Signal Transport and Networks for the SKA

Roshene McCool[1], Simon Garrington[2], Ralph Spencer[2]

[1]Square Kilometre Array Program Development Office, Jodrell Bank Centre for Astrophysics, 3rd Floor, Alan Turing Building, The University of Manchester, M13 9PL, UK. mccool@skatelescope.org
[2]The University of Manchester, Jodrell Bank Observatory, Macclesfield, Cheshire, SK11 9DL, UK. simon.garrington@manchester.ac.uk, ralph.spencer@manchester.ac.uk.

Abstract

The signal transport and networks of the SKA are the backbone of the telescope, they interface with almost every aspect of the system. They provide services, fundamental to the operation of the SKA as an aperture synthesis interferometer, such as timing and synchronization and the transmission of data from receptors to a correlator. Signal transport and networks provide communication links both internally to the telescope and externally to the SKA regional centers around the world. This paper will describe the requirements placed on these networks by the telescope and the technical progress in developing solutions to deliver this required functionality.

1. Introduction

The networks of the Square Kilometre Array (SKA) represent one of the largest and most challenging network systems in science. The network infrastructure physical layer will be, in the main part, based on optical fiber cable. The network infrastructure will carry functions that are advanced and challenging in their own right such as timing and synchronization, data transmission and monitor and control (M&C). These functions are essential for the operation of the telescope as an aperture synthesis interferometer and will be described, in turn in this paper.

A system engineering approach has been adopted, and indeed, is considered essential, to the successful definition, design and development of the SKA.[1] The project is at a preparatory phase in which the system is being defined and described at a concept level and possible technical solutions are under development at participating institutions engaged in the global SKA collaborative effort. In the STaN domain, these groups can draw upon advances in the fields of telecommunications, computing and timing and synchronization.

2. Phased Approach to construction of network infrastructure

The construction of the SKA represents a major undertaking. A phased approach has been adopted in order to spread the cost impact of such a large infrastructure project [2]. The international project has adopted the following terminology to describe this phased approach: SKA1 is the initial deployment (10%) of the array at low and mid-band frequencies and is a sub-set of Phase 2 (SKA2) [3], SKA2 is the full collecting area at low and mid-band frequencies (~70 MHz to 10 GHz). The phased construction of the SKA enables the project to make maximum use of advances in technology. In parallel with the design of a baseline SKA design, advanced instrumentation programs (AIP) will develop wide band and wide field of view technologies for inclusion into the telescope when these designs mature.

The phased approach described here, has an impact on the design of the physical layer of the STaN. The cable networks, once installed, will not be easy to upgrade. The cable routes are part of the fixed infrastructure of the telescope and as such need to be designed to support the instrument throughout its lifetime. For this reason the extensibility of the SKA1 cable infrastructure to SKA2 requirements will be an important part of the preparatory phase analysis. Extensibility, in this context, does not mean that cable infrastructure will be constructed to potential SKA2 sites in SKA1, but that those SKA1 cable routes that will serve SKA2 sites in the future have sufficient capacity to do so. Figure 1 illustrates the distribution of receptors in SKA1 and SKA2.

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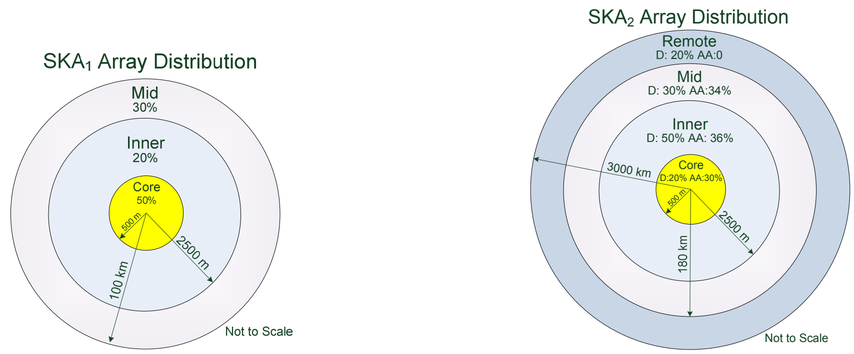

Figure 1 Distribution of collecting area for SKA1 and SKA2

3. Timing and Synchronization

Aperture Synthesis telescopes, like the SKA, add signals together from many distributed elements in order to provide the performance, as an array, of a single instrument with equivalent diameter and collecting area. Coherence of signals from individual elements of the array is fundamental to the operation of the telescope as an interferometer. It is the function of the synchronization sub-systems within the SKA to provide the signals required, over the required bandwidths and distances. Coherence requirements and the period over which that requirement holds are linked to the observations that will be undertaken by the telescope. Notable parameters that effect these requirements are the highest frequency of interest, the maximum integration time of signals at the correlator and the calibration regime adopted for the observations [4].

For SKA1 the highest frequency of interest is 3 GHz. In order to provide extensibility to SKA2, the synchronization system will have to provide a coherence time suitable for observations up to 10 GHz. Figure 2 shows a plot of coherence loss (1-C) against r.m.s phase variation δ for a Gaussian distribution of phase values of zero mean. The figure indicates that a 2 % loss occurs for a 0.2 radian (= 11.5 degrees) phase variation. This is about at the level of accuracy of amplitude calibration of current instruments. In practice this means that for SKA2 a frequency reference is required with an r.m.s fractional frequency variation (Allen deviation) of less than; $3x10^{-12}$s within a typical integration period of 1s. Longer term stability is likely to be required and will depend on the calibration approach adopted and different frequencies, this is being investigated [5].

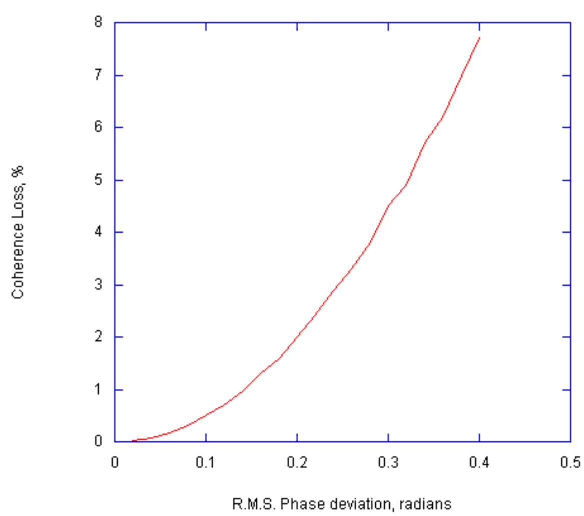

Figure 2. Plot of coherence loss as a percentage *vs* r.m.s. phase deviation for a random variation within the integration time.

Local oscillator systems and clocks for analogue to digital converters will use this frequency reference as their source. In radio telescopes operating at up to 40 GHz today, synchronization to the required stability is provided by a local, hydrogen maser (in the VLBI case) or a distributed frequency reference signal, locked to a central 'master' hydrogen maser frequency standard. Either of these methods might be used by the SKA. Other oscillators are being reviewed for use within the system, such as passive hydrogen masers and high quality crystal oscillators.

While interferometers require relative synchronization for coherent integration, there are also requirements on absolute timing, mostly for timing observations of pulsars. One of the key experiments for SKA is the detection of gravitational waves using a network of pulsars in the Galaxy. Currently the best timing observations of millisecond pulsars achieve an accuracy of a few tens of milliseconds. The goal for timing systems in SKA 1 is 10 nanoseconds or better and the goal for SKA2 is a few nanoseconds. On long timescales, >3 yrs, pulsars may offer the most stable timescales, and are currently comparable to microwave clocks [6]. There are many SKA functions that have will use the time server at a station or dish location, such as the monitor and control (M&C), correlator and computing systems.

GPS offers the most readily available technique for time transfer – since the transmissions from satellites are linked to international atomic time standards. Current accuracy using direct timing is around 10 ns [7], though common view techniques where an individual GPS satellite is observed by multiple spaced receivers to reduce atmospheric propagation delay variations can achieve < 5 ns, with stabilities of ~ 1 ns /day [8] Use of carrier phase techniques can achieve < 0.5 ns [9].

4. Monitor and Control

The M&C system for the SKA will have to connect many thousands of elements in the array. The architecture of the M&C system will be dictated by the availability requirements and the safety critical functions identified for the system. The nature of the SKA networks leads us naturally to the implementation of large data streaming 'pipes' in a star network configuration. This network architecture has been used in other radio telescopes around the world. Commercial networks favor ring or mesh architectures for their ability to provide alternative routes in the case of breakages, and hence better reliability. Ring and mesh architectures are, however, more expensive and require intelligence in the networking equipment. For the SKA, further analysis of the M&C network reliability requirements may lead us to a compromise between ring or mesh and star architectures. It is very likely that the M&C networking equipment will be sourced from commercially available standard product lines. Using commercially available products will allow expansion of the system from SKA1 to SKA2. Access to spares and support will help in the operation of both phases of the project.

5. Data Transmission

The data transport function represents the largest user of the SKA network. The total bit rate (R) of the receptor array with an effective area (A_{tot}) scales proportionally according to the relationship shown in equation 1. Where λ is the wavelength of operation, B is the instantaneous bandwidth of the receiver and Ω is the field of view:

$$R \propto \frac{BA_{tot}\Omega}{\lambda^2} \quad (1)$$

The data from each element in the array must be transported to a Signal Processing Facility (SPF), located somewhere near the centre of the array. In SKA1 alone the transport of data from dishes and stations to the SPF is estimated to be the equivalent of the global IP traffic generated in 2010, or around 67 Terabits/s [10]. Developments in the field of telecommunications mean that systems operating at 100 Gbps are available commercially, today. The suitability and scalability of such systems to a radio astronomy environment is being studied as part of the SKA design process. An alternative approach to the provision of transmission systems from commercial vendors is to design and construct equipment customized to the radio astronomy environment. The nature of the SKA network is very different from the interconnected mesh that is the world-wide web and this can be used to simplify the transmission infrastructure. Notable differences between a radio telescope data network and a standard commercial network are;

- A radio telescope can accept a lower availability than a commercial network,
- The data are not, in their own right, valuable.

- The network is deterministic. That is to say the data always flows from one known location to another and the route is static.
- The data traffic is unidirectional (this excludes, of course, the clock and M&C functions).
- The stability of timing is critical.
- For SKA1 the collecting area is within 100 km of the core

The motivation for simplification is driven by the desire to reduce cost, power and radio frequency interference without compromising the required performance or operation of the system.

In addition to the networks described in detail here, the SKA will also have networks that connect the HPC to; the SPF, the wider world and the SKA Headquarters. The precise locations of these facilities and their requirements have yet to be described in detail. The proposed architectures and solutions for these networks will be developed in the next stage of the project, after site selection.

6. Conclusion

The networks of the SKA represent one of the most complex network systems in science. It contains systems for M&C, timing and synchronization, data transport of received data within the array and data transport in order to communicate to a wider world. The data transmission system for receivers, alone, compares in scale with the aggregate of the world's IP traffic. A system engineering approach has been adopted and a global collaboration of participants is working towards specifying requirements, identifying technical solutions to meet those requirements and developing designs to fit into an SKA system. This process has begun in the SKA preliminary phase and there are plans to continue into a pre-production phase. Upon construction a first phase SKA1 will be built followed by a much larger observatory SKA2, possibly with the inclusion of wide band and wide field of view expansion technologies.

7. Acknowledgments

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