





### M&C STRATEGY TO PROCEED TO THE NEXT PHASE

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## TABLE OF CONTENTS

### Contents

<b>1</b>	<b>INTRODUCTION .....</b>	<b>7</b>
1.1	Scope of the document .....	7
1.2	Purpose of the document .....	7
1.3	Introduction to the Monitoring and Control System for the SKA .....	7
<b>2</b>	<b>REFERENCES .....</b>	<b>8</b>
<b>3</b>	<b>OVERVIEW .....</b>	<b>9</b>
3.1	SKA Phases and Milestones .....	9
3.2	SKA Work Packages .....	10
3.3	Different stages of the work .....	11
<b>4</b>	<b>THE DEFINITION PHASE .....</b>	<b>13</b>
4.1	Towards the SRR.....	13
4.2	Plugging the Gaps.....	14
4.2.1	Gaps within WP2 .....	14
4.2.2	Gaps outside WP2 .....	14
4.2.3	Gaps due to incomplete system definition .....	14
<b>5</b>	<b>BEYOND THE SRR : THE PRE-CONSTRUCTION PHASE .....</b>	<b>15</b>
5.1	M&C effort estimation .....	15
5.2	Intelligent Resource Management.....	22
5.2.1	<b>Opportunity for savings in operational costs .....</b>	<b>22</b>
5.2.2	Proposal for the next phase of work:.....	22
<b>6</b>	<b>OVERALL M&amp;C COST ESTIMATES .....</b>	<b>23</b>
6.1	M&C development for SKA1 .....	24
<b>7</b>	<b>THE ROLE AND POSITION OF M&amp;C IN THE SKA EFFORT:.....</b>	<b>25</b>
7.1	Positioning of M&C in the overall SKA context .....	25
7.2	Indian Participation in M&C and Outlook for the Future.....	26
<b>8</b>	<b>APPENDICES : .....</b>	<b>27</b>

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## LIST OF FIGURES

Figure 1: SKA top level phases and milestones .....	9
Figure 2: SKA Work Packages .....	11
Figure 3: SKA Phases, Reviews and Baselines.....	11

## LIST OF TABLES

Table 1 : List of M&C tasks in the PEP .....	15
Table 2 : SKA top level schedule.....	27

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## LIST OF ABBREVIATIONS

AD	.....	Applicable Document
ASKAP	.....	Australian SKA Pathfinder
CoDR	.....	Concept Design Review
CDR	.....	Critical Design Review
LOFAR	.....	Low Frequency Array
M&C	.....	Monitoring and Control
NCRA	.....	National Centre for Radio Astrophysics
PEP	.....	Project Execution Plan
PDR	.....	Preliminary Design Review
PrepSKA	.....	EU FP7 SKA development program
SKA	.....	Square Kilometre Array
SKA1	.....	SKA Phase 1
SKA2	.....	SKA Phase 2
SPDO	.....	SKA Program Development Office
SRR	.....	System Requirements Review
TBC	.....	To Be Confirmed
TBD	.....	To Be Determined
TBF	.....	To Be Filled In
TBW	.....	To Be Written
WP	.....	Work Package

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## GLOSSARY

**Central M&C:** The portion of the M&C system that is located at the Operations & Maintenance Centre, and is responsible for the management of the system as a whole, rather than a portion of it.

**Domain M&C:** An auxiliary M&C system that manages resources belonging to a particular domain e.g. signal transport equipment, power equipment. This is developed (or acquired) by that domain and is outside the primary M&C hierarchy.

**Entity:** A generic term that might span any granularity from Element to Component to Part.

**Local M&C:** The lowest tier of the monitoring and control hierarchy, that provides control and monitoring capabilities for a particular Component, such as a receptor, power equipment, signal transport equipment, beamformer, correlator etc. Local M&C may itself be hierarchical, and function semi-autonomously; it interfaces to the sensor and actuator hardware, and provides all necessary control, monitoring and exception handling capabilities for the Component. It also provides monitoring data to Regional M&C and operates in response to commands from the Regional M&C node to which it is connected. Alarms may also be propagated up the chain from Local M&C to Regional M&C to Central M&C to human operators for handling.

**Monitoring points:** Data items (including logs and reports), alarms or events that are forwarded up the system periodically or on-occurrence from the point of origin. Monitoring points may be processed, combined or abstracted by receivers to generate new monitoring points.

**Regional M&C:** M&C functionality that has primary responsibility for the management of a portion of the system. This could be a station, a portion of the Core, or the collection of sensors and actuators in the system that is not associated with any station or Core.

# 1 Introduction

## 1.1 Scope of the document

This document relates to the Phase 1 SKA Monitoring and Control Domain Element and its Sub-elements. It is of a maturity commensurate with a Concept level of definition of the M&C Domain and the SKA Observatory as a whole.

## 1.2 Purpose of the document

The purpose of this document is to describe the strategy to move to the next SKA element level engineering phase for the monitoring and control aspects of the project, the definition phase.

In support of the purpose of the document the following aspects are covered:

- List high level milestones
- Identify the gaps at the CoDR
- Identify the activities to address gaps
- Identify activities to mitigate risks
- Identify activities in heading towards the next review, the SRR
- Project the activities beyond the SRR, and outline the effort that may be required for the PEP phase

This M&C Strategy to Proceed to the Next Phase document is part of a document series generated in support of the M&C CoDR. This document set includes the following:

- |   |                         |
|---|-------------------------|
| • M&C CoDR Review Plan                                      | WP2-005.065.020-PLA-001 |
| • M&C High Level Description                                | WP2-005.065.020-TD-001  |
| • M&C Element Level Requirements                            | WP2-005.065.020-SRS-001 |
| • M&C Design Concepts Description                           | WP2-005.065.020-TD-002  |
| • M&C Element Design Concepts Summary                       | WP2-005.065.020-TD-003  |
| • M&C Element Level Risk Register                           | WP2-005.065.020-RE-001  |
| • M&C Strategy to Proceed to the Next Phase (this document) | WP2-005.065.020-PLA-002 |

## 1.3 Introduction to the Monitoring and Control System for the SKA

The monitoring and control system for the SKA forms the nervous system of a very complex telescope that combines millions of hardware elements with complicated software to stream and process prodigious volumes of science data. Successful orchestration of all components of the SKA system to perform scientific observation of the required quality is the key goal of the M&C system. The SKA telescope will be spread over a vast and remote area. It will be built incrementally and operated for decades. This poses enormous challenges for the design of the M&C system.

In the PrepSKA framework, the concept design of the M&C system is being carried out as part of Work Package 2.1.5 (Monitoring and Control) which is a sub-package of WP 2.1 (System Design) which in turn is part of Work package 2 (SKA Design). The 2.1.5 work package has a mandate to focus on all aspects of the M&C system for the SKA. Guidance is being provided from the system level to ensure that the M&C system remains coherent and incorporates the complete set of requirements. At this concept design phase, the emphasis is on gathering a representative set of requirements that are complete enough for concept designs to be evaluated against.

Within WP2, progress on the Monitor and Control task, was slow in the first part of the WP2 PrepSKA project. In January 2011, the National Centre for Radio Astrophysics in Pune, India, took over the role of lead institution for this task and reinitiated work on PrepSKA package 2.1.5 in collaboration with the SPDO and Indian industry. M&C team members from ASKAP, LOFAR and MeerKAT contributed documents from their respective projects and provided

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review comments for this document set. It is anticipated that the monitor and control system requirements on the monitor and control network will be refined as we work towards the SRR at System level.

## 2 References

The following documents are referenced in this document :

- [1] 'Strategy to to Proceed To The Next Phase', K. Cloete, WP2-005.010.030-PLA-002, 15 Feb 2011.
- [2] 'Project Execution Plan – Pre-Construction Phase for the Square Kilometre Array (SKA)', R. T. Schilizzi et al., SKA Document -- MGT-001.005.005-MP-001, Rev K.
- [3] 'PrepSKA FP7 Work Package 2 Project Plan', K. Cloete et al., SKA Document -- MGT-040.030.002-PLA-001, Rev I, 16 Feb 2011.
- [4] 'System Engineering Management Plan', T.J. Stevenson, SKA Document -- WP2-005.010.030-MP-001, Revision F, 15 Feb 2011.
- [5] 'SKA Phase 1 System Requirements Specification', T. Stevenson et al, SKA Project Document – WP2-005.030.000-SRS-002, February 2011, Rev B.
- [6] 'The Square Kilometre Array Design Reference Mission: SKA Phase 1', January 2011, Rev v1.3.
- [7] 'Strategies and Philosophies', K. Cloete et al, document WP2-005.010.030-TR-001, February 2011, Rev F.
- [8] 'Monitoring and Control Element Level Requirements', document WP2-005.065.020-SRS-001.
- [9] 'Monitoring and Control Design Concepts Description', document WP2-005.065.020-TD-002.
- [10] 'Monitoring and Control Design Concepts Summary', document WP2-005.065.020-TD-003.
- [11] 'Monitoring and Control High-level Description', document WP2-005.065.020-TD-001.



### 3 Overview

This section presents a high level overview of the SKA project and its milestones to provide the appropriate context for the M&C domain. The overview includes:

- Identification of the SKA Project Phases
- Identification of top level SKA milestones
- SKA Work Package breakdown and the position of M&C in the same

Further detail is provided in the system level documentation [1].

#### 3.1 SKA Phases and Milestones

Figure 1 provides a time line for phases of the project and identifies the top level milestones of the project. The current top level schedule for the SKA is presented in the Appendix of this document.

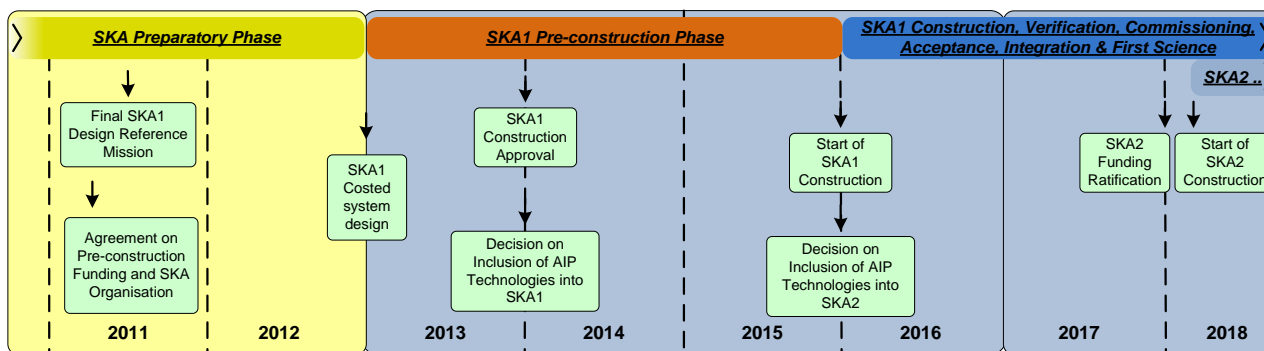


Figure 1:SKA top level phases and milestones

The phases include:

- Preparatory phase (current phase)
- Pre-construction phase
- SKA1 construction, verification, commissioning, acceptance, integration & first science
- SKA2 construction, commissioning, acceptance, integration & first science
- SKA Operations

##### 3.1.1 Preparatory Phase

During this phase and within Work Package 2 of the project [3], organisations from around the globe are working under the guidance and co-ordination of the SPDO to define and deliver a costed system design for SKA1. Several verification programs form part of this phase with the main aim to deliver preliminary designs for particular elements of the SKA1 such as the dish and the low frequency aperture array receptors.

During this phase several milestones must be achieved, and the phase will be concluded with the delivery of the costed system design for SKA1 and the deployment plan for the full SKA.

Although the preparatory phase will not have been completed, the structure described above will be replaced by the end of 2011 with the establishment and transition to the SKA Project Office (SPO) (see [2] for more details)

Significant events for the M&C domain during the Preliminary phase are:

- The SPDO will transition to the SPO.
- There will be a decision about the site for the SKA.

- There will be a CoDR for the Software & Computing Domain, which has a close relationship with the M&C domain.
- At the end of the preparatory phase the M&C Domain will conduct an SRR.
- Decisions on detailed allocations of work packages for the Pre-construction phase will be taken.

### 3.1.2 Pre-Construction Phase

During this phase large scale engagement with industry will start. The preliminary designs of SKA1 delivered during the preparatory phase will be 1) utilised to solicit proposals from industry for the supply of these elements and 2) used as inputs for the refinement and detailed design of the elements. Although not strictly part of the pre-construction phase, depending on the level of funding available, preliminary production units will be developed, built and tested for elements that have been identified as having achieved sufficient technical readiness during this phase [2].

Significant events for the M&C domain during the Pre-Construction phase are the following:

- The M&C Domain will likely conduct a PDR and a CDR
- Other domains with which M&C has close interactions/interfaces will conduct their PDRs/CDRs
- Construction and testing of prototypes of various sub-systems will begin, requiring M&C functionalities

### 3.1.3 SKA1 Construction, Verification, Commissioning, Acceptance, Integration & First Science

During this phase the SKA1 equipment will be rolled out on site, integrated, tested, accepted and commissioned. It is critical that a functional M&C system be available for these purposes. Early science observations will be conducted as soon as the array is large enough and will be grown as the array is enlarged during construction and more and more collecting area becomes available.

### 3.1.4 SKA2 Construction, Commissioning, Acceptance, Integration & First Science

During this phase the roll out of equipment is escalated to achieve the levels necessary for completion of the array by the end of 2022.

## 3.2 SKA Work Packages

Within the current preparatory phase of the SKA project, the work is broken down into seven top level work packages which are identified in Figure 2. Of these, the technical work packages are overseen by a domain specialist at SKA Program Development Office (SPDO), based in Manchester. It is the domain specialist's responsibility to oversee and coordinate the work, and execute some of it directly. Work package WP2, which relates to the bulk of the technical design activities, is further broken down into smaller work packages, relating to the following technical domains:

- WP2.1 – SKA System
- WP2.2 – Dish Verification program
- WP2.3 – Aperture Array Verification program
- WP2.4 – Signal Transport and Networks
- WP2.5 -- Digital Signal processing
- WP2.6 -- Software and Computing
- WP2.7 – WP2 design study management

Within these, Monitoring & Control has been defined as part of work package 2.1 (SKA System Design). This document will describe the strategy to proceed to the next phase for WP2 work package 1.5 (WP2.1.5), SKA Monitoring & Control.

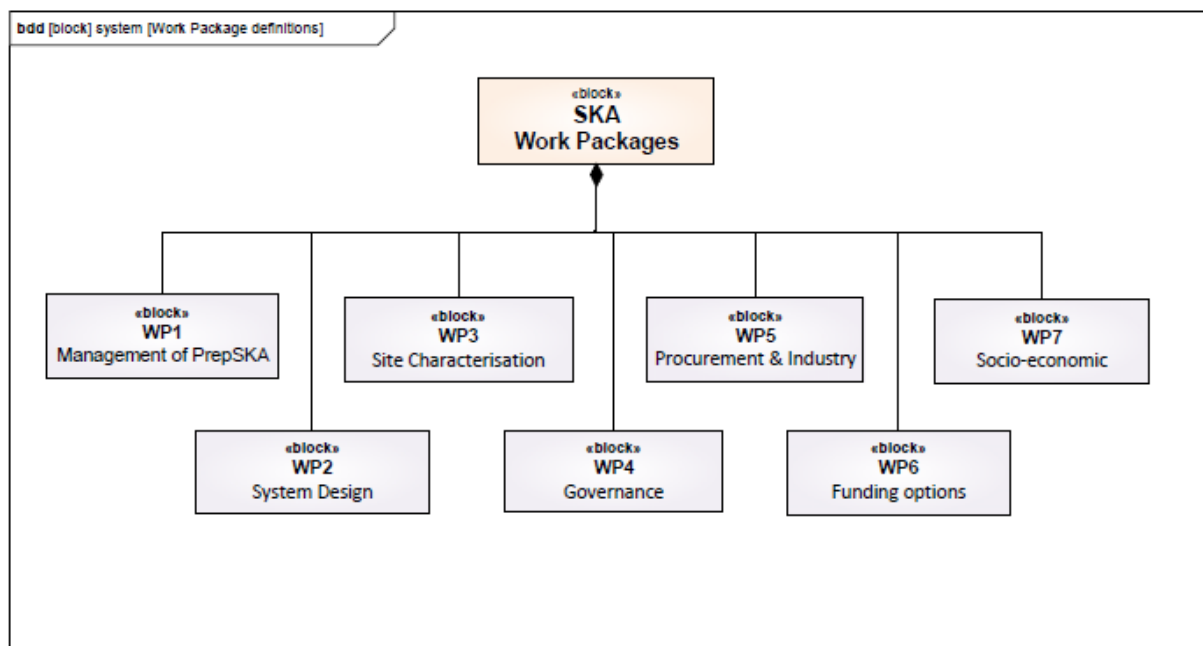


Figure 2: SKA Work Packages

Although the preparatory phase will not have been completed, the structure described above will be replaced by early 2012 with a new set of work packages drawn up under the PEP plan of the Pre-construction phase [2]. We expect that M&C will retain its position under the System Design Work Package (see also section 7 of this document).

The Monitoring & Control CoDR will focus on work that has been performed against these work-packages with a focus on phase 1 of the SKA project whilst keeping in mind extensibility to SKA2. Details with regards to the WP2 objectives and work are presented in [3]. In summary, the primary objective is to produce a detailed costed system design for the different aspects of SKA1, supported by a deployment plan for the full SKA. It is towards this goal that all the effort is directed, with the establishment of the conceptual baseline following the successful completion of the CoDR as the first and important milestone on this road.

### 3.3 Different stages of the work

As part of the detailed description of work, the phases, design reviews and baselines that have been identified for the SKA project are shown in Figure 3. The milestone reviews are briefly described below:

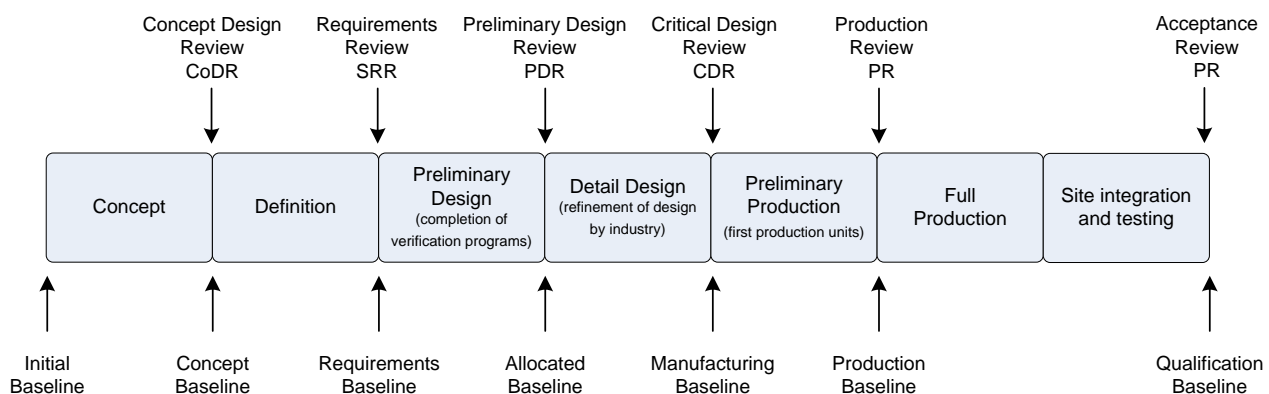


Figure 3: SKA Phases, Reviews and Baselines

### 3.3.1 Concept Design Review, CoDR

The purpose of the CoDR is to review potential solutions against systems requirements. The outcome of the review will provide recommendations on how to proceed in terms of which of the solutions presented are judged to have potential and are worth investigating/developing further, and weed-out those solutions that have fundamental or technical problems. In addition, if potential solutions are not presented for particular problems, the recommendations would also point those out as requiring further detailed investigation.

### 3.3.2 System Requirements Review, SRR

The SRR, conducted at the end of the definition phase, will primarily review the definition of the specific building item as reflected in its relevant Requirement Specification. The review will typically be conducted after the conclusion of the requirement analysis and validation activities.

As detailed in the System Engineering Management Plan [4], delivered SRR outputs to be reviewed at this stage will include:

- Report outlining the findings of the investigations of the candidate technology options as well as statements and justifications of the selected baseline option to be carried forward
- Finalised requirement specification (including the cross verification matrix indicating the kind of tests to be performed for each of the requirements)
- First draft of Interface Control Documents (internal and external)
- First draft of the Architectural Design Description document
- First draft acceptance test plan/procedure
- Updated risk register and related mitigation strategies
- Updated block diagram of the relevant systems, elements or subsystems
- Updated requirements traceability matrix/database
- Strategy and plans for proceeding to the next phase
- Updated cost, schedule, power and reliability estimates
- Logistical and software documents (to be defined)
- First draft of the health and safety plan

The output of this review is a well defined item at the project level at which it is being performed.

### 3.3.3 Preliminary Design Review, PDR

The PDR will be conducted at the end of the preliminary design phase and is aimed to review and confirm the final design of the item as reflected in its relevant Architectural Design Description Document. The review will be performed at the conclusion of the functional analysis, verification, synthesis and design verification activities at the end of the preliminary design phase.

As detailed in the System Engineering Management Plan [4], delivered PDR outputs to be reviewed at this stage will include:

- The final, revised Requirements Specification
- Final Architectural Design Description document
- Final Interface Control Documents (internal and external)
- Final block diagram
- Acceptance test plans and procedures
- First draft integration plan
- Updated requirements traceability matrix/database
- Consumables, spares and test equipment
- Updated risk register and relating mitigations strategies
- Upgrade plans
- Roll out/build plans

- 
- Logistical and software documents (to be defined)
  - Audit of manufacturing data packs for designs to be carried forward (if applicable)
  - Final health and safety plan

Together, the above set of documents must reflect the fully costed design of the item. The output of the review will be a fully designed item at the project level at which it is being performed at.

### 3.3.4 Critical Design Review, CDR

The CDR will be performed at the end of the detailed design phase and will determine whether the item under review is ready to enter the preliminary production phase.

As detailed in the System Engineering Management Plan [4], delivered CDR outputs to be reviewed at this stage will include:

- Confirmation of the requirement specifications and design description baseline
- Review of all aspects of the production process as well as the supporting documents
- Review of test and verification plans/procedures
- Review of updated risk registers
- Presentation of final design data on costs, power, reliability etc.
- Review of integration and test plans

The exact details of this phase will be developed and expanded during PrepSKA.

## 4 The Definition Phase

After successful completion of the CoDR, the M&C work will enter the definition phase (as shown in figure 4), leading to the SRR. The aim of the definition phase is primarily to perform requirements analysis and validation to ensure that the complete set of requirements is understood and is present [4]. Gaps will be identified and actions to address these shortcomings will be initiated. The result of these activities will be captured in the relevant Requirements Specification to be reviewed at the conclusion of this phase.

The technology option(s), as confirmed during the CoDR, will be investigated in more detail. Further prototyping and testing may be done and analyses and simulation work will continue. Studies of trade-offs between the possible solutions will be performed in order to identify and select a preferred solution. The trade-offs will include aspects and inputs from the tiers above and below. It is recognised that for some elements or subsystems it may not be possible to arrive at a preferred solution during this phase and that more than one solution might be carried forward to the next phase.

The next section provides an overview and some details of the strategy to proceed from the CoDR towards the SRR.

### 4.1 Towards the SRR

The main jobs and tasks identified for the M&C systems readiness for the SRR are as follows:

- Finalising the System level requirements specification (including the cross verification matrix indicating the kind of tests to be performed for each of the requirements)
- Detailing the requirements allocation/flow-down to M&C domain/element including verification planning
- Drafting sub-element level requirements and specifications documents for the M&C system
- Working on the standards identification and analysis activities
- Participating in the architectural design derivation at the system level
- Proposing one or more M&C architectures and identifying the tasks required to carry through these designs
- Identifying any high risk technologies and detailing the scope of the work required to develop these in detail

- 
- Identifying M&C interfaces and producing first drafts of the interface control documents
  - Identifying data exchange interfaces with other sub-systems
  - Drawing up a detailed plan for the creation of a common software platform along with the Software and Computing domain
  - Working out a detailed program for possible industry involvement in the next phase of the M&C work
  - Updating the risk register and detailing further mitigation strategies

## 4.2 Taking care of gaps

A gap analysis of the M&C system has been presented in the High Level Description document [11]. In short, this identifies gaps in the project which are of 3 different categories. Given below are the action items required to address some of these gaps before the SRR:

### 4.2.1 Gaps within WP2

- A number of data exchange interfaces need to exist between the science data path and the M&C system as the science data flow all the way from the receptors to the correlator, so that the telescope can be dynamically configured to meet science requirements. These have not been understood adequately, and this will be one of the major issues that will need to be addressed for the SRR.
- Overall, a better understanding and definition of M&C interfaces with the other systems/domains is required for the SRR phase.

### 4.2.2 Gaps outside WP2

- In the absence of a reasonably detailed concept of an operations plan, it has been difficult to define the interface between M&C and the topmost tier of the system hierarchy e.g. role based user interfaces can only be designed once such roles are clearly defined. We believe that developing a comprehensive lifecycle view of telescope operations should be an important priority in the next phase of the project. The M&C team will need to spend some time and effort in this direction, working closely with the team working on the operations plan within the Systems work package.
- Data traffic in the M&C system is very uncertain at the present time. Although we believe that these data volumes can be comfortably handled by the SKA network infrastructure, a quantitative estimation of data volumes is necessary, to put the matter beyond reasonable doubt. The detailed numbers will need to be worked out, in consultation with other relevant domains where needed.
- A number of radio telescopes -- the SKA pathfinders and precursors -- are presently under construction which are likely to generate learnings relevant to SKA over the next few years. Although we have studied the design documents of the M&C system of such telescopes in some detail, the learnings in terms of the pros and cons of the design decisions will only become apparent over some period of time. The M&C team will need to spend time and effort to gather and digest learnings from the precursor projects.

### 4.2.3 Gaps due to incomplete system definition

- There are gaps due to incomplete System definition, and some of these are reflected as “orphan” requirements in the M&C Element level Requirements Document [8]. Work will be required to identify as many missing requirements as possible in time for the SRR, and include these in an appropriate manner in the System requirements.
- Furthermore, the site for the SKA is yet to be finalized. Environment regulations vary a lot from country to country. Any compliance requirements imposed on M&C and other systems by such regulations can only be

determined once the site is finalised. New requirements and constraints may need to be brought into consideration once the site selection is finalised. This is expected to happen before the SRR.

- Scalability in the context of SKA addresses the question of whether the system architecture, interfaces and application components allow performance to increase reasonably linearly with the addition of components. A better understanding of these aspects needs to be carried out. This will become easier as the M&C requirements of the other domains become better defined.

## 5 Beyond the SRR : The Pre-construction phase

This section outlines the road to be followed for M&C work during the rest of the Pre-construction phase, as part of the PEP. This includes an estimate of the total effort required, in terms of staff days, from the CoDR onwards (including the SRR stage). Note that these are preliminary estimates at this point of time, and will get refined and firmed up much better by the time of the SRR. This section also includes a proposal for a new research initiative in Intelligent Resource Management during the PEP phase, which we show could be extremely beneficial for the SKA project.

### 5.1 M&C effort estimation

During the PEP phase, the M&C domain must produce the following deliverables:

- Complete requirements definition, for the System Requirements Review
- Firmed-up architecture and preliminary design for the Preliminary Design Review. This includes
  - Architecture decisions, modelling and analysis.
  - Definition and documentation of the Standardized Component Interface, since it will affect design and procurement of all SKA Components.
  - Standardized technology choices for M&C hardware, to minimize inventory and expertise issues during operations. This also has project-wide impacts, since most sensors, actuators and fieldbuses will be part of Components in other domains.
  - Choice of M&C software platform and design of deployment aspects.
  - Definition of integration interfaces, common data formats, common software libraries and operations support databases to establish clear connects with other domains.
  - Design of internals of M&C solution, including addressing critical quality attributes.

A preliminary design for the M&C system must be available by the end of the PEP, to facilitate testing of Component M&C systems. During this period, the following activities (listed as Table 1) must be carried out:

**Table 1 : List of M&C tasks in the PEP**

Sr No.	Task/Deliverable	Sub Tasks description	Interaction	Order of magnitude effort estimate (staff months), other costs & explanatory notes	
1	<b>SRR</b>				
	Report outlining the findings of the investigations of the candidate technology options and statements and justifications of the	Investigation and characterization of alternative technology choices for sensors/actuators, fieldbuses, data acquisition boards, software platform.	Technology vendors, precursor projects	12	
		Building exploratory prototypes to investigate scalability of each	Software platform vendors	24	(prototype development)



	selected baseline option to be carried forward. (SRR)	software platform. Determining the feasibility of alternative software platform architecture (separate namespaces with brokers to deal with potential scale issues) by developing a prototype implementation.			effort, including learning). Licenses and training costs.
		Setup of evaluation criteria for each area, in collaboration with all stakeholder domains. Evaluating and selecting technologies for each area, and obtaining agreement on the choice.	Other domains, System, project office, community.	12	(mostly on interactions and consensus building)
	Finalised requirement specification (including the cross verification matrix indicating the kind of tests to be performed for each of the requirements)	Further requirements analysis and interactions with other domains to establish the M&C requirements, in particular the types of Components, likely number of monitoring points associated with different Component types and special needs for M&C interactions.	Each of the other domains. System.	12	(~2 staff months per domain, including detailed responsibility and boundary definitions and reaching agreement)
		Understanding other requirements, including regulatory requirements, operations support requirements, reporting requirements etc.	System, site	8	(need to work closely with System Operations team)
		Developing detailed requirements documentation and building tool-based requirements models.	Reviews by Software Computing, community.	20	(mostly on models creation). Licenses and training costs.
	First draft interface control documents (internal and external)	Development of the Standardized Component Interface, including developing principles, guidelines and common requirements, prototyping and analysis of impacts on Component procurement	Other domains	15	(Includes identifying areas to be covered, obtaining agreement)
		Guidance documentation on Standardized Component Interface. Local M&C development	Other domains	10	(Good guidance can minimize integration issues)
		Preliminary design of the various operational integration interfaces, including metadata interface, scheduling system interface, science path parameter exchange,	Other domains	15	(at least 3 staff months per interface)



		domain M&C interfaces, resource request interfaces etc.			
	First draft of the architectural design description document	Analysis of architectural variation points, making architecture decisions		6	
		Elaboration and selection of architectural principles and mechanisms.	System, Software & Computing	10	(Detailing of architecture)
		Architecture modelling using SysML		15	Licenses and training costs.
		Documentation of preliminary architecture and design	Reviews by community.	20	(Includes detailing of preliminary design)
	First draft acceptance test plan/procedure	Test plan containing the overall test strategy for various kinds of testing (unit, integration, system testing, user acceptance, factory acceptance, migration testing, regression testing, stress testing, reliability testing etc.).	Reviews by community.	25	Not only M&C testing, but also Local M&C acceptance and certification testing for all Components. Integration procedures design.
		Specifications suggesting the creation of the test cases for various kinds of testing including test scripts. Guidance for the generation of the reports on testing.		5	Output is a guidance doc for developers.
	Updated risk register and related mitigation strategies	Identification of perceived risk, area of impact and contingency plans.		2	
	Updated block diagram of the relevant system, element or subsystem	Identification of the types of sensors and actuators that will be needed throughout the system; elicitation of requirements for these sensors and actuators from different domains, to establish common baselines that can serve as a basis for standardization.	Other domains, precursor projects	10	Will involve interactions with domains and providers to agree on common tech choices in this area.
		Definition of common data	Software	5	

		formats in collaboration with Science Computing and System Operations	&Computing, System		
		Preliminary design of the Common Software Library in collaboration with Science Computing	Software & Computing	6	
		Preliminary design of operations support databases and integrations	System, Software & Computing	10	
		Generic M&C node design and prototyping. This is the actual entire internal design of the M&C system.		40	
	Updated requirements traceability matrix/database	Provides links to system requirements, design, and system test cases/scripts.		6	Intensive on documentation , tool use and reviews.
	Strategy and plans for proceeding to the next phase	Development of processes and materials for guiding Local M&C development and certification of work product. Testing and simulation approach design (Based on Software & Computing governing inputs).		6	(Mitigate quality & integration risk due to distributed development of M&C solution)
	Updated cost, schedule, power and reliability estimates	Estimation, sizing and evaluation of choices for M&C hardware platform and design of associated deployment aspects.	System, Software & Computing	12	Includes failover and other deployment aspects.
	Logistical and software documents (to be defined)	Design of approach for M&C aspects of integration and commissioning. Design of scheme to facilitate continuous commissioning and upgrades without disruption to operations.	System	6	Architectural support for the commissioning process.
		Master document list (MDL) is an index of all deliverables and their location. This includes the supporting documentation, and may also include additional system references.		12	Includes all preparatory & administrative work for each of the three meetings.
	First draft health and safety plan	Development of fault trees for M&C reliability and availability analysis. Reliability & availability design.	System, community	8	(Includes fault management design)

		Development of workload models. Software platforms benchmarking. Performance analysis.	System, other domains	6	(May need to build performance models)
		Definition of safety threat models and security threat models. Development of performance requirements, including analysis of feasibility. Development of user interface support requirements.	System, Software & Computing, community.	12	(~4 staff months per area)
		Feasibility study of service capability matching and QoS composition, including prototyping	Need research collaborators.	10	Funding for research collaboration.
2	<b>PDR</b>				
	Revised and final requirements specification	Includes reviews, comments processing and all the associated work to finalize requirements.		6	
	Final architectural design description document	Architecture document shall identify interaction between components, the design styles, tools and technologies implementing the final system, the schemes for achieving properties and behaviours such as failover, scalable data processing, QoS and system integrity management, and how software and platform capabilities work together to achieve the desired behaviour.		12	Includes all the effort for diagramming and document creation. Creation of architectural views and design diagrams is highly iterative and effort intensive.
	Final interface control documents (internal and external)			4	
	Final block diagram			2	
	Acceptance test plans and procedures			3	
	First draft integration plan	The strategy to integrate components into the M&C framework.		6	Internal M&C development

					and integration.
		Exploration and identification of tools that may aid system integration.		3	
	Updated requirements traceability matrix/database	Depending on the various phases of the project the different types of requirements traceability matrix will be produced. But the one of primary interest will be traceability matrix for the system requirements.		4	
	Consumables, spares and test equipment	For M&C, this will primarily be identifying M&C support aspects and infrastructure needed for M&C testing.		3	
	Updated risk register and related mitigations strategies			2	
	Upgrade plans	M&C evolution strategy and analysis.		5	
	Roll out/build plans	M&C development plans.		3	
	Logistical and software documents (to be defined)	Glossary document defining common terms and acronyms used across the project deliverables.		1	
		User manual for component developers. It would allow system/component developers to integrate with the M&C infrastructure.		4	
		Platform configuration document suggesting the procedure to configure the M&C platform for operation/testing.		4	
	Audit of manufacturing data packs for designs to be carried forward	Unclear if this is applicable to M&C			
	Final health and	Collaboration with System on		4	

	safety plan	developing this.			
3	<b>CDR</b>				
	Confirmation of the requirement specification and design description baseline			2	
	Review of all aspects of the production process as well as the supporting documents (Manufacturing data packs).	For M&C, this is largely detailed design, plus deployment planning for M&C infrastructure and hardware.		6	
	Review of test and verification plans/procedures			6	
	Review of updated risk registers			2	
	Presentation of final design data on costs, power, reliability etc.			8	
	Review of integration and test plans			4	
	Total			456	

This represents 38 staff years worth of effort, over a 4 year period -- beginning of 2012 to end of 2015. This work must be completed during the PEP, since it leads to a preliminary design. A more refined estimate of these costs will be available at the time of the SRR.

The costs associated with this work include:

- People costs. Much of this work requires senior personnel, as it involves making architectural and design decisions that affect the entire project. Some of the tools-related work on modelling and prototype building could be done by relatively junior people with ~ 5-10 years' experience.
- Travel costs for meetings and collaborative work. Since M&C has extensive interfaces and relationships with every other SKA domain, there is a need for face-to-face interactions and meetings with many other parties in addition to long distance collaboration over telecom and email.
- Cost of software licenses for modelling and prototype building.

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## 5.2 Intelligent Resource Management

Apart from this work that is needed directly for the PEP, it is desirable to initiate a research effort in the area of intelligent resource management. SKA operating costs will be dominated by resource costs (power, computational resources). Intelligent resource management along the lines of SmartGrid, that exploits information about demand patterns, degrees of freedom in achieving goals, resource consumption profiles of devices, resource availability and cost patterns, has the potential to achieve significant savings in operational costs; however, this capability must be built into the M&C architecture. We need a research / advanced design program in this area to work out the capabilities and support that must be provided at all levels of the M&C system (sensors and actuators, local control loops, regional and central controllers, interfaces to external suppliers of resources etc.) to enable smart resource management. While this research has the potential to produce significant savings in operating costs for SKA, the resulting innovation would be much more widely applicable. National Instruments has indicated that they would have an interest in partnering with the SKA project for this work. Funding for this research / advanced design program should be included in the M&C budget.

### 5.2.1 Opportunity for savings in operational costs

SKA is intensive in its consumption of power and computational resources (processing power, storage, and communications). It is likely that there will be degrees of freedom in both the sourcing and consumption of these resources, including:

- Resources such as power, computing and communications will likely involve a combination of captive and externally sourced capabilities. Technology trends such as generation of renewable energy and virtualisation of computing infrastructure indicate the need to provide for possibilities beyond pure captive computing capabilities or grid-based sourcing of energy.
- Demand-based pricing of power and virtualized computing capabilities and SmartGrid-style interactions between consumer and provider are likely to become the norm, creating opportunities for dynamic optimisation of sourcing.
- Computing equipment increasingly operates in multiple modes with variable power consumption. Sensors and actuators may have degrees of freedom (e.g. sampling frequency, local vs. remote processing of data) in operating modes that generate different amounts of data and consume different amounts of power.
- Different observations and observational modes may have different needs for science performance parameters, creating degrees of freedom in resource consumption (some dimensions need not be pushed to the limit).
- The energy needs of devices may vary with ageing of their parts, and there may be opportunities to save costs by replacement of even non-defective parts that contribute to substantial resource inefficiencies, especially given the possibility that replacement parts may be newer models that are much more energy efficient.
- Environmental variations such as temperature may affect energy consumption e.g. for cooling.
- There are degrees of freedom in utilization of computational resources, including differences in archival and logging policies, performing particular computations remotely or locally, techniques such as compression that create trade offs between utilization of processing and communications resources etc.
- SKA will have enormous captive computing resources and perhaps even power generation capabilities. There may be opportunities to "sell" some of these resources during idle periods e.g. maintenance periods, weather and RFI-related downtime etc.

### 5.2.2 Proposal for the next phase of work:

Given this outlook and the long lifetime of SKA, it is highly desirable to build SmartGrid-style intelligent resource management capabilities into the SKA M&C architecture. This capability will have extensive architectural impact,

since the architecture must be designed to provide all the information flows needed to facilitate intelligent distributed decision-making. There are five kinds of information that need to be combined for decision-making:

- Knowledge of sourcing alternatives with associated time-dependent costs, characteristics and constraints.
- Knowledge of current and future demand patterns. SKA has an advantage here because observation schedules create high predictability of demand, which can be utilized to lower sourcing costs.
- Performance parameter targets associated with observations & activities currently in progress.
- Resource consumption profiles of current system entities.
- Available degrees of freedom in resource sourcing and consumption.

M&C must support the acquisition, flows, storage and access for all this information, as well as the provisioning of intelligent algorithms for the decision-making at various points in the system. Conceptualizing and building these capabilities into the system architectural framework will involve close collaboration between instrumentation providers, M&C architects and the System domain. National Instruments, a premier provider of instrumentation technology, has expressed preliminary interest in this problem. Systems architecture for Intelligent Resource Management is an emerging area that has the potential for benefits well beyond SKA. We strongly recommend that SKA should invest in this research/advanced design project.

## 6 Overall M&C cost estimates

This section attempts a rudimentary scoping of cost sources for the fully developed and deployed M&C system (as also described in document [10]). At this stage, it is very difficult to attempt an actual cost estimate; however the ingredients of cost can be identified.

The costs of M&C realisation come from several sources:

1. Detailed design and realisation of Regional M&C and Central M&C software, including integration interfaces.
2. Support to Local M&C and Domain M&C development teams.
3. Efforts for M&C integration and commissioning.
4. Cost of M&C computational infrastructure (processors, storage).
5. Cost of development of Local M&C systems.
6. Hardware costs for sensors/actuators, fieldbuses and data acquisition boards.
7. Cost of non-Component sensing equipment (weather sensors, security monitoring equipment etc).
8. Regional safety monitor, if an independent safety monitor for the region is considered desirable.

Of these costs, the first three items would be included within the M&C budget. The fourth item, computing infrastructure for M&C should probably be included in the M&C budget, though actual platform decisions and procurement are part of the Software & Computing domain. Development of Local M&C systems and associated sensor and hardware infrastructure will be part of the procurement of Components of which the M&C system would be a part, so its cost is included within other domains. It is unclear whether the cost of other sensing equipment would be part of the facilities domain. If a Regional safety monitor is deemed necessary that too would be part of M&C development costs.

The infrastructure costs to be included within the M&C budget include processors and storage, additional engineering efforts and materials needed for installation and deployment of M&C. The processing infrastructure costs depend on the number of monitoring points, which is not known at this time. If a node has  $N$  monitoring points, and a single processor is capable of handling  $M$  monitoring points, then the number of processors needed is

$(N / M + 2 + k)$ , where the 2 represents processors for control and the storage interface, and  $k$  represents a redundancy factor (typically 2 or more). With current technology,  $M$  is of the order of  $\sim 2000$  for PLCs and high-end processors (depending on complexity of processing and several other characteristics), but this can be expected to increase over time. The storage needs to be large enough to hold at least a month of engineering data, and possibly more. It is too early in the design to identify the materials needed for installation and deployment of M&C, given that much of M&C installation and deployment will be part of Components deployment.

This leads to the following preliminary breakdown of the cost sources for M&C development:

- People effort for
  - Engineering the M&C solution.
  - Development of M&C software. Testing, installation and deployment of the M&C solution.
  - Guidance and support to Local M&C development, including possibility certification.
  - Support for commissioning and deployment of other systems, since M&C will be central to all commissioning and integration efforts.
- Infrastructure costs. These will consist primarily of
  - Computing infrastructure in each region, including processors and storage. A preliminary order-of-magnitude estimate would be  $\sim 10$  processors and  $\sim 1$  PB of storage.
  - Associated networking, sensor and other infrastructure.
  - Computing infrastructure at Central M&C. This could be up to an order of magnitude more than at each region, depending on some of the choices and trade-off.
  - Sensor costs for any sensors that will be the responsibility of M&C.
- The regional safety monitor could be potentially relatively expensive, since it would be a safety-critical item. The cost would be not merely for the hardware, software and all the costs to verify and certify it, but also for all the redundant sensors and associated wiring to independently connect them to the sensor.
- Costs for software licenses (including modelling and development tools), hardware setups for integration and testing.

## 6.1 M&C development for SKA1

The design of M&C is aimed at SKA2, since it will be difficult to retrofit scalability considerations into the architecture, and most M&C features are needed for SKA1.

The following is a representative list of M&C features whose implementation can be deferred to SKA2, though it is preferable to design for them in SKA1:

- Implementation of configuration and fault management functionality for Component types that are not part of SKA1.
- Storage at Regional M&Cs. For SKA1, it is likely that there is plenty of spare communications bandwidth. It may be simpler to eliminate the problem of deploying and maintaining archives in each region by pushing all the data to Central M&C, though it would have costs in terms of additional processing power.
- Independent safety monitors is another feature that can be considered for deferment. The smaller scale of SKA1 could mean fewer safety concerns related to remote outlying stations having safety problems that must be dealt with fully automatically. Emergency travel to SKA1 outlying stations may be relatively quick



and first-level safety mechanisms may suffice, rather than requiring ultra-reliable and ultra-safe automated operation. This option requires an explicit project decision.

- Dealing with software platform architectural issues related to scale: partitioning of the data into multiple namespaces with brokers to create a transparent subscription space for users.
- Alarm filtering for intrusive vs. non-intrusive presentation. The number of alarms in SKA1 may be sufficiently tractable so that possibly all significant alarms can be presented to the operator.

## 7 The role and position of M&C in the SKA effort:

This section discusses some aspects of the role and position of M&C in the overall SKA context, and the role and scope of the Indian effort and contribution.

### 7.1 Positioning of M&C in the overall SKA context

In the preparatory phase, M&C is part of the System Design work package (WP2.1), whereas during the Pre-construction phase, M&C is currently included as part of the Software & Computing work package. Though M&C has multiple touchpoints and relationships with the Software & Computing domain, there is a point of view that M&C is more closely affiliated with the System. The challenge is to find the right positioning of M&C work that will honour all of the interrelationships and maximize the chances of project success. This section presents our analysis of these matters.

An analysis of the interrelationships reveals the following:

- Software & Computing has a governance relationship with M&C. M&C is largely software, and must conform to all the guidelines established by the Software & Computing domain. M&C software technology choices must be made in conjunction with Software & Computing, since some of the decisions might affect Science Computing as well.
- Software & Computing consists of three parts: (1) project-level guidance and infrastructure to facilitate and manage software development; (2) science computing capabilities, including post-processing of science data, science data reduction and archiving, scientist interfaces, proposal handling and observation scheduling systems, and M&C applications to perform observations; and (3) core M&C software.
- M&C has operational integrations with each of the functionalities of Software & Computing. This includes providing metadata and carrying out scheduled observations.
- M&C also has operational integrations with Signal Processing, Operations Management software and enterprise applications. This includes exchange of parameters for science performance management, and forwarding information about faults for maintenance scheduling.
- M&C has collaborative relationships with domains such as Signal Transport and Power & Cooling to support the development of Element M&Cs.
- M&C has collaborative relationships with every SKA domain to facilitate the development of Component M&Cs.
- M&C engineering is most closely related to System Operations. Nearly all of the architectural and design considerations that drive M&C design arise from systems concerns.
- The operation of the Observatory can be considered to consist of two halves: automated operations, addressed by M&C, and non-automated (human) operations, addressed by System Operations. As such, M&C and System Operations together form a whole. There must be tight coupling between the automation and the human operations so that the automation can effectively support the system operational philosophy.
- M&C integration will effectively be System integration and commissioning. M&C will be central to the system integration and commissioning activity.

- M&C implementation has touchpoints with Software & Computing, including the development of the Common Software Library, exploitation of commonalities in user interface development, and providing support for M&C applications development.
- System M&C software has significantly different timelines and quality requirements from Software & Computing. System M&C software must be available in advanced prototype form by early in the Construction phase, to facilitate integration and system testing of each Local M&C solution, and so that the software and tools from System M&C software can be reused in the development of Local M&C software. System M&C software will have a reliability requirement of at least 99.9% and probably much higher, requiring a completely different approach to engineering and development than Science Computing software. Finally, while Science Computing software development is largely within the control of the domain, most M&C software will be built by providers who are not part of the domain teams, hence the focus of M&C work even during the implementation phase will be as much on interactions with other teams as on its own implementation work. These considerations make even the M&C software implementation (which is only a small part of the total M&C activity) vastly different from other software work within SKA.

Based on these arguments, the following understandings emerge:

- The governance aspect of Software & Computing has system-wide force, including on the development of Signal Processing software. It could reasonably be considered a Systems concern.
- M&C has several significant touchpoints, commonalities and collaborative interrelationships with Science Computing. However, it also has collaborative relationships with other domains.
- M&C has tight coupling with the System and in particular System Operations, both during the design phase and during system integration. The touchpoints with Science Computing mostly relate to M&C implementation, and even there, there are vast differences in concerns and approach.

Successfully addressing the challenge requires that the M&C team work closely with System Operations, develop strong linkages to Science Computing, good collaborative relationships with all domains, and conform to guidelines laid down by Software & Computing. We strongly believe that M&C needs an independent team, working under the overall Systems umbrella.

## 7.2 Indian participation in M&C and outlook for the future

In January 2011, the Indian team, led by the NCRA, took over the lead institution role for the M&C work during the PrepSKA phase. The Indian team took on this role as part of India's contribution to the SKA project, without requiring any immediate, additional funding from other sources. The M&C effort was identified as the main area of initial, tangible contribution by India to the SKA effort. The Indian team consists of around 12 people, half of whom belong to commercial organisations that are part of the SKA India Consortium. The total effort invested in the M&C work to date is over 60 staff months. The contributions of the NCRA staff and some of the commercial organisation participants are currently being funded by the NCRA as pilot funding for India's planned participation in the SKA. This has been an excellent example of astronomy research institutes working in collaboration with local industry to produce useful deliverables for the SKA design work.

The Indian team has demonstrated the competence and commitment to take independent charge of delivery of the M&C system as a major and critical component of the SKA. Even as the Indian SKA consortium grows in strength and purpose, and explores other avenues of additional contributions to the SKA effort, we will maintain a strong and leading interest in M&C and keep it as a significant part of the Indian contribution-in-kind to the SKA, working in close collaboration with the SKA management.

## 8 Appendices:

Table 2 : SKA top level schedule

