DETERMINATION, CONTROL AND IMPROVEMENT OF AN SKA RADIO ENVIRONMENT IN SOUTH AFRICA

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ABSTRACT

South Africa, in its bid to host the SKA[2], has adopted a dual approach to determine, assess and improve the radio environment and RFI[3] that would be experienced by the SKA. The one approach was to determine all the transmissions that would provide signals which exceed the various threshold levels, including the saturation level, by means of computerised signal level calculations and the establishment of a database which could be used for assessment and analysis. The other was to carry out RFI measurements at the sites according to the RFI Measurement Protocol. This paper provides a review of the data collection and the computerised signal calculation process.

As the telecommunications and broadcasting regulatory framework will play a key role in the control and improvement of an SKA radio environment, an analysis of the existing regulatory framework in the context of the SKA was done considering the SKA science requirements, ITU[4] Recommendations and Resolutions and South African legal provisions. An overview of this process is provided.

Even in sparsely populated areas there is a significant amount of RFI. Reduction of the existing interference is required remove saturation level signals and to decrease the amount of mitigation required.

INTRODUCTION

The South African project to study the radio environment for the SKA started early in 2003 with the first target being to provide input for the South African site proposal due at the end of May 2003. The initial study was focussed on the SKA core site for which three optional locations had already been chosen in the sparsely populated Northern Cape Province. Study of the remote sites would follow later.

It was considered to be critical to know what the existing radio environment was like, how the three optional sites compared and how they related to the threshold levels specified in Recommendation ITU-R RA.769-1. The initial

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[2] Square Kilometre Array
[3] Radio Frequency Interference
[4] International Telecommunications Union

study covered the frequency spectrum from 150 MHz to 22 GHz and was limited due to the time constraint to a search distance of 150 km and signals down to the VLBI[5] level. It provided an understanding of the radio environment and all the role players, but was not considered to be an adequate analysis. The study had to be continued to provide a representative, adequate and consistent result.

The second phase of the study started in the second half of 2003 and continued until April 2004. This phase was focused on a deeper analysis of the radio environment, on the development of concept plans to improve it and an analysis and determination of policy and regulatory requirements to control and maintain the radio environment. The frequency spectrum covered was extended to 25 GHz to accommodate more recent specifications for the SKA. Recommendation ITU-R RA.769-2, which had in the meantime been published, was used as a reference. The Resolution of the ITU in WRC-03[6] to study the requirements of new generation radio telescopes and to consider the results in the WRC-07 was noted.

The radio environment study was subject to limitations in respect of available expertise and funds, but notwithstanding these limitations a considerable amount of work was done by the available experts and by using computerised planning systems.

DETERMINATION OF THE EXISTING RADIO ENVIRONMENT

The various aspects to determine the existing radio environment are discussed below.

Strategy adopted

The process to determine the existing radio environment was carried out as follows:

- The collection of data on all transmissions which would exceed the spectral-line threshold level at the centres of the core site options.
- The calculation of signal levels at the centre of the core sites. It was not feasible to determine signal levels at the periphery of the core sites, e.g. at a certain radius. The calculation process was integrated with the first step on data collection.
- The creation of a database in which all the data and calculation results were placed and which could be used for the analysis. Microsoft Excel was used because of its general availability.

[5] Very Long Base-line Interferometry
[6] World Radio Conference held in 2003 by the ITU

At the start of the process, the challenge was how to obtain the data and determine the signal levels. It was at first thought that at least the data should be available at the South African communications regulator but this was not the case. Independent regulation in South Africa was only established 1994 and has not yet matured to the point where it possesses a comprehensive and accurate radio environment database. Furthermore, it was realised that interaction with and the co-operation of the broadcasting signal distributors and the telecommunications facility operators would be necessary on the road ahead to determine the existing radio environment and to improve it. There is also confidential information involved where undertakings had to be given to protect commercial and competitive positions. This arrangement did not exclude a relationship with the regulator as their role is essential to support the SKA and to create the required regulatory framework as discussed later in this paper. The strategy to follow was thus determined.

Calculation and prediction of signal levels

The calculation of signal levels was carried out by using computerised broadcasting transmission and telecommunications radio communications planning systems which are normally used to assign frequencies with acceptable interference levels, to evaluate link paths and to determine coverage areas. These systems include those provided by ICS Telecom in France, LNS in Germany and others. The calculation process was governed by ITU Recommendations[7] and was carried out according a calculation procedure agreed to between the parties. Both free space propagation loss and propagation path loss due to topography were taken into account in predicting the signal levels. The signal levels provided were evaluated by spot calculations, experienced judgement and comparison between similar systems operated by the different entities.

Only the tropopheric propagation mode was considered at the percentage of time probability of 50 % that is normally used for service planning purposes. It could be argued that predictions should also have been done for small percentages of time but then other modes of propagation over very long distances, such as tropopheric scatter and meteor scatter, would also have to be considered and would have increased the complexity of the process and the size of the database considerably. It probably would have involved all the higher powered transmission in South Africa and its neighbouring states. Such signals would have been lower than that from nearby transmissions but would also be on the same frequencies as those already taken into account.

[7] Recommendations ITU-R PN.525-2; ITU-R P.341-5 and ITU-R P.1144-3

Future developments

In the above process, future development plans to expand networks and coverage were also probed but not much information was gained from that process except for trends that will be useful when the improvement of the radio environment is considered. Operators are reluctant to divulge their future plans due to competitive positions but they have also moved away from long term network development plans and rather respond to market demands and technological developments. Capacity utilisation and profitability also has its impact on this approach to future planning.

Comparison to RFI measurements

Some comparison of the calculated signals with radio frequency interference (RFI) measurements has been done. The higher level signals which could be measured could be identified and related. More analysis and improvement of the measuring technique is required to take the matter further.

STUDY RESULTS AND DISCUSSION

Radio environment database

The database is really a set of large spread sheets with one spread sheet for each site (4 Excel sheets for each site). Frequency spectrum heads up the columns and the various signals and transmission data are stacked in the columns below the respective frequencies. All the frequencies being used for transmissions which produce signals exceeding the spectral-line threshold level at the SKA core site options are reflected. The columns contain the following information:

- Aggregate interfering signal level, saturation signal level and the VLBI and spectral-line threshold levels at each of the frequencies. The threshold level values were obtained by interpolation from the tables in Recommendation ITU-R RA.769-2.

- Provision is made for transmission data and signals from 6 stations on each frequency and which are entered in decreasing signal level order for all the available signals. If the number of signals exceed 6, then the lower level signals are not entered.

- Each station block contains a station name or reference, geographical coordinates (degrees, minutes and seconds), operator, effective isotropic radiated power, antenna height, distance to SKA site, signal level categorised in above saturation, VLBI or spectral-line level, and the bandwidth in categories below 250 kHz, above 250 kHz but below 10 MHz and above 10 MHz.

All this data was used to analyse, to quantify and to understand the radio environment.

Saturation level

The saturation level is defined as that level which may overload the front end (at radio frequency level) of the SKA telescope and drive it into a nonlinear regime or cause loss of observation data. Filtering or mitigation techniques may of course be applied to overcome the situation but the purpose in the study is to determine the source and where in the spectrum such high level signals occur.

The saturation level for the SKA telescope receivers is as yet an unknown quantity. In order to proceed with the radio environment study work, we adopted a level of -100 dBm across the SKA spectrum, as recommended in the description of the Mode 1 RFI measurement protocol. This power level was converted to spectral power flux-density across the SKA spectrum in the same way as in Recommendation ITU-R RA.769-2 for the threshold levels. It will be seen from the study results that the consideration of signals exceeding the saturation level is important.

Analysis and discussion of the results

The aggregate signals across the spectrum are available in graphs together with the threshold levels and also in a combined graph to compare the three optional sites.

A summary of the total number of signals at each optional site which exceeds the respective threshold levels are given in the table below.

Number of signals exceeding the relevant levels			
Site	**Saturation**	**VLBI**	**Spectral-line**
Kalahari	60	275	1195
Karoo	44	278	1045
Namaqua	49	239	828

The distance of interfering signal transmitters from the SKA core site options for signals in the different threshold level categories vary due to different radiated power levels and topographical paths as illustrated in the table below.

Distances of interfering transmitters to SKA core sites						
Site	**Saturation**		**VLBI**		**Spectral-line**	
	Min	Max	Min	Max	Min	Max
Kalahari	66	184	66	552	67	822
Karoo	14	270	65	576	52	871
Namaqua	63	315	53	665	78	900

The database includes satellite based transmitters but they are not considered in the above table in connection with distances. Conclusions drawn from this information are:

- That the distances of the transmitters over which the interfering signals travel vary considerably as a result of different transmission characteristics, including power levels, elevation of transmitting sites and the intervening topography.

- That the interfering level signals are produced over very large distances.

The frequency spectrum occupancy is defined as the sum of all the signals exceeding a threshold level, multiplied by their respective signal bandwidths and is expressed as a percentage of the SKA frequency spectrum from 150 MHz to 25 GHz. The spectrum occupancy at the saturation, VLBI and spectral-line threshold levels are as shown in the table below.

Frequency occupancy at the three optional core sites			
Threshold levels	**Kalahari**	**Karoo**	**Namaqua**
Saturation level	0.10 %	0.17 %	0.16 %
VLBI	2.93 %	2.88 %	2.82 %
Spectral-line	7.68 %	7.48 %	6.52 %

Another analysis carried out was to determine the numbers of signals for the different bandwidths which exceed the various threshold levels. The results are given in the following table for one of the core site options. Aeronautical and weather radar systems were left out of this analysis.

Number of signals at different bandwidths exceeding the threshold levels at the Karoo site			
Bandwidth	**Saturation**	**VLBI**	**Spectral-line**
12 & 25 kHz landmobile	32	136	526
200 kHz cellular telephony	0	19	38
0.5 to 3.5 MHz wireless local loop and digital links	0	37	299
6 MHz analogue television broadcasting	8	41	119
28 to 40 MHz microwave and satellite	0	15	45

Prevailing interference impact

From the various analyses, it is concluded that the greatest impact on the SKA radio environment can be summarised as follows:

- Narrow band land mobile signals
- High power analogue television broadcasting signals
- Primary aeronautical surveillance radar and weather radar

CONTROL OF THE RADIO ENVIRONMENT

The control of the radio environment means control of the radio frequency spectrum which is a public resource and which is controlled by means of national policy (legislation) and regulation. Such control is of course based on ITU Radio Regulations and Recommendations. The future of the radio environment can be influenced by appropriate policy directions and regulatory implementation. Consultation would of course be required in connection with existing rights and the cooperation of the frequency users obtained. The time available before the SKA telescope goes into operation should be sufficient for normal migration processes in connection with frequency allocation and usage.

Policy and regulatory development

The major steps required to provide for the SKA telescope and an acceptable radio environment could be summarised as follows:

- Policy promulgated by the National Assembly (legislation) to mandate the establishment of the SKA telescope and to ensure a long term stable radio environment.

- Radio quiet zones (reserves) need to be declared and demarcated on official maps.

- Amendment of existing legislation in respect of broadcasting and telecommunications to provide for the control of emissions in radio quiet zones and for provisions to support the SKA radio environment.

- Participation in ITU activities to develop recommendations and resolutions for the new radio astronomy.

- Review of existing local regulations and the making of new regulations to support the SKA telescope in the control of the radio environment.

- Review of existing frequency licences and inclusion of provisions in new licences to support the SKA radio environment.

The regulator

The South African regulator for both broadcasting and telecommunications is ICASA[8]. A working relationship has been established with ICASA in respect of the SKA project. The ICASA Council established a Special Committee to attend to regulatory matters in respect of the SKA telescope. The activities which preceded this step are the following:

- A study was carried out for the SASSC[9] in October 2003 on the spectrum regulatory framework required for the radio environment at the SKA sites. The study included a review of the requirements for radio quiet zones as set out in SKA Memorandum #2, provisions of the ITU Radio Regulations and Draft Resolutions from WRC-03, existing South African broadcasting and telecommunications legislation and frequency plans and the policy and regulatory improvements and provisions required.

- The SASSC also participated in a public enquiry process conducted by ICASA early in 2004 to review an existing frequency band plan for the frequency spectrum from 20 MHz to 3 GHz. Substantial written and oral submissions were made in connection with the shortcomings in the frequency band plan for radio astronomy. The opportunity was also used to provide information on the SKA telescope and its requirements, which is now part of the public record.

[8] Independent Communications Authority of South Africa, established in terms of Act number 13 of 2000, and which succeeded the former Independent Broadcasting Authority (IBA) and the South African Telecommunications Regulatory Authority (SATRA)
[9] South African SKA Steering Committee

Meetings with ICASA are ongoing and involve the progression of the following activities:

- ICASA's support and involvement in ongoing RFI measurements.
- Discussion and planning on policy and regulatory framework development.
- Interaction with the regulators in the neighbouring countries.
- Participation in ITU developments for new radio astronomy.

Regional regulation

If the SKA telescope were located in South Africa, its remote antenna stations would inevitably overspill into neighbouring countries, so it will be important to facilitate a similar policy and regulatory framework in these countries. An approach has already been made to TRASA[10] which involves the SADC[11] countries but direct relationships will be established with the particular countries in which remote stations will be placed. A meeting has also been held at ministerial level.

IMPROVEMENT OF THE EXISTING RADIO ENVIRONMENT

The primary goal of the improvement would be to reduce the number and level of signals that cannot be removed so that the burden on mitigation is minimised.

Role of radio communications

Radio communications play a critical role in providing broadcasting and telecommunication services, in particular in the Northern Cape Province of South Africa which is sparsely populated with a low level of infrastructure development compared to higher population density areas. This part of the country does not provide a lucrative opportunity for broadcasting and telecommunication services; however certain industrial activities such as mining and transport demand services, as does the universal service policy of government. In a low service density scenario, radio communication is more effective than cable or wire systems although the latter (in optical fibre format) is increasingly being used to interconnect radio stations.

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[10] Telecommunications Regulatory Association for Southern Africa

[11] Southern African Development Community which includes Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.

Possible improvement of the existing radio environment has to seen against the above scenario. Fortunately, the new radio communication technologies in digital format and in broadband provide lower power spectral densities.

Improvement scenarios

The time available before the SKA telescope goes into operation is a strong positive factor which offers a significant opportunity for RFI environment improvement without financial impact necessarily attributable to the SKA project. All the existing systems with their equipment will become obsolete within the available time frame. In the replacement process, re-engineering can take place to improve the radio environment. It would however be critical that timeous decisions are made in respect of government policy and provisions in the regulatory framework for the SKA telescope.

There are many options and scenarios that can be considered. Some examples are described below:

- High power analogue television broadcasting is one of the high impact activities. It is also a fact that these transmitters are not an adequate or an economical solution in sparsely populated areas. These areas are in any case also served with direct to home digital satellite broadcasting. Analogue terrestrial broadcasting is due to be succeeded by digital terrestrial broadcasting in the next decade. In the sparsely populated areas, a more economical solution would be to rely on satellite broadcasting and low power digital terrestrial re-transmission where population concentrations occur. This scenario presents the opportunity to significantly improve the SKA radio environment.

- High power aeronautical surveillance radar and weather radar also have a significant impact. The opportunity for improvement in this case lies with a migration to aeronautical secondary surveillance radar systems which interact with transponders on the aircraft and operate at much lower power levels. For weather radar, the use of satellites may be the answer.

- Another activity with significant impact is narrow band land mobile radio communication operating in the VHF and UHF frequency bands. The solution here is either to migrate to frequency bands below the SKA band or to migrate to broadband digital systems.

These are just a few examples. Fortunately, new technology radio communication, particularly in digital broadband format, does seem to be less troublesome. It would however be necessary to obtain the cooperation of the operators and users, and to promulgate national policy and regulations to encourage, mandate and support a migration process. The migration would also have to be managed and monitored to ensure that it is timeously carried out.

CONCLUSIONS

The radio environment and the regulatory system are inextricably linked and are critical elements in the development, establishment and operation of an SKA radio telescope. The existing SKA radio environment, even in sparsely populated areas, contains significant interference but can be improved. The regulatory system needs to be developed to provide for new radio astronomy.

11 June 2004