1 Document purpose

The purpose of this document is to present the set of requirements for planning the computing infrastructure of a test sub-array for the EISCAT_3D project. This document is intended for EISCAT_3D project members and stakeholders associated to the project.

2 Introduction

A test facility will be created in order to address the bottlenecks that need to be passed in order to start construction of the EISCAT_3D radar system. This will be accomplished by procuring, installing, commissioning and test-operating a sub-array unit (the Test sub-array) of the radar system under realistic conditions of an Arctic environment near where the full EISCAT_3D system will be installed. In order to follow the EISCAT_3D implementation schedule, the computing requirements first deal with requirements for the test sub-array. These requirements, by extension and based on the experience of operating the sub-array, would be those for the sub-arrays in the final deployment.

In the final deployment, the EISCAT_3D sites will be remotely controlled by the operations centre. The EISCAT_3D data from levels 1a to 3a [1] from the receive arrays will be sent to the operations centre and the transmit and receive arrays controlled by the operations centre. Therefore, the EISCAT_3D test sub-array deployment should imitate the final deployment as closely as possible.

In order to test the dipoles in a realistic environment, it is planned to deploy a test sub-array at Ramfjordmoen, under conditions that are similar to those of the
proposed transmit/receive site, near the EISCAT Tromsø facility. There is also a
plan to install a radar transmitting module for the EISCAT_3D test sub-array at
Ramfjordmoen as in-kind contribution by an associate country.

There is a VHF transmitter available nearby that will be used to generate the
test radar signals. The signals that are received and processed are then sent from
the test sub-array to the computing facilities at Ramfjordmoen. This will give an
opportunity to test the on-site computing model for sub-arrays. This document
gives the requirements for the on-site computing for an EISCAT_3D test sub-array.

Each of the EISCAT_3D sites has an antenna array consisting of 9919 double-
dipole antennas (one dipole for each of the two polarizations). The antennas are
physically laid out on a triangular lattice, with a distance between the antennas of
about 1 m. The overall shape of the antenna field is close to circular with a diameter
of about 100 m, Figure 1 shows a representation of this configuration. In order to
simplify the on-site processing and hardware optimization, the antennas are split
into 109 sub-arrays with 91 antennas each. These sub-arrays form hexagons with
sides of about 5 m.

Figure 1: The EISCAT_3D array, top left, is composed of 109 sub-arrays.
Each sub-array has 91 dipole antennas.
3 Sub-array computing

The sub-array computing, directly attached to each sub-array, is used to perform the first stage beam forming. This sub-array computing in the overall EISCAT_3D computing model is represented by block 3 in Figure 2. The test sub-array is planned to be a prototype for the production installations and should replicate the conditions foreseen for the final EISCAT_3D experiment.

The digital samples from each of the 91 antennas are combined using ten different phasings, resulting in up to ten wide-angle beams [2] [1] (with two polarizations). The raw data stream from each antenna will be sampled at a 60 MHz rate by an analogue-to-digital converter resulting in a series of 16 bit numbers (one bit reserved for timing to be discussed).

It is planned to operate with two two different bandwidths 5 MHz and 34.67 MHz. The initial EISCAT_3D operation will be at 5 MHz bandwidth, subsequently moving to 34.67 MHz. The operations are planned in this manner due to projected equipment costs at the start-up time. It is planned to provision computing and network capacity sufficient for the full 34.67 MHz operations from the start of the EISCAT_3D project.
3.1 Computing capacity requirements

The beam forming performed in the sub-array is essentially a series of digital signal processing (DSP) operations. The lower bound on computing power for these DSP operations in the test sub-array can be calculated. Each data stream coming from a single polarization of an antenna is sampled digitally at 104 MHz [4]. This sample rate is divided by 3 resulting in a bandwidth of 34.67 MHz of complex in-phase and quadrature samples. These are passed through a 51 tap (real coefficient) DSP Finite Impulse Response (FIR) filter with delays in the order of picoseconds applied [5]. The number of Multiplications and Additions (MACs) required per FIR filter is generally one. Hence, the total number of MACs required for each FIR filter is 34.67 MHz × 51 MAC = 1.768 GMAC/s. Computing power is generally expressed in Floating-point Operations Per Second (FLOPS) and 1 floating-point MAC/s is considered equivalent to 2 FLOPS. Therefore 1.768 GMAC/s is equivalent to 3.536 GFLOPS.

At the sub-array level, the 182 data streams (91 antennas each with 2 polarizations) are formed into 10 wide-angle beams. This results in a total sub-array computing requirement of 3.536 GFLOPS × 182 × 10 = 6.435 TFLOPS. A consideration must be made that at the sub-array level the output data must be screened for satellite trajectories. This will require input from the EISCAT_3D operations centre computing to sub-array computing and will require some more computing capacity.

3.2 Network requirements

The network for the test sub-array computing must receive the data streams from the antennas via the Analog to Digital Converters (ADCs). The signals from the ADCs must be passed by network cables to the back plane or bus of the DSP computing described above. After the beams are formed, the output data must be passed by the network back to the Ramfjordmoen controlling station.

The data rate that arrives at the sub-array computing from each dipole antenna is as follows:

- The analogue signal is passed through an band-pass filter, with bandwidth of 34.67 MHz;

- Hence, each polarization direction is sampled at a rate of 104 MHz due to undersampling of signals [4].

- An ADC converts each sample to a 16 bit digital signal.

This results in a digital bit-rate per dipole of each antenna of:

\[ 16 \text{ bits} \times 104 \times 10^6 \text{ s}^{-1} \approx 1.66 \text{ Gbit/s} \]

\(^\text{1Current microprocessors can carry out 4 FLOPs per clock cycle. A single-core 2.5 GHz processor has a theoretical performance of 10 GFLOPS. Therefore approximately 400 cores would be required.}\)
3 SUB-ARRAY COMPUTING

3.3 Operations requirements

Hence, the test sub-array infrastructure will need a connection between each ADC (182 per sub-array) and input of the DSP computing of at least 1.6 Gbit/s. The signal at this stage is a series of 16 bit numbers (with one bit reserved for timing to be discussed) arriving at a rate of 60 MHz.

As described above in Section 3.1, the 10 wide-angle beams are formed in the sub-array DSP processing. In order to avoid round-off errors [2] the data from the wide-angle beams for each polarity are stored as 32 bit numbers (with precise timing information incorporated). Therefore the total anticipated data rate from a sub-array with EISCAT_3D operating at 34.67 MHz bandwidth is

\[
10 \times 2 \times 32 \text{ bit} \times 2 \times 34.67 \times 10^6 \text{ s}^{-1} \approx 44 \text{ Gbit/s}.\]

In order to transmit data back to the Ramfjordmoen controlling station, the test sub-array must have a wide-area connection that can handle approximately 67 Gbit/s.

3.3 Operations requirements

The EISCAT_3D systems are intended to be unmanned for long periods of time and, as a result, cooling, power delivery and information about the status of the sub-array are important. The ideal time that a sub-array could be expected to run without a physical intervention needed is 7 months. This number is subject to trade-offs directly against costs. For the final EISCAT_3D deployment the historical weather records can give an indication of the difficulty or ease of accessing a site during winter.

3.3.1 Sub-array computing and networking cooling

The sub-array computing should be installed in an enclosure that uses standard components. The sub-array enclosure should follow a requirement to have sufficient ventilation and cooling capacity to maintain the computing infrastructure at a manufacturer-specified ambient temperature and humidity. This cooling and ventilation capacity must be able to function autonomously for the time that is determined above.

The power needed for this requirement will not be known until the sub-array computing technology is fully understood. Also, the annual temperatures expected at the proposed installation site need to be taken into account.

3.3.2 Sub-array computing and networking power

The power delivery to the sub-array computing enclosure will logically be part of the overall power delivery (at kW level) to the EISCAT_3D site array. The 230 V power supply line for the computing and network equipment can be stepped down on site. The computing and networking equipment must be protected against unreliable electrical conditions (e.g. power outages, brown-outs, phase losses). A default requirement is that the computing and networking should function in the event of unreliable power supply for at least 1000 s, the time it takes to empty the site of data, and then proceed to an orderly shutdown of services.
3.3.3 Sub-array monitoring

The sub-array computing must be remotely monitored to meet the requirement of long periods of autonomous operation. In the event of a faulty or non-working antenna, this needs to be communicated to the DSP processing computers. The faulty or missing signal is then dropped from the beam forming processing.

For the test sub-array computing it is required that the beam forming cluster machines report through some standard mechanism e.g. syslog and/or standard monitoring framework to a monitoring node. The monitoring node will then communicate with the Ramfjordmoen facility. The hardware and software monitoring function should be commercial or open-source standard, installed on off-the-shelf computers and using standard input/output cards.

3.4 Hardware requirements

The hardware that will be installed for the test sub-array not only has to fulfill the capacities and operational requirements described above but also a set of physical requirements.

3.4.1 Computing

The DSP processing may be implemented on any computing architecture: “traditional” x86 servers, ARM servers, field-programmable gate array (FPGA), GPU or state of the art parallel co-processors e.g. Intel Xeon Phi.

The EISCAT_3D requirement for the DSP processing is that the beam-forming operations in each sub-array must be able to run autonomously, without direct intervention, for the period of time determined above. Therefore, the machines selected must be able to be rebooted and be able to receive software updates remotely. The machines should be able to receive firmware updated remotely.

The sub-array computing can be selected to be specialized to the task of performing the digital signal processing and forming the beams. As the EISCAT_3D project is planned to run for 30 years or more, the hardware selected should be “future-proof” in that it should be a technology that will not become obsolete in the medium term. Ideally, the technology would have widespread use in industry as well.

The first requirement on the sub-array computing hardware for the DSP processing is that it should be easy to program and the support for the programming (APIs, libraries) must be planned. The hardware could be extensible, scalable and flexible: the data rates from the antennas and the DSP tasks are understood so it is not foreseen that any large changes to the beam forming hardware will be needed.

The requirement on cost includes not only the purchase cost but energy consumption and heat efficiency and must fit within the EISCAT_3D budget. In order to mitigate unforeseen circumstances beyond the medium term, the computing hardware should be compatible with a standard hardware rack system.
3.4.2 Networking

The network installation for the test sub-array must provide a standard TCP/UDP service with the capacities specified above. The networking equipment should be off-the-shelf commodity hardware. In order to protect against quite common attacks, this hardware must be capable of rebooting and receiving firmware updates remotely over a secure connection.

4 Conclusions and recommendations

The requirements in this document are summarized below. The summary tries to follow the standard terminology as given in the NASA document [3].

- **Sub-array Computing**
  - MUST be at least 6.435 TFLOPS.
  - MUST be able to be rebooted and receive software updates remotely.
  - SHOULD be able to receive firmware updates remotely.
  - SHOULD be future-proof and used in other fields.
  - SHOULD be easy to program and have future programming support.
  - MUST be cost efficient in purchase price and operation to fit the EISCAT_3D budget.

- **Networking**
  - Capacity from each ADC to DSP computing MUST be 1.66 Gbit/s.
  - Capacity from DSP computing to remote controlling site MUST be 67 Gbit/s.
  - MUST provide standard TCP/UDP connections.
  - SHOULD be standard commodity hardware.
  - MUST be able to update firmware remotely.

- **Operations**
  - The sub-array computing and networking MUST be able to operate autonomously for long periods of time.
  - The sub-array computing and network MUST be remotely monitored and controlled.
  - Monitoring functionality SHOULD be open-source or commercial standard.

- **Hardware**
  - The sub-array computing and network SHOULD be installed in an enclosure with industry-standard hardware.
– The enclosure MUST provide cooling and ventilation to maintain manufacturer specified temperature and humidity levels and avoid condensation.
– The sub-array computing and network MUST be protected against unreliable electrical conditions.

References


