Practical Configurations for the SKA

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A shifting target

A sobering thought:

We have reached a point in time where the next generation large radio astronomical facility, the SKA, has to consolidate current thoughts on how to lay out such a system, and design these configurations, even when ongoing insight will challenge these designs before the telescope will be built...

We have to do the best we can.
Overview

• Introduction
  – Setting the scene
  – The Configuration Design Task Force

• Configuration Design
  – References
  – Identification of key issues
  – Parameters, figures-of-merit

• Real world aspects
  – Masks
  – Infrastructure cost

• Final remarks
  – Status
  – The science loop
Introduction
Configurations for the SKA

PrepSKA tasks us to do:

**WP3.5: Optimize the array configuration**

“Study the *ideal* configurations for the SKA for the different Key Science Projects and determine the single configuration that optimises the total return from the Key Science Projects. Match the “ideal” configuration to the geographical *realities* of the two short-listed sites in order to determine the optimum configuration for each site. (...)

The due date for this is T+18 (end 2009).
Configurations for the SKA

So, in practical terms, by the end of this year the SPDO has to:

- study previous configurations work
- make an inventory of requirements, in relation to the current scientific framework: the Reference Science Plan
- derive *figures-of-merit* that are part of the configurations assessment process
- ensure that the configurations can be realised in the host environments – the *Masks*
- ensure that the developed configurations are economically feasible
- develop and use practical simulation and optimisation tools
Configurations for the SKA

In other words:
- it is now time to get serious about the design of the configurations,
- the results of earlier studies will have to be consolidated into this ‘final’ effort.

And in order to do so:
- the science community needs to decide what they want the SKA to be able to do (and the SWG is doing that),
- the engineering community needs to come up with technically and economically realistic scenarios for phase 1 and 2, for SKA-lo and SKA-mid (and WP2 and 3 are doing that too).
Configurations for the SKA

Urgency in designing configurations:
• We need to do additional high sensitivity RFI monitoring measurements, at the core, but also at a number of ‘representative’ remote stations.
• So, we have to find out which locations will very likely be chosen as remote stations for doing the measurements.
• And these monitoring activities will start in the second half of 2009.
Configuration Design Task Force

• For this configuration design work, a Task Force has been assembled, under the SCWG:
  – Rosie Bolton (University of Cambridge)
  – Mattieu de Villiers (SKA South Africa)
  – Sundaram (Jive, NL)
  – Rob Millenaar (SPDO, millenaar@skatelescope.org)
  – small number of ‘sounding board’ contributors

• A report with two configurations, one for each host, is expected by the end of 2009.
The simulations and optimisations tool that is going to be used for that is Mattieu de Villiers’ \textit{AntConfig} program.

See: http://www.kat.ac.za/public/wiki/AntConfig for the latest Windows version of \textit{AntConfig} (V1.4), and a preliminary Mac version of \textit{iAntConfig}.
Kick-off meeting

In March 2009 a kick-off meeting for the work of the Task Force was held in Manchester. The 2.5 day workshop established what the SKA community considers to be the:

- scientific and engineering boundary conditions,
- requirements of the configurations,
- physically and economically feasible targets,
- appropriate methods and tools.
Kick-off meeting

The outcome of this meeting was that:

• the Task Force understands what is expected of them, to be delivered by the end of 2009;

• the SKA community understands that the Task Force is working towards “final” configurations, which will go into the costed design for the SKA phase 1, the PrepSKA main deliverable, and phase 2.

• Nevertheless, there are a number of open issues that the two host countries and the SPDO have to get agreement on.
Configurations Design
References

Apart from drawing information from previous and ongoing work (EVLA, ALMA, ATA, LOFAR, LWA, SKADS, the precursor telescopes, etc), two baseline documents are used:

1. **Memo 100**: Preliminary Specifications for the Square Kilometre Array (last issue 12/2007)

3. Information available from the site bids of 2005

4. RFP, CSTF Guidelines:
   - Max angular resolution
   - Axial ratio of PSF
   - Uniformity and circularity of uv coverage
   - PSF sidelobe levels

   — evaluated for:
   - Long integration obs
   - Short integration obs (snapshots)
   - Continuum multi-freq synthesis (MSF) observations
   - Spectral line (narrow band, single channel) observations

Note that the RFP specified that min elevation for any station should be 30°. This must be reconsidered...
References

5. From the CSTF, the evaluation of the LNSD configurations report, example:

• uv coverage and psf calculations, done for:
  – 4 h obs for northern vis limit (4 h obs time available for all stations) for MFS (25% frac bw) and sp. line (single channel)
  – 4 h obs for southern vis limit, MFS+sp. line
  – max duration at declination of pk vis, MFS+sp. line
  – snapshot (5 mins) for northern vis limit, MFS+sp. line
  – snapshot for southern vis limit, MFS+sp. line
  – snapshot at declination of pk vis, MFS+sp. line
LNSD Australia
Reference Science Plan

• Purpose
  Is an assembly of science component studies to be used to define the requirements (SKA-low and mid only)

• Structure
  For each of the KSP’s one or more components, with summary of scientific and technical requirements per component.

• Status
  Being written by the SWG. Latest draft March 09, not released. Final version expected by 2010.

• The RSP is used for configuration design
  Starting assumptions, performance parameters.
Reference Science Plan

Science Case

Reference Science Plan
(Requirements)

Case Studies
Eng. Simulations
Technical R&D
Prototypes
Pathfinders
Configuration
Costing
Readiness

Engineering Design
& Cost
Parameters

From Memo 100 and later AA studies:

• Gross distribution of collecting area for phase 1 and 2. Memo 100 specifies in table 1:

<table>
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<th></th>
<th>dish Memo 100</th>
<th>provisional AA</th>
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<td>180</td>
<td>100%</td>
</tr>
<tr>
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<td>3000</td>
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</table>
Parameters

From RSP:

• **Frequency and baseline range** (angular resolution) per receptor technology type: for WBSPF and PAF in dishes, sparse and dense AA.

• **Imaging Dynamic Range** -> 77dB

• **Array filling factor**

• **Sky coverage**
Separate cores

• Considering 3 receptor technologies: AA-low (sparse), AA-high (dense), dishes
• All want large filling factor in the core
• Need to separate in the core, because of:
  – mutual shadowing
  – sub-optimal filling possibilities if all combined
  – accessibility
  – inter-RFI/EMI arguments
• Extra complication: presence of precursor telescopes
• Note: Remote stations, up to a certain baseline, will need real estate for multiple receptor stations.
Overall SKA Configuration

- Comms links
- Dishes in stations spread along spiral
- Core ~5km dia
- Station
- Central Processing Facility

Dishes

- AA-hi
- AA-lo

courtesy A. Faulkner
Key Issues

Some more items to (re)consider:

• In many studies so far symmetrical log spirals have been investigated. We have the practical need to come up with highly asymmetrical configurations for the longest baselines.

• In a densely packed core, shadowing becomes a serious issue.

• To what baseline range do we consider PAFs.
Key Parameters

Initial design assumptions:

• The number of stations that we design for 150
• of which 70 equivalent stations in inner 5 km
• the number of antennas per station 20
• bring back all signals from stations to the correlator for baselines <180km, beyond that beamformed data.
• Practical question to answer: how do we fit the required baseline range on the two continents in a scientifically useful fashion.
Figures-of-merit

Prime FoM for imaging will be the \textit{rms side lobe level} of the PSF, resulting from the uv coverage for:

- snapshot observations
- spectral line imaging observations
- for multi frequency synthesis (MFS)

- Being programmed into \textit{AntConfig} now.
PSF rms side lobe level

1. Ambition is to have 77 dB of DR
2. Wide field of view and >50x increase in array sensitivity will place enormous amount of sources in the field; of which the stronger ~1000s can be removed for calibration -> sky model, but will leave:
3. ex. ~1 million 1 sigma sources in the field, and
4. side lobe confusion will increase noise, 1\textsuperscript{st} order estimate, by factor $\sqrt{\text{nr sources}}$/side lobe level, so for this example...
5. side lobe level 0.1% would still double the noise.
Log spirals

The very demanding imaging FoM is likely best realised by a smooth log spiral configuration:

• many short spacings (for high brightness sensitivity)
• enough long spacings (to minimize confusion)
• comparable sensitivity at all scales
• aiming to prevent holes in the uv plane, for continuum work through MFS...
Multi Frequency Synthesis

• Holes in uv plane can be filled up by using multi frequency synthesis
• Needs assumptions on the frequency dependance, spectral index
• Works till what fractional bw
  – Urvashi Rau’s thesis work very relevant
• uv -‘holiness’ metric to be worked into AntConfig, MdVs method and possibly Lobanov’s uvgap metric.
Real World aspects
The Mask

The mask defines where stations can or cannot be located, as determined by a range of aspects. Example no-go areas:

- Geographically constrained areas
- RFI constrained areas

- The mask is thought to have the most importance for placing stations within the range of ~30-~300km.
Mask, Geographical

- Bodies of water
- Roads
  - small, single-lane
  - multi-lane
  - rail
- Slopes
- Mountains
- Floodplains
- Environmental
  - Parks
  - Cultural exclusion areas

This is the ‘easy’ part, even though careful consideration for:

- buffer zones
- seasonal influences
- climate zones
- historic data
- future projections
- slope data
- geology aspects
- plateaus
- data sources
- common criteria
- integration in AntConfig
Criteria

• RA769-2 continuum for the central area
• RA769-2 VLBI for the longer baselines
• Bottom line: given the unavoidable sources of RFI anywhere in the array (aircraft, satellites), the levels of RFI should be less than the level where cost&performance would be affected by having to:
  — design in more receiver headroom
  — use more signal bits
Mask, format

• Mask generated as a GIS ESRI shapefile, to be used within AntConfig

• ESRI shapefile is standard data format for the compilation and distribution of ‘geographical’ information
  – Hydrology, topography, meteorology, demography, geology etc.

• Data sources
  – Common data source, where possible: use of satellite datasets, eg. landsat.org, SRTM-90
Mask Example

transport routes, mines, rivers

courtesy A. Tiplady
Masks and *AntConfig*

- The masks will be supplied by the two host countries.
- Will be read into *AntConfig*, to constrain the placement of stations during manual antenna shuffling and during automated optimisations.
Infrastructure cost

• Cost of infrastructure must be considered while designing configurations
• Proximity of services and accessibility
  – fibre
  – power
  – roads
  – support base
• Tools to evaluate infrastructure cost:
  • SKADS costing tool
  • Routing optimiser for fibre
  • Costing ‘layer’ in AntConfig
Costing layer

• Engineering consultancy for input parameters, common for SA and AUS

• **Pre-process** costing and generate site specific costing layer – $f(x,y,\text{cost})$

• Components
  – Site establishment cost
  – Bulk infrastructure cost
Costing layer

- Establishment + infrastructure costing (illustrative only)
Final remarks
Status

• Reaching agreement on methods (ongoing)
  – masks
    • specification to be completed
    • production of the masks
  – costing
    • specification
    • consultancy
Status

• Development work on *AntConfig* (ongoing)
  – functionality for mask and costing layer
  – developing and implementing FoMs
  – additional analysis functionality
  – add multi-computing node functionality
  – the tool is intended to evolve into a general configuration research and education platform.

  – mid May first release of *iAntConfig* (Mac edition)
Feedback and iterations

• A set of developed configurations will be presented to the SWG

• Iterations will narrow down the options and can possibly also cause the RSP to be modified

• Configurations that are deemed to be suitable will be presented to SSEC, who will make final selection of one preferred configuration per host country.

• These will be used in further planning and costing of the array, also in PrepSKA WP2.
End