Engineering Processes for the African VLBI Network

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Abstract. The African VLBI Network (AVN) is an initiative by the SKA-SA and HartRAO, business units of the National Research Foundation (NRF), Department of Science and Technology (DST), South Africa. The aim is to fill the existing gap of Very Long Baseline Interferometry (VLBI)-capable radio telescopes in the African continent by a combination of new build as well as conversion of large redundant telecommunication antennas through an Inter-Governmental collaborative programme in Science and Technology. The issue of human capital development in the Continent in the techniques of radio astronomy engineering and science is a strong force to drive the project and is expected to contribute significantly to the success of Square Kilometer Array (SKA) in the Continent.

1. The Motivation for AVN
The AVN is strongly motivated from scientific [1,2] and political perspectives.

The 26m radio telescope, HartRAO, at Hartebeesthoek in South Africa is the only VLBI-capable instrument currently operational in the entire African continent. The absence of a similar telescope between Africa and Europe as well as Africa and Australia for astronomical, astrometric and geodetic VLBI is a strongly felt scientific need for the past many decades. The AVN will be filling this need and will also act as a convenient platform for co-locating geodetic instrumentation and other scientific facilities in the same infrastructure.

With a major share of SKA having come to the African Continent, there is a strong political motivation to facilitate activities in the Science and Technology of Radio Astronomy in the SKA Partner Countries, well ahead of the SKA roll-out programme. AVN is seen as an immediate vehicle for this goal and act as a pathfinder towards SKA. It is managed by the Department of Science and Technology of South Africa, with active participation from partner countries, to address the issues of human capital development in the continent with a specific focus on specialized skills transfer to operate, maintain and sustain a radio astronomy facility.

SKA-SA and HartRAO have been mandated by DST, South Africa, to carry out the above task with a goal of VLBI Demonstration by 2017.

2. The Solution for AVN
The SKA in the African continent will encompass radio astronomy facilities in eight partner countries, namely Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia and Zambia with the core located in South Africa.

Some of these partner countries have large 30m diameter class redundant telecommunication antennas which could be converted as radio telescopes of the AVN at a moderate investment. Work along these lines has been initiated in Ghana and will be started shortly in Kenya. Other partner
countries will need a new-build radio telescope with a performance acceptable by the International VLBI Community to be included as a part of the existing European VLBI Network (EVN) and other consortia. A nodal processing facility will be located in South Africa when about four of the VLBI stations are successfully operational and thus result in the African VLBI Network.

With the goal being clearly set as above, issues of political, scientific, technical and management nature are currently being addressed as under:

- Is there a strong inter-governmental foundation and support available for the effort to succeed?
- What is the most efficient way to do what we want to achieve?
- What are the initial tests and studies required?
- Who is responsible for what?
- How to make the Human Capital Development efforts successful?
- What resources are required (budget, manpower) and where do we get them?

3. The Groundwork towards a Technical Solution

The Implementation Flow Diagram for AVN under Conversion process is given in figure 1. It visualizes a Memorandum of Agreement with an Operating Institution with a clear top-down mandate as an important pre-requisite.

![Implementation Flow Diagram for AVN - Conversion Process](image)

A similar model applies for new-build stations to produce a firm foundation for the effort. In this instance, the initial technical feasibility studies in Figure 1 will have to be aimed towards developing a decision matrix for optimal location of the station considering all aspects like Radio Frequency Interference (RFI) potential, approach roads, power, water, geo-technical and topographical studies, optical fibre connectivity, environmental factors (wind, humidity, temperature) and others.

A criterion to define the new-build VLBI station at such a location chosen as above in the form of initial frequency of operation and a figure of merit for sensitivity as used by VLBI community has evolved. Considering the requirements of astronomical and geodetic VLBI as well as non-VLBI programmes of pulsar timing and spectroscopy, the frequency bands to support have been chosen as (a) 1.4-1.73 GHz; (b) 2.2-2.4 GHz; (c) 4.7-5.2 GHz; (d) 6.6-6.8 GHz and (e) 8.2-9.0 GHz.

Table 1 gives the figure for System Equivalent Flux Density (SEFD), defined as the number of Janskys \(10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}\) of source flux density that are required to double the system noise temperature, for some of the important operating VLBI stations around the World. From this table the target SEFD for the AVN at 5 GHz has been set at better than the median value of 220 Jy.

This figure would translate into a decision matrix for the receiver system with diameter of each antenna, an array of antennas from 1 element to a reasonable number and choice of the receiver with a cryogenic or non-cryogenic front-end as parameters.

The decision matrix for site and system selection as described above will have to be optimized for “Expectation – Cost – Performance” trade-offs before embarking on realization.
4. The Engineering Process towards Realisation

The System Engineering [3] approach, which has been successfully demonstrated for the SKA precursors in South Africa, will be adapted and adopted for AVN. This adaptation needs to take into account the way the Partner Country team works and the practicalities with respect to collaboration with South Africa, without jeopardising the integrity of the process.

The approach needs a process of Validation and Verification (V&V) at all levels of development and implementation as depicted in the V-Diagram in figure 2. The Requirements, as specified by the User (AVN URS) for New-Builds and Conversion approaches, generates a System Description Document (AVN SDD) as an output to a system design activity. It describes a high level solution to meet the requirements and enables the required functionality associated with each requirement to be defined. The System Engineer uses the AVN SDD as an input to produce a Station System Requirement Document (Station SRD) and an associated Station System Description Document (Station SDD), with traceability to the AVN URS. The SDDs will be used to derive all aspects of budget estimates, time schedules, resources etc in a System Engineering Management Plan (SEMP).

There could be a few iterations as depicted, to result in a mature Station SDD which is acceptable to all stake-holders as a good “requirement – cost – time – performance” optimised solution.

The Station SDD will become the input to a team of Design Engineers to derive the next level of sub-system SRDs and associated SDDs. The typical sub-systems for a radio telescope will have Signal Chain (SC), Software (SW), Control and Monitor (CAM), Structural-Mechanical (SM) and Other (Infrastructure, Operations, maintenance, logistics etc) elements. Each of the sub-systems to form the telescope could have interfaces between any or all of the others which needs to be adequately and unambiguously captured in the Interface Control Document (ICD). Each of the sub-system SDDs will need to be addressed by the Development Engineer at Equipment level (ERD and EDD) as well as component level (CRD) to result in a low-level realisation of the building blocks of the telescope.

Associated with each SRD is a Qualification Test which is performed at the same level as where the SRD resides, e.g. a derived requirement appearing in the SRD for the azimuth angle decoding...
subsystem will have an associated SDD describing the solution and a Qualification Test Procedure (QTP) to verify that the SRD requirement has been met. (Right hand V in figure 2). This test will typically be done on a jig of the subsystem and performance verified before the higher level integration (installed onto telescope) can begin. Thus the documentation at various levels as the process percolated down from the User to Component will be used for verification and validation as the telescope takes shape.

![Figure 2 Validation and Verification Diagram (V-diagram).](image)

The system engineering process as described above has been widely used in a rigorous manner in the Industry and is expected to contribute considerably to the success of AVN as it rolls out.

5. **Human Capital Development Aspects in AVN**

Human Capital Development with specialized skills transfer is a vital element for the success of AVN. To assist in this, a training programme in South Africa is being developed for core technical and scientific members from each of the partner countries. The aim of the initial training to a focused and dedicated technical team from each of the partner country will be for operation and maintenance of the telescope system in that country. The program is expected to enlarge with appropriate skill development in various disciplines as the work moves towards SKA.

6. **Summary**

SKA is acting as a motivating driver in facilitating setting up experimental facilities for radio astronomy research in Africa. The African VLBI Network, when realized, will cater to a long awaited scientific need in the Continent and will serve as a pathfinder towards SKA.

**References**

[1] Gaylard M J, Bietenholz M F, Combrinck L, Booth R S, Buchner S J, Fanaroff B L, MacLeod G C, Nicolson G D, Quick J F H, Stronkhorst P and Venkatasubramani T L 2011 *An African VLBI Network of radio telescopes* Proceedings of SAIP2011, the 56th Annual Conference of the South African Institute of Physics, edited by I. Basson and A.E. Botha (University of South Africa, Pretoria, 2011), pp 473-478, ISBN: 978-1-86888-688-3. Available online at [http://www.saip.org.za](http://www.saip.org.za)

[2] Gaylard M J 2012 *Expanding radio astronomy in Africa* Proceedings of the RADIO 2012 Conference, Mauritius

[3] INCOSE 2011 “*System Engineering Handbook – A Guide for System Life Cycle Processes and Activities*”, Version 3.2.2. San Diego, CA, USA: International Council on System Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2