ASKAP Array Configurations: Options and Recommendations

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Executive Summary

In this discussion document we consider the various configuration options available to ASKAP, within the context of the overall system parameters, budget, telescope lifetime and the science case. We focus our discussion on the options available for a 30 and a 45 antenna system and come to the following recommendations.

If ASKAP consists of only 30 antennas, the initial configuration should be one which achieves the best possible returns for ASKAP's top science priority: *Understanding galaxy formation and gas evolution in the nearby Universe through extragalactic* HI *surveys*. There should be the option to reconfigure the antennas twice after ∼2-3 and ∼4-6 years of operations. The two subsequent configurations would enable other ASKAP science priorities.

If ASKAP consists of 45 antennas, the configuration should be a hybrid array comprising two principle spatial scales near $\sim 30''$ and $\sim 10''$ which has a maximum baseline of ∼6 km. This hybrid configuration satisfies the requirements of the majority of the ASKAP science priorities and potentially allows multiple science surveys to be carried out in parallel. There could be an option to reconfigure the antennas to enable low surface brightness science after the hybrid surveys are completed.

The technical studies behind these recommendations are presented in a companion paper (Gupta et al. 2008). These papers should be read in conjunction with the science priorities for ATNF telescopes presented in *ATNF Science in 2010-2015* by Ball et al. (2008). Comments on the recommendations for ASKAP configurations, and the reasoning behind these comments, are requested from the larger community.

1 Introduction

ASKAP is a next generation radio telescope on the strategic pathway towards the staged development of the SKA. ASKAP has four goals:

1. to carry out world-class, groundbreaking observations directly relevant to the SKA Key Science Projects,

2. to demonstrate and prototype the technologies for the mid-frequency SKA, including field-of-view enhancement by focal-plane phased arrays on new-technology 12-metre class parabolic reflectors,

3. to establish a site for radio astronomy in Western Australia where observations can be carried out free from the harmful effects of radio interference.

4. to establish a user community for SKA.

ASKAP will become operational from 2012, SKA Phase I will become operational from ∼2015 and full SKA will become operational from ∼2020. The *default* lifetime of ASKAP is 30 years and current planning assumes this default. However, the *practical* lifetime of ASKAP is likely to be much shorter if the Murchison Radio Observatory is chosen as the site for the SKA — this decision will be made in 2011−12. Regardless of where the SKA is built, it is crucial that ASKAP return the best science outcomes during its first 5-7 years of operation; this is ASKAP's *competitive* lifetime. Beyond this time, ASKAP will be superseded by SKA phase I, and eventually SKA.

The system parameters and science case for ASKAP are presented in Johnston et al. (2007) and will not be repeated in any detail here. For the purposes of this discussion paper, which concentrates on configuration issues, we note that the strawman design consists of a 30 antennas with a system temperature of 50 K whereas the stretch goal is to have 45 antennas with a system temperature of 35 K. The number of antennas that can be constructed with the available funds should be known before the end of 2008, but the receiver performance will likely not be well determined until mid 2009 at the earliest. Broadly speaking, the science goals for ASKAP fall into three main categories, which relate to configurations as follows.

- **A highly compact configuration (baselines less than 300 m:)** This is necessary for low surface brightness science (Galactic science and the cosmic web) and for pulsar surveys.

- **A medium configuration (baselines less than 2 km:)** This is optimised for surveys for extragalactic H I in emission (Staveley-Smith 2006). It also serves well for polarization and transient science.

- **A long configuration (baselines to 8 km):** This is optimised for high resolution continuum surveys. It overcomes the confusion limit at 10 μJy rms, whilst retaining some surface brightness sensitivity to local, extended objects (Condon 2008).

The science priorities for ASKAP in the period 2010-2015 are presented as part of the Ball et al. (2008) document *ATNF Science Priorities in 2010-2015*. As listed in that document, the order of science priorities for ASKAP is:

- Understanding galaxy formation and gas evolution in the nearby Universe through extragalactic HI surveys, including near-field cosmology

- The characterisation of the radio transient sky through detection and monitoring (including VLBI) of transient and variable sources

- Determining the evolution, formation and population of galaxies across cosmic time via high resolution, confusion-limited, continuum surveys

- Exploring the evolution of magnetic fields in galaxies over cosmic time through polarisation surveys

2 Configuration Options

The challenge for the configuration studies has been to attempt to satisfy the various science drivers in regards to the resolution they require while at the same time maintaining sufficient sensitivity on the relevant spatial scales. In constructing this document we have kept within the following framework: (i) 30 antennas, with a system temperature of 50 K and a field-of-view of 30 square degrees is a minimum number for ASKAP to achieve the survey speeds and dynamic range necessary to carry out ground breaking science, (ii) the back-end computing available can only process data at full spectral resolution (16000 channels) to a maximum baseline of 2 km and image deconvolution will not be possible at full spectral resolution, and (iii) site constraints, data rates and processing capability mean that maximum baseline lengths cannot exceed $\sim$10 km. Within this framework, we have considered single-scale, hybrid and scale-free array configurations.

Technical aspects of these configuration options and layouts on the site of the Murchison Radio Observatory are considered in the companion paper (Gupta et al. 2008; hereafter GJF08). The conclusions of the technical studies can be summarised as follows:

- Configurations with 45 (or 30) antennas can be created on the site which satisfy either the compact, medium or long configurations as listed above. There are no major constraints within the site itself which have a detrimental impact on the configurations.

- With only 30 antennas it is exceedingly difficult to devise an array configuration which satisfies more than one option without severely impacting on the sensitivity and hence the time required for a given science survey.

- With 45 antennas it becomes possible to devise a hybrid array which satisfies the requirements of the medium and long configurations simultaneously and returning an equivalent sensitivity of a $\sim$30 antenna system for each.

- A scale-free array with 45 dishes cannot return the sensitivity requirements for any of the major science surveys.

3 Discussion

The results of the ASKAP Array Configurations Technical Studies document (GJF08) allow the following options:

3.1 Fixed, single-scale configuration

The first option is a single, fixed configuration of 30 (or 45) dishes, optimised for the compact *or* medium *or* long configuration with no reconfigurability planned in the short term. This is the most inexpensive option for ASKAP both in terms of dollars (number of trenches, number of stations, physically moving antennaes) and time (approximately 8 weeks downtime to implement a reconfiguration in addition to the survey times for other configurations). But it comes with the insurmountable trade-off that only a small fraction of the science case is included, and therefore will be considered, in the initial planning and design of ASKAP. The top science priority for ASKAP implies that the fixed, single-scale configuration be the mid-baseline option optimised for extragalactic H I emission surveys (GJF08). The lifetime of ASKAP for a single, fixed layout is unlikely to exceed its practical lifetime if the Murchison Radio Observatory becomes the site for the SKA — with the anticipated operation of SKA phase I commencing in 2016. Should the latter not be the case, future planning should obviously consider a reconfigurable option for ASKAP in order to enable other science not possible with the mid-baseline configuration.

3.2 Reconfigurable arrays

The second option is to design into ASKAP the opportunity for reconfiguration. In this case, an example might be that initially ASKAP is configured with medium-baselines for the H I emission surveys. On some reasonable and pre-determined timescale (like 2 years) the dishes would be reconfigured with long-baselines for the extragalactic continuum surveys. A second reconfiguration would occur 2 years later into the compact configuration where the low surface brightness surveys could be carried out. Beyond these reconfigurations, there is no short-term plan for ASKAP to be continuously reconfigurable.

The reconfigurable array option will mean that each science subcase can benefit from full sensitivity and optimised *uv*-coverage available with the full complement of dishes. This is crucial if ASKAP if only base model is realised because less than about 30 dishes is detrimental to the ASKAP science case in terms of survey speed and dynamic range. The expense, and time, for reconfiguration (possibly 8 weeks and a cost of A$0.5M) needs to be factored into the operations costs. Provision and cost should be made for long baselines during the design and planning stages for ASKAP, even if antennas are not initially placed there. Also crucial is that reconfigurability demands that each of the compact, medium and long-baseline science cases are instituted consecutively and the ASKAP science priorities should determine the order of the configurations. This means that the third ranked science case will begin 4-6 years into the lifetime of ASKAP. This is a reasonable option assuming the default (30 year) lifetime for ASKAP. However, if SKA is built on the Murchison Radio Observatory, the practical lifetime of ASKAP is unlikely to exceed 5 years after which time SKA Phase I will become operational.

3.3 Multifarious Arrays

This option is to design ASKAP with a (semi-)permanent multifarious array configuration where the visibilities can be weighted (offline) to produce the various resolutions required of some (or all) of the science subcases. The multifarious array option is an up-front sacrifice of at least 23% in sensitivity (see Table 2 in GJF08). This would be detrimental in the event that only the ASKAP base model is realised since an equivalent sensitivity of a 22-dish ASKAP telescope will not achieve the required survey speeds. If the expanded ASKAP is realised, then a hybrid array could, in principal, allow all the medium and long-baseline science to be obtained simultaneously with an equivalent 33-dish telescope. The drawback of all multifarious arrays are that although they may have natural 'sweet spots', the resulting surveys will not be as efficient as a single-scale array. For example, the long-baseline science would be scaled down from 5″ resolution to 10″.

3.3.1 Scale-specific hybrid array

With a hybrid array, the H I emission survey and the extragalactic continuum survey can be done in parallel with a loss of 23% in sensitivity compared with the optimised single-scale configurations, whilst the imaging performance of the hybrid array is as good as the single-scale configurations (see GJF08). This hybrid array has virtually no option for the low surface brightness science that requires compact configurations or very high resolution continuum science that requires better than 8″ angular resolution.

In principal, a hybrid array will allow the H I emission survey and the extragalactic continuum survey to occur simultaneously. Other science such as the transient and polarisation surveys will also piggyback on these. Issues with synoptic observing like this may arise in the process of instigating the survey strategy. Choices such as the observing frequency, the cycle and cadence of pointings and the implementation of priority fields will require measured consideration. These issues are beyond the scope of this document but will be addressed in the ASKAP Science User Policy.

3.3.2 Scale-free array

The exploration of the unknown could be the most ground-breaking of all ASKAP's scientific harvests. In this regard, a scale-free array is conceivably beautiful because by reducing the design limitations one maximimises the potential discovery space. The ASKAP optimised scale-free array has the capability to perform the compact, medium and long-baseline science with reduced sensitivity and imaging quality compared to the hybrid and fixed-scales for the former two and the fixed-scale for the latter. GJF08 presented the optimised scale-free and hybrid configurations for ASKAP. It showed that with 45 antennas, the best scale-free configuration will yield 25-dish, 27-dish and 23-dish equivalent sensitivities for the H I emission (medium-baseline), extragalactic continuum (long-baseline) and low surface brightness (compact baseline) surveys, respectively. This would mean a factor of 2.7-4 blow-out in the survey times required to achieve many of the science goals. In addition, the sidelobe levels are higher than the sidelobes for the scale-specific hybrid array. In terms of both survey speed and dynamic range, the scale-free array is clearly inferior to the hybrid configuration.

4 ASKAP Configuration Option Recommendation (ACO)

Although provisions are in place for a default ASKAP to operate for 30 years, its practical lifetime may be shorter if SKA is sited at the Murchison Radio Observatory. Necessarily, the ASKAP Configuration Option will be in place before the site for the SKA is chosen in 2011.

Regardless of the SKA site choice, the capabilities of SKA Phase I will supersede those of ASKAP. The timelines for SKA Phase I and the full SKA then imply that ASKAP's competitive lifetime is 5-10 years. The ASKAP science case (Johnston et al. 2007) and science priorities (Ball et al. 2008) have been considered together with the technical study by GJF908 in making the following recommendation for the ASKAP Configuration Option. Equally we have considered the science goals of ASKAP in the context of the default, practical and competitive lifetimes for this pathfinder telescope into the SKA phase I era and beyond.

- **Expanded Model ACO:** If ASKAP consists of 45 antennas, the initial configuration should be a hybrid one containing two principle spatial scales near $\sim 30''$ and $\sim 10''$. This hybrid configuration satisfies the requirements of the majority of the ASKAP science case and most of ASKAP's top science priorities and potentially allows multiple science surveys to be carried out simultaneously. A reconfiguration after the hybrid surveys are completed will enable very compact-baseline science.
- **Base Model ACO:** If ASKAP consists of only 30 antennas, then the inital configuration should be one which achieves the best possible science returns for the top ASKAP science priority. This involves arranging the antennas in a quasi-Gaussian fashion inside a circle of diameter $\sim$ 2km. This yields a $30''$ beam with an excellent point spread function obviating the need for image deconvolution. There should be the option to reconfigure the antennas twice after $\sim$2-3 and $\sim$4-6 years of operations. The two subsequent configurations would be optimised for extragalactic continuum science (long baselines) and low surface brightness and pulsar science (short baselines).

References

Ball, L., 2008, ATNF Science in 2010−2015.
Condon, J., 2008, ATNF SKA Memo Series, 015
Gupta, N., Johnston, S., Feain, I., ATNF SKA Memo Series, 016
Johnston S. et al., 2007, PASA, 24, 174
Staveley-Smith L., 2006, ATNF SKA Memo Series, 006