Resolution and the xNTD

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1 Introduction

The Extended New Technology Demonstrator (xNTD) is an Australian concept in the development of the Square Kilometer Array (SKA). The key concept behind the xNTD is to demonstrate wide field-of-view operations on a parabolic dish using a large focal plane array to give a very large field of view.

The headline science goals for the xNTD, as outlined in the science case (Johnston 2006), are:

- The detection of 500,000 galaxies in H I emission across the southern sky out to a redshift of 0.2 to understand galaxy formation and gas evolution.
- The detection of 10^7 continuum sources, 5×10^5 polarized sources and measurements of 60,000 rotation measures across the sky enabling cosmological tests and the evolution of cosmic magnetism.
- The characterization of the radio transient sky through detection and monitoring of transient sources such as gamma ray bursts, radio supernovae and intra-day variables.
- The discovery of up to 1000 radio pulsars.

We are getting closer towards having to formulate a configuration for the xNTD. The configuration depends on the science drivers; both on the angular resolution, uv coverage and dynamic range they require. The maximum extent and layout of the configuration impacts on

- the computing costs which increase with the square of the baseline
- the uv coverage and fidelity of the beam due to the finite number of elements in the array
- the location of the xNTD relative to the LFD which impacts on the cost via shared facilities and/or fibre links.

In this short note, I consider each of the science drivers in turn and summarise what is likely to be their optimum resolution. In a companion paper, Cornwell (2006) discusses possible layouts of the antennas and imaging issues.

2 Pulsars

Pulsar surveys with an interferometer are expensive computationally because of the need to process every single pixel in the primary beam(s) independently. The pulsar requirement therefore is to have as few pixels as possible, so an ultra-compact configuration is desirable. There is a separate document by Johnston & Edwards (2006) which shows that it may be possible to carry out a pulsar survey with the xNTD out to a maximum baseline of around 1 km. Even this, however, cannot be done for the fastest pulsars but only for relatively slow pulsars.

3 Continuum surveys

Continuum surveys with the xNTD require high resolution for three main reasons. First, deep surveys become confusion limited at low resolution very quickly. Secondly, matching the radio sources with sources at other wavelengths requires arcsec positional accuracy. Thirdly, the NVSS and SUMMS have covered the sky with 45 arcsec resolution (at 1.4 and 0.84 GHz respectively) and it would be desirable to do significantly better. At the same time, there is a need not to resolve out bigger sources. There is an on-going debate about how many sources are missed during deep surveys at 5 arcsec resolution but the general consensus appears to be that the number is small ($< 10\%$) and not really an issue.

The science case of the xNTD shows that for an all-sky survey of duration 1 year, the theoretical sensitivity should be of order 9 μJy (implying detections around the 50 μJy level). The Huynh et al. survey at 1.4 GHz with the ATCA found 466 sources in 0.35 sq deg with a beam of 5 arcsec and an rms of 11 uJy. The mean separation between sources was around 50 arcsec, 10 beamwidths, enough to avoid confusion. As the Huynh et al. survey rms was similar to that achievable by the xNTD, we ideally require resolution of at least 5 arcsec, or baselines in excess of 10 km. This seems unlikely given the current computing budget.

The table above is estimated from Fig 1 in Jackson's SKA article and shows the detection limit, the number of sources per square degree, the number of sources in 30000 sq deg (i.e. the sky visible to the xNTD) and the nearest neighbour distance in arcsec. The final column gives the time it would take to achieve this detection limit with the xNTD across 30000 sq deg of sky.

With a 30 arcsec beam therefore, one may just about acheive the final line of the table, but even then there is 1 source every 6 beams which is marginal in terms of beating confusion. This survey would only find 1/10th the sources of the ultimate 1 year survey and would be confusion limited after 3 days observing.

Table 1: Source counts

5-σ limit (μJy)	N/deg^2	N (all sky)	sep arcsec	time
10	8600	200x10^6	20	25 yr
50	1300	40x10^6	50	1 yr
100	600	20x10^6	75	3 mo
500	110	3x10^6	170	3 day

4 Transient surveys

Two types of transient can be considered, ‘fast’ and ‘slow’. Slow transients (with periods greater than an integration time; 1 min or so) can be detected through normal imaging techniques. To detect fast transients (potentially down to a few ns) requires specialised machinery similar to that for finding pulsars.

Detecting fast transients imposes an enormous computational load. For coherent detection, one needs to sample every pixel in full field of view. Unless the array is extremely compact, fast transient detection is not possible at least in the early days of the xNTD.

Very few (several hundred at best) slow transient sources across the whole sky will be detected and in this sense confusion is not an issue for a transient survey. Repeated images of the entire sky can be subtracted from a global sky model and any deviations recorded virtually regardless of the resolution. However, most transient sources are likely to be very compact (arcsec in size or smaller) and because of the desire to identify the transient counterparts at other wavelengths, high resolution would be better than low resolution. This is less of an issue if follow-up of the sources can be done with a more extended array (eg the 6km ATCA).

5 Polarization surveys

As most sources have very little polarization, the confusion limit is not the same in linear/circular polarization as it is in total intensity. However, the same argument largely applies as for continuum surveys. High resolution is needed for example to resolve double sources and measure any difference in their rotation measure. On the other hand, too much resolution will resolve out the low-surface brightness lobes of radio galaxies. For establishing the RM grid, high resolution is not particularly important (cf the Arecibo survey which will have a few arcmin resolution) and 20-30 arcsec would be adequate.

For the tomography experiment, in contrast, somewhat lower resolution is needed so as not to resolve out the foreground faraday screens. Resolution in the vicinity of 20-40 arcsec is likely ideal for this project.

6 HI (spectral line) surveys

The H I surveys have competing interests as regards the best resolution. The H I line is weak, and galaxies are large in their HI extent. For a detection, therefore, it is preferable not to resolve the galaxy. The all-sky xNTD survey will find M* galaxies to z=0.13 (500 Mpc) and deep survey will detect M* galaxies to z=0.32 (1200 Mpc). If a typical M* galaxy has a diameter of 30 kpc (in H I) it will have an angular size of 50 arcsec at z=0.03, 15 arcsec at z=0.1 and 5 arcsec at z=0.3. Lower mass galaxies have proportionally smaller sizes. This then implies that the optimum resolution would be in the vicinity of 30 arcsec and would almost certainly not want to be as small as 10 arcsec.

In order to identify the H I galaxy with an optical counterpart, good precisional accuracy is required. With a 30 arcsec beam, typical positional errors will be 5-10 arcsec, probably largely sufficient to correctly ID a large fraction of the detections.

Finally, there is a desire to map out the H I in nearby large galaxies which again requires a beam significantly less than 60 arcsec.

The document by Staveley-Smith (2006) provides an in-depth analysis of these issues. His conclusion is that 30 arcsec is about the ideal resolution for the H I survey with the caveat that better (smaller) resolutions will be needed for IDs at higher redshifts.

7 Summary

Table 2: Summary table

Science	desire (arcsec)	cope with (arcsec)
Pulsars	200	40
Continuum	5	25
Polarization	10	30
Slow Transients	1	60
H I	30	60

I have summarised in the table above what each of the key science projects for the xNTD would (a) desire and (b) put up with. The conclusion is that, as we know, the xNTD cannot be everything to everybody. A moderate resolution of 30-40 arcsec would be a fair compromise although it impacts badly on continuum science and may be borderline for providing IDs at other wavelengths.

More work needs to be done, likely with full sky simulations followed by imaging simulations in order to understand all these issues more.

Note that a possible upgrade path to xNTD would be to start compact and, as more antennas come on-line, to increase the baseline length and absorb the computing costs in Moore's Law.

A companion to this paper by Cornwell (2006) discusses configuration designs for the xNTD.

References

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Johnston, S. 2006. ATNF Memo Series 5.
Johnston, S. & Edwards, R. 2006. ATNF Memo Series 9.
Staveley-Smith, L. 2006. ATNF Memo Series 6.