An African VLBI network of radio telescopes

M J Gaylard[1], M F Bietenholz[1,2], R S Booth[3,4], S J Buchner[1], B L Fanaroff[3], G D Nicolson[1], J F H Quick[1], T L Venkatasubramani[3]

[1] HartRAO, P. O. Box 443, Krugersdorp 1740, South Africa
[2] Department of Physics and Astronomy, York University, Toronto, Ontario M3J 1P3, Canada
[3] SKA South Africa, 17 Baker St, Rosebank, Johannesburg, South Africa
[4] Onsala Space Observatory, SE-439 92 Onsala, Sweden

E-mail: `mike@hartrao.ac.za`

Abstract. The advent of international wideband communication by optical fibre has produced a revolution in communications and the use of the internet. Many African countries are now connected to undersea fibre linking them to other African countries and to other continents. Previously international communication was by microwave links through geostationary satellites. These are becoming redundant in some countries as optical fibre takes over, as this provides 1000 times the bandwidth of the satellite links.

In the 1970's and 1980's some two dozen large (30m diameter class) antennas were built in various African countries to provide the satellite links. As these antennas become redundant, the possibility exists to convert them for radio astronomy at a cost of roughly one tenth that of a new antenna of similar size.

HartRAO and the South African SKA Project have started exploring this possibility with some of the African countries.

1. Introduction

New undersea fibre optic cables provide communication bandwidths a thousand times greater than radio links via communications satellites. Large antennas at satellite Earth stations are becoming redundant as a result. This trend has now reached Africa with the advent of fibre optic cables down the East and West coasts of the continent.

More than two dozen large Satellite Earth Station antennas built in the 1970's and 80's exist in Africa. Antennas that are redundant could be refitted for radio astronomy at comparatively small cost.

Africa currently has only one antenna equipped to participate in global radio astronomy using Very Long Baseline Interferometry (VLBI) for high resolution imaging, this being the 26m ex-NASA antenna at Hartebeesthoek in South Africa. The window of opportunity to create an African network of VLBI-capable radio telescopes from redundant large satellite antennas exists now. This African VLBI Network would initially work with existing VLBI Networks such as the European VLBI Network (EVN), but could operate independently if sufficient antennas become available.

Such a network would bring new science opportunities to participating countries on a short time scale, enable participation in SKA pathfinder development and science, and would help create the environment for bringing the Square Kilometre Array (SKA) to Africa.

Figure 1. Locations of identified large Satellite Earth Station antennas in Africa

2. Intelsat Satellite Earth Stations

2.1. Intelsat Standard A Satellite Earth Station antennas

From the 1960's, communication via satellites orbiting the Earth was introduced to carry voice, data and TV signals, to supplement undersea cables. The radio bands allocated for this were 5.925 − 6.425 GHz for uplink and 3.700 − 4.200 GHz for downlink. These are within the frequency range known as "C-band". Intelsat defines Earth Stations for this band as Standard A, B, F or H depending on their technical characteristics [1]. Initially a Standard A antenna had to be at least 30m in diameter, and the antennas built in Africa from 1970 to 1985 are this size. From 1985 new technology enabled satellite transmitter power to increase and the required size was greatly reduced.

2.2. Large Satellite Earth Station antennas in Africa

SA SKA partner countries identified with large antennas are South Africa (3 antennas), Ghana, Kenya, Madagascar and Zambia. Other African countries in which large antennas have been located are Algeria (2), Benin, Cameroon (2), Congo Peoples Republic, Egypt (2), Ethiopia, Malawi, Morocco, Niger, Nigeria (3), Senegal, Tunisia, Uganda and Zimbabwe. These two groups are shown in Fig. 1. In addition, Gabon probably has one and one is reported in the Congo Democratic Republic. The antenna in Mozambique was dismantled and probably also the one in Togo.

2.3. Large Satellite Earth Station antennas outside Africa converted for radio astronomy

Operational converted antennas are the 30m Ceduna antenna in Australia [2] and the 32m Yamaguchi antenna in Japan [3]. The Warkworth 30m antenna in New Zealand was handed over for conversion on 19 November 2010 [4]. In Peru the Sicaya 32m antenna is being converted with assistance from the Yamaguchi team and saw first light in March 2011 [5]. Three antennas at the Goonhilly Downs station in the UK decommissioned in 2008 are proposed for conversion for use with e-Merlin and the EVN [6]. On 10 May 2011 it was announced that the 32m Elfordstown antenna outside Cork in Ireland is to be converted [7].

3. Astronomical applications for redundant large antennas in Africa

3.1. Astronomical Very Long Baseline Interferometry (VLBI)

Widely separated radio telescopes operating together create a virtual telescope equal in size to the project distance, or baseline, between the telescopes. The angular resolution of a telescope depends on its size, so the larger the separation, the better the resolution. Practically, to create good images a number of telescopes are needed, separated by small, medium and large distances.

The HartRAO 26m radio telescope is valuable in providing long baselines to radio telescope arrays in on other continents, e.g. Europe (European VLBI Network - EVN) and Australia (Australia Telescope Long Baseline Array - AT-LBA), and thus high angular resolution imaging. However, the large distance between the South African telescope and the others makes for less than ideal imaging. It would be helpful to have antennas filling the gap between SA and Europe and SA and Australia (for example) and the image quality would be substantially improved. They would be a powerful addition to the radio telescope arrays on other continents.

To create an interferometer able to operate independently to produce images, a minimum of four antennas are needed to provide both phase and amplitude closure. Thus a minimal African VLBI Network (AVN) able to operate independently of the radio telescopes on other continents could be formed if four suitable antennas were brought into use on the continent and on neighbouring islands. Science capability would improve substantially if more large antennas could join the network. With four antennas, 50% of the phase information and 33% of the amplitude information can be recovered; with ten antennas these rise to 80% and 78% respectively [8].

Astronomical objects suitable for study by VLBI are those that are radio-bright and of small angular size. Objects of very large physical size meet this requirement if they are quite distant, and radio galaxies and quasars are examples. Radio-bright supernovae in external galaxies are good examples of objects whose evolution can be studied with VLBI. Masers in star-forming regions in the Milky Way are examples of nearby bright, compact sources. Methanol masers at 6.668 GHz and 12.178 GHz are of particular interest currently. Measurement of their annual parallaxes by repeated VLBI observations enables their distances to be determined, and thus the locations of the spiral arms in the Milky Way, where these occur, to be measured accurately. This is only being done by northern VLBI arrays currently, leaving the fourth quadrant of the Milky Way, in the far southern skies, so far unmapped by this method.

Distances to pulsars can be obtained by astrometric VLBI. Transient sources and gamma-ray bursters are all potential targets. The on-going study of southern hemisphere radio galaxies (TANAMI project) would be enhanced with extra telescopes able to see the southern skies. Microquasars in the Milky Way are targets, as are radio-loud interacting binary stars such as Circinus X-1.

Spacecraft in interplanetary space and at other planets that are equipped with 8.4 GHz frequency-stable transmitters are being used for precise spacecraft position determination and for study of the interplanetary medium. This technique is known as the Planetary Radio Interferometry and Doppler Experiment (PRIDE). The HartRAO 26m telescope, and others, are regularly observing the Venus Express (VEX) spacecraft in orbit around Venus for this purpose. The Russian Phobos-Grunt mission to Mars' moon Phobos is due for launch late in 2011 and will use this technique. Converted satellite antennas with 8.4 GHz receivers in Africa would be good for this owing to their collecting area and location near the equator.

3.2. Single-dish astronomy

The only VLBI array that runs essentially continuously is the US Very Long Baseline Array (VLBA). The EVN now runs much more frequently than the traditional three four-week sessions per year of the past, with monthly e-VLBI (real-time data streaming to the correlator) and Target Of Opportunity (TOO) VLBI. However there would still be substantial non-VLBI time available for operation of each telescope as a stand-alone instrument.

This time would be valuable for student training purposes and for selected research projects. Techniques that could be developed would be radiometry - measuring the brightness of broad-band emission sources, spectroscopy - measuring emission and absorption line strengths, and pulsar timing - measuring the arrival times of pulses from neutron stars. Establishing a capability for unattended queue-scheduled single-dish observing (as on the HartRAO 26m telescope) would greatly assist in permitting time series to be built up of the behaviour of scientifically interesting variable sources that can be observed with these techniques.

4. Towards the AVN

4.1. Identifying candidate antennas

Intelsat documentation and internet mapping services using high resolution photography of the Earth's surface enabled the current existence of the large antennas to be confirmed. Postage stamps commemorating their inauguration were another valuable source of information. Government level contact has been made with some of the countries to further investigate the possibility of conversion. Ghana was one of those approached, and was quick to seize the opportunity.

4.2. The Kuntunse Satellite Earth Station in Ghana

The Ghanaian government and Vodafone, the owners of the Kuntunse Satellite Earth Station outside Accra, have agreed to convert the 32m antenna at the station for radio astronomy. This antenna has been out of service for about ten years; an adjacent 16m antenna is carrying the remaining satellite traffic. A HartRAO team and Prof. Michael Jones from Oxford University visited Kuntunse in March 2011 for an initial feasability investigation, which indicated that it was in a suitable condition to proceed (Fig. 2). A HartRAO/SASPO team visited in May to assist in starting the rehabilitation.

This antenna is located roughly half way between South Africa and Europe. Fig. 3 shows how it fills the gap in UV coverage for VLBI of the EVN with Hartebeesthoek. It is 6^o north of the equator and so it can see the entire plane of the Milky Way and almost the entire sky.

4.3. The antenna conversion process

The drive systems of out of service antennas will generally need some rectification, and this is in process with the Kuntunse antenna.

More challenging is the development of radio astronomy receiver systems. The initial aim is to build receivers for operation in radio astronomy bands within the original Intelsat band range, possibly re-using the existing microwave feed horn. The most commonly used frequency band for VLBI in the EVN is 4.8 - 5.1 GHz; it falls between the current transmit and receive bands of the antenna and should not be difficult to implement with the existing feed. The 6.7 GHz methanol maser line lies a little above the feed design upper frequency and tests will be needed to see if it works at this frequency. Wide (octave) band feeds and multi-band feeds are now commonplace. A feed covering 4.5 to 9 GHz, either continuously or only in the relevant radio astronomy bands, would include the two bands already discussed and the 8.4 GHz VLBI band and would permit a wide range of science to be done.

Various options exist for developing capability outside these bands. The antenna design is the so-called "beam waveguide" in which large diameter pipes with 45^o mirrors pass the signal

Figure 2. The Kuntunse 32m antenna photographed in March 2011.

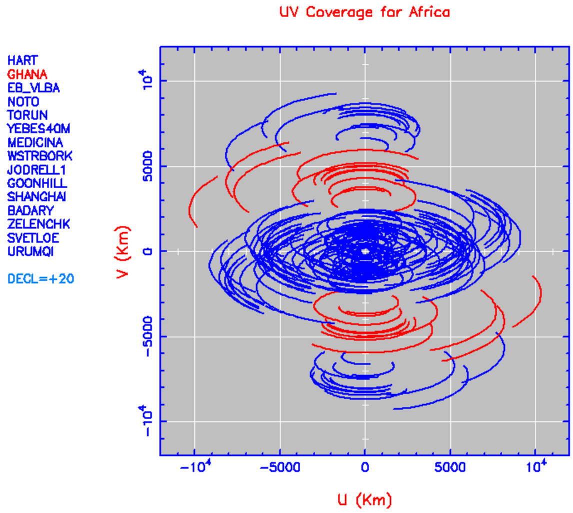

Figure 3. VLBI UV diagram for a source at +20° declination. The red tracks show how the Kuntunse antenna improves the UV coverage by filling the gap between Europe and South Africa.

to a focus in the room below the antenna, where the receiver is located. Most of the African antennas are of this design. It comes with some advantages and disadvantages compared to the Cassegrain design widely used on radio telescopes of this size, but the technical issues are solvable.

5. Summary

The potential for converting obsolete large antennas for radio astronomy has been recognised World-wide. The opportunity exists for African countries to re-use these expensive assets that are becoming redundant to promote science development on the continent, at relatively low cost.

References

[1] *Intelsat Earth Station Standards (IESS) Document IESS-207 (Rev. 4)* 2005 (Luxembourg: Intelsat)

[2] McCulloch P M, Ellingsen S P, Jauncey D L, Carter S J B, Cimo G, Lovell J E J and Dodson R G 2005 *ApJ* **129** 2034

[3] Fujisawa K, Mashiyama H, Shimoikura T and Kawaguchi N 2002 Proc. IAU 8th Asian-Pacific Regional Meeting, vol II, ed S Ikeuchi, J Hearnshaw and T Hanawa (Astron Soc Japan) p 3

[4] Mansfield I 2010 *Telecom New Zealand Converts Satellite Dish into Radio Telescope* http://www.-cellular-news.com/story/46534.php

[5] Finn E 2011 *Peru: Interstellar contact made in Huancayo observatory* http://www.livinginperu.com/-news-14300-environmentnature-peru-interstellar-contact-made-huancayo-observatory

[6] Heywood I, Klockner H-R, Beswick R, Garrington S T, Hatchell J, Hoare M G, Jarvis M J, Jones I, Muxlow T W B and Rawlings S 2010 *Astronomy with Megastructures: Joint Science with E-ELT and SKA* ed I Hook, D Rigolpoulou, S Rawlings and A Karastergiou (*Preprint* http://-arxiv.org/abs/1103.1214)

[7] Fitzpatrick L 2011 *32m Dish To Get New Life As Deep Space Radio Telescope* http://www.-nationalspacecentre.eu/#/release-deep-space-radio-tel/3845815

[8] Pearson T J and Readhead A C S 1984 *ARAA* **22** 97