TM, which are translated into low-level commands by respective LMCs and sent to the element equipment(s). The Element LMCs gather monitoring data from each of the element equipment and send it up to TM. Figure 1 below shows the SKA Monitor and Control structure.

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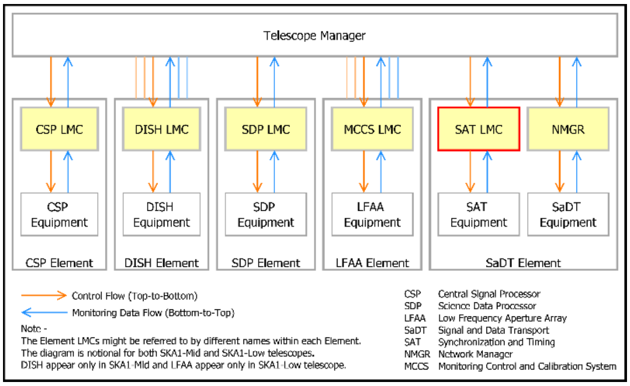

Figure 1: SKA Monitor and Control Structure.

SAT.LMC ARCHITECTURE

SAT.LMC solution is predominantly software and is based on the TANGO Control System Framework [3]. TANGO is selected as the preferred choice for the SKA control system framework technology by representatives of all LMCs, TM, SKA Office (SKAO) along with industry experts in March 2015.

The SAT.LMC solution is architected and designed incrementally [4] using the structures and processes recommended by The Open Group Architecture Framework (TOGAF) [5]. TOGAF 9.1 recommends the use of ISO/IEC 42010:2007 for describing the software architecture.

Solution Concept

The SAT.LMC solution is a two-tier hierarchical control system with control instructions flowing top-down from TM to the SAT equipment and the monitoring data flowing bottom-up from the SAT equipment to TM. SAT.LMC monitors approximately 452 pieces of hardware equipment for SKA1-Mid and 143 pieces of hardware equipment for SKA1-Low (approximately 25 being distinct SAT equipment). Together all the equipment constitute around 45,200 monitoring points for SKA1-Mid and 14,300 monitoring points for SKA1-Low.

SAT.LMC solution consists of four control system software applications (products) that are a collection of bespoke TANGO Device Servers:

- TANGO Device Server Central (TDS-CN).
- TANGO Device Server Clocks (TDS-CLK).
- TANGO Device Server Frequency Distribution (TDS-FRQ).
- TANGO Device Server UTC Distribution (TDS-UTC).

TDS-CLK, TDS-FRQ and TDS-UTC software applications monitor and control the three SAT subsystems – CLK, FRQ and UTC. They interface northbound with the TDS-CN software product and southbound with the SAT equipment. They receive control commands from TDS-CN and send back monitor information from the connected SAT equipment.

Figure 2 below shows the SAT.LMC hierarchical solution concept.

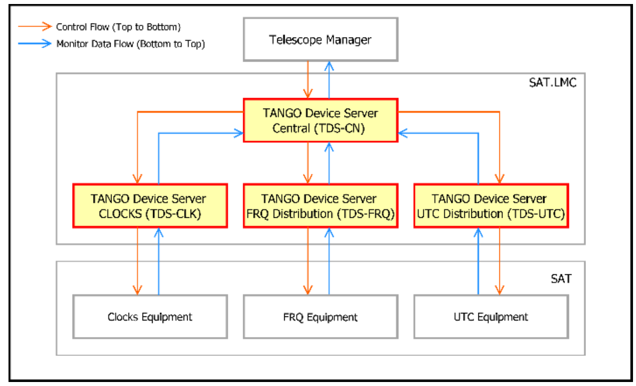

Figure 2: SAT.LMC Hierarchical solution.

The TDS-CN software product interfaces with TM at the northbound and with the TDS-CLK, TDS-FRQ and TDS-UTC software products at the south bound. The TDS-CN receives commands from TM and relays it to TDS-CLK, TDS-FRQ and TDS-UTC as appropriate. The TDS-CN aggregates monitor information from TDS-CLK, TDS-FRQ and TDS-UTC and sends it to TM.

Application and Data Architecture

The application portfolio for SAT.LMC consists of the four bespoke software applications – TDS-CN, TDS-CLK, TDS-FRQ and TDS-UTC. Each of these applications are a set of TANGO Device Servers.

Figure 3 below shows the TANGO Device Server hierarchy with the TANGO servers grouped within each of the SAT.LMC applications.

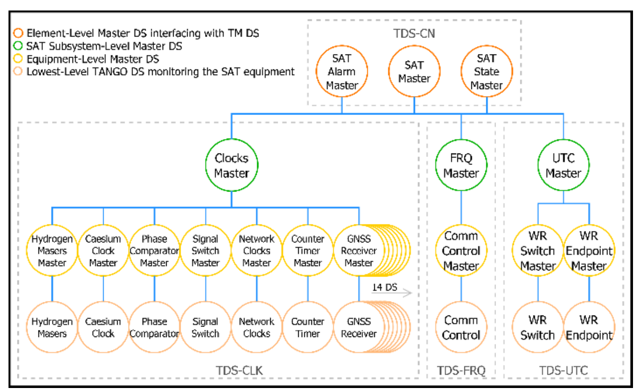

Figure 3: SAT.LMC TANGO Device Server Hierarchy.

The TDS-CN application consists of the top-level TANGO Device Servers that interface with TM. The TDS-CLK, TDS-FRQ and TDS-UTC applications each, have a 3 tier-hierarchy of TANGO Device Servers.

At the top-level within each of the TDS-CLK, TDS-FRQ and TDS-UTC applications, the SAT subsystem master device servers aggregate information with respect to SAT subsystems (CLK, FRQ or UTC). At the second-level, the equipment-type master device servers aggregate information based on the SAT equipment type that is being monitored and controlled. At the lowest-level, de-

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vice servers monitor and control the actual SAT equipment.

For each telescope, there will be one SAT TANGO facility containing all the controllable SAT TANGO devices. There will be 4 TANGO Domains within the SAT TANGO facility – three TANGO Domains consisting of TANGO devices belonging to each of the three SAT subsystems and the fourth domain consisting of devices belonging to the SAT Master system.

SAT.LMC uses TANGO for all its communications with TM (at northbound), the SAT subsystems (at southbound) and also within itself. It uses the data entities as defined by the TANGO for all communications as shown in Fig. 4 below.

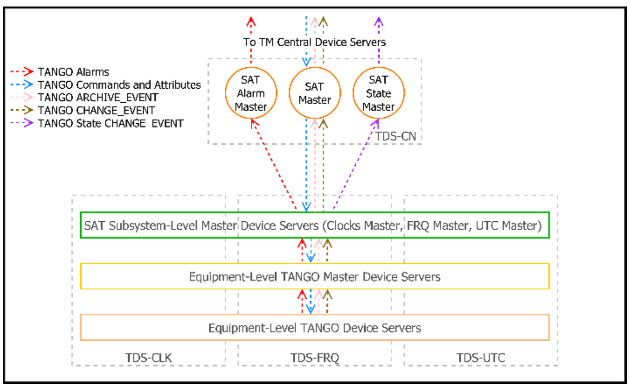

Figure 4: SAT.LMC Communications.

Control commands are passed using TANGO Commands and by setting TANGO Attributes from the topmost device servers to the lowest level device servers. Monitoring uses TANGO Commands to query the equipment monitored and stores the results within TANGO Attributes. SAT.LMC uses TANGO ARCHIVE_EVENTs that are triggered when a TANGO CHANGE_EVENT is detected. Both these TANGO Events flow bottom-up from the lowest-level TANGO Device Servers to the TM Central Device Servers. SAT.LMC relies on TM for all data storage.

SAT.LMC uses TANGO Attributes – min_alarm, min_warning, max_warning and max_alarm for setting the quality factors – ATTR_ALARM, ATTR_WARNING and ATTR_VALID. These attributes are initialized with appropriate values across all TANGO devices that SAT.LMC monitors. For alarms that are not based on verifying ranges, business logic within TANGO Device Server code is inserted to set the quality factors. All event communications take place using the publish-subscribe pattern.

SAT.LMC uses the TANGO Logging Service (TLS) to log messages at different levels and the TANGO Log Viewer utility to view TANGO Logs.

At southbound, the TDS-CLK software application interfaces with all the different Clocks equipment using custom application protocols for differing equipment. In 80% of the cases, the mechanism is query-response. The TDS-FRQ software application interfaces with the FRQ subsystem. The FRQ subsystem sends a 48 Byte byte stream every second to SAT.LMC. This byte stream, containing information regarding the FRQ equipment, is then parsed by the TDS-FRQ into attributes, analysed for event/alarms/warnings and then forwarded to TM. The TDS-UTC software sends Simple Network Management Protocol (SNMP) commands to the WR equipment to obtain the Object Identifier (OID) values from the WR equipment. The values are then stored as attributes within the TDS-UTC application.

At the northbound, the TDS-CN software application interfaces with the TM Central Device Servers using the publish-subscribe pattern. Though SAT.LMC generates data, it relies on TM for all its storage requirements.

Technology Architecture

SAT.LMC is predominantly a software solution and uses the TANGO Control System Framework to achieve its functionality. Along with TANGO, there are other technologies that SAT.LMC leverages to achieve its core functions. Table 1 below lists the various software technologies used in the SAT.LMC solution.

Table 1: SAT.LMC Software Technologies

Function	**Technology**
Implementation Language	Python
Application Isolation	Dockers
Operating System (OS)	Ubuntu Linux
OS Base Image	Ubuntu, Debian or CentOS
TANGO Database	MariaDB

The SAT.LMC technology stack is shown in Fig. 5 below.

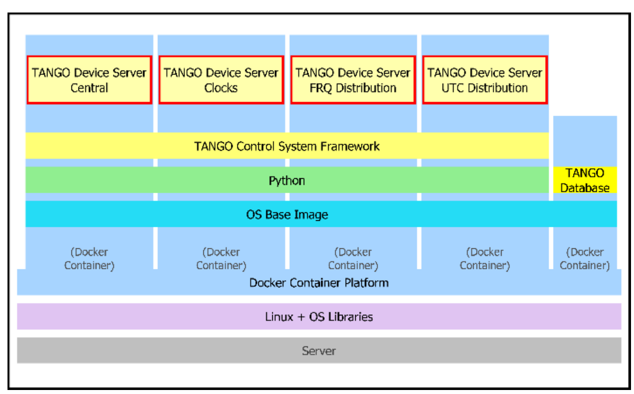

Figure 5: SAT.LMC Technology Stack.

The SAT.LMC software applications run on a single industry-class server machine (one for each telescope) housing the Linux OS at the Central Processing Facility (CPF) of each telescope. The choice of Linux OS is a result of the TANGO community support available for Linux platform.

Docker [6] is chosen as the preferred containerization platform. The Docker containerization platform forms an

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important supporting software application to achieve isolation between the 4 application software products. Each container houses one of the 4 software applications and its associated dependencies and the fifth container houses the TANGO Database. MariaDB [7] is the preferred choice for implementing the TANGO configuration database. Containers is chosen due to the robust and simple application isolation it provides, light-weight nature and faster deployments across environments (as opposed to virtual machines). Each container contains the TANGO Control System Framework (including the supporting middleware libraries), the Python [8] interpreter and its supporting libraries to interpret the device server code and an OS base image consisting of the necessary OS libraries. While building a Docker container, Docker re-uses the software that is used for building an earlier Docker container. Thus the TANGO Control System Framework, Python and the OS base image are re-used while creating the other containers.

SAT.LMC uses a network of cables and switches provided by the Non-Science Data Network (NSDN), part of SaDT consortium to communicate with TM and SAT subsystems. Figure 6 below shows the logical connectivity of SAT.LMC solution with SAT and TM using NSDN.

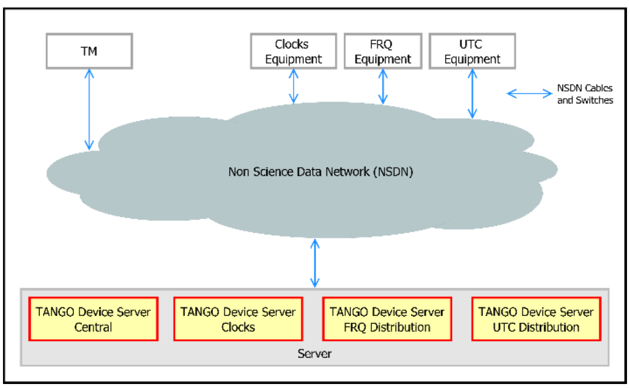

Figure 6: SAT.LMC-NSDN-SAT Logical Connectivity.

PROTOTYPE

The prototype work for SAT.LMC [9] was undertaken over a period of 1 year involving TANGO usability study with respect to SAT.LMC functions, study of various TANGO tools (JIVE, POGO and ASTOR) and integrations with representative equipment of the three SAT subsystems (CLK, FRQ and UTC) / TM. Python was the preferred language for prototyping due to ease of programming and TANGO support available. Along with verifying the fitness of SAT.LMC solution with TANGO, performance tests were also performed.

The TANGO Control system and its various concepts were studied. The SAT.LMC hierarchical solution, consisting of the various device servers was coded in Python language and verified. SAT equipment simulators were written to help verify the SAT.LMC hierarchical solution, data flow, events and alarm cascading. A TM simulator was written to interface the SAT.LMC solution at the northbound. Towards the end of in-house tests, TANGO was found to be conforming to the SAT.LMC design requirements. In the process, feedback was shared with representatives of LMCs and TANGO community with regards to improvement of the TANGO documentation and TANGO tools.

Subsequent to the successful in-house interface tests with the SAT simulators, field interface tests were carried out with representative SAT equipment - Hydrogen Masers belonging to National Physical Labs (NPL) UK, Communication Control Module belonging to e-MERLIN Telescope UK and WR Switch belonging to Joint Institute for VLBI in Europe (JIVE) Netherlands. The results of the field interface tests were positive with SAT.LMC TANGO commands being successfully sent across long distances and responses received as expected.

Alarm latency tests to verify the SKAO Level 1 requirement (SKA1-SYS_REQ-2312: Latency from the time a measurement crosses an alarm setpoint until the time it is signalled to the operator shall be no more than 1 second) were performed with the TDS-FRQ software application interfacing with the Communication Control Module simulator. It was verified that the difference between the time at which the alarms were triggered and the time at which alarms were available with the top-level device server within TDS-FRQ were well within the limits (approximately 1 ms) of the SKAO alarm latency requirement of 1 s.

SAT.LMC TANGO solution was verified with Docker containerization platform. As part of the verification, SAT.LMC application products were containerized and integrated with SAT and TM simulator. Events, warnings, alarms were recorded and logs observed. The verifications demonstrated that the SAT.LMC TANGO solution worked as expected with Docker containers.

All in-house and field tests were carried out with the SAT.LMC solution being developed and housed at National Centre for Radio Astrophysics (NCRA)/Giant Metrewave Radio Telescope (GMRT) [10] India, Jodrell Bank Centre for Astrophysics - The University of Manchester (UMAN) UK, South African National Research Network (SANReN) SA and Science and Technology Facilities Council (STFC) UK.

The SAT.LMC technology stack is verified as a result of the in-house and field tests.

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