

SCADA IN THE LOFAR RADIO TELESCOPE

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ABSTRACT

The LOFAR radio telescope is a wide area sensor network covering an area of 350 km diameter. Distributed over this area are 77 so called station fields where sensor arrays are installed. Each station field contains 100 radio antennas for astronomy observations along with tens of sensors for geophysical and high precision agriculture measurements. At the station fields, analogue and digital signal processing is applied on the data streams and the resulting, condensed, data streams are transported to a central computer for further coherent processing.

The complete distributed sensor network contains of order hundred thousands elements that should be controlled accurately in order to achieve a coherent result. The PVSS-II system delivers the basis infrastructure on which the LOFAR monitoring and control system is built. This monitoring and control system contains software models of both the physical system, as well as a model of the logical operation of the telescope in terms of service providers and observations. These two models are mapped onto the real-time distributed database of PVSS-II. The LOFAR monitoring and control system is integrated in all processing software and a real-time interface to the signal processing devices is made, together providing fully distributed real-time control over the LOFAR instrument.

In this paper we will discuss shortly the special requirements of the LOFAR system and show how these are translated in the monitoring and control architecture. In particular, we will explain the usage of software models to reflect the physical and logical views on the system and the connection of those with the PVSS-II database.

INTRODUCTION

LOFAR is an acronym for the low frequency array, a phased-array radio telescope operating over the very low frequency range from 30 to 240 MHz. The LOFAR telescope is built as a distributed sensor network, with about 100 station fields distributed along five spiral arms. Those arms cover an area of over 100 km in diameter and plans are being developed for expansion to thousands of kilometres. The topology of the stations distribution over the Netherlands is shown in figure 1. The stations are distributed in a logarithmically condensed way to obtain an optimal synthesized coverage in the final images. Each of the 100 station fields hosts multiple sensor types that are attached to the digital processing platforms and yield data streams for further processing at the central processing facility. For radio astronomy observations, two antenna sets are installed which are sensitive to the 10 - 80 MHz and 110 - 240 MHz bands respectively, skipping the FM radio transmissions in the 80 - 110 MHz band. The antenna processing chains include a direct sampling at 200 MHz with 12 bits accuracy. At the station sites, the individual antenna signals are filtered in both the RF and digital domain after which all antenna signals are combined in spatial sensitive signals that are sent to the central site. The antenna systems sample the complete electromagnetic field, from which multiple spatial sensitive "beams" can be reconstructed in the processing chain. The digital processing chain reconstructs the same spatial sensitive signal as a parabolic dish would do, but at lower price. More importantly, with the same antenna array we can generate multiple beams at the same time.

Apart from the antennas used for radio astronomy, additional sensors are installed at the station fields for other scientific research. Among those are sensors for passive seismology, which are buried 10 meters deep under the sensor fields. Also low frequency acoustic sensors are installed to observe infra-sound. The station sites are local hubs for high-precision agriculture using wireless sensors in crop fields. See [1] for more details on the LOFAR scientific applications. For a more extensive description of the astronomical aspects of the LOFAR system see [2] and [3].



Figure 1. Configuration of the LOFAR station fields. The station fields are located along five arms with the central field in the northern part of the Netherlands.

THE LOFAR MONITOR AND CONTROL SYSTEM

The Monitoring and Control (MAC) system of LOFAR controls all hardware in the distributed instrument. A SCADA system is used to distribute the control settings over the LOFAR station fields and central facilities, see figure 2. Using the same SCADA system, monitoring values from all equipment is gathered. Software applications are controlled and monitored in a similar way. A real time adaptation layer is provided at the station fields in order to achieve high accuracy timing for the activation of new instrument settings.

The MAC system also controls the execution of observations on the instrument. An observation can be seen as a specific configuration of the instrument, along with a specific combination and configuration of software applications executing on some of the instrument resources. This brings in another dimension to be controlled, which becomes quite complex when multiple observations are executing on the instrument concurrently. For this reason the observation concept is an explicitly part of the architecture.

The instrument control and observation control are implemented as two hierarchies which are mapped onto each other. That is, the leaves of the observation hierarchy (tree) correspond with applications, which run on hardware which are nodes in the instrument hierarchy. On a higher level in the observations tree, logical parts of an application are mapped onto larger structures in the resource tree. The MAC system will continuously optimise this mapping based on the availability or failure of hardware resources.

In contrast to the instrument control hierarchy, which remains almost constant in time, the observation control hierarchy is very dynamic. During typical LOFAR operation 8 observations are performed concurrently. Each of those may have a different duration. We thus have typically 8 observation control hierarchies concurrently in the MAC system. These hierarchies will also share parts, such as calibration applications.

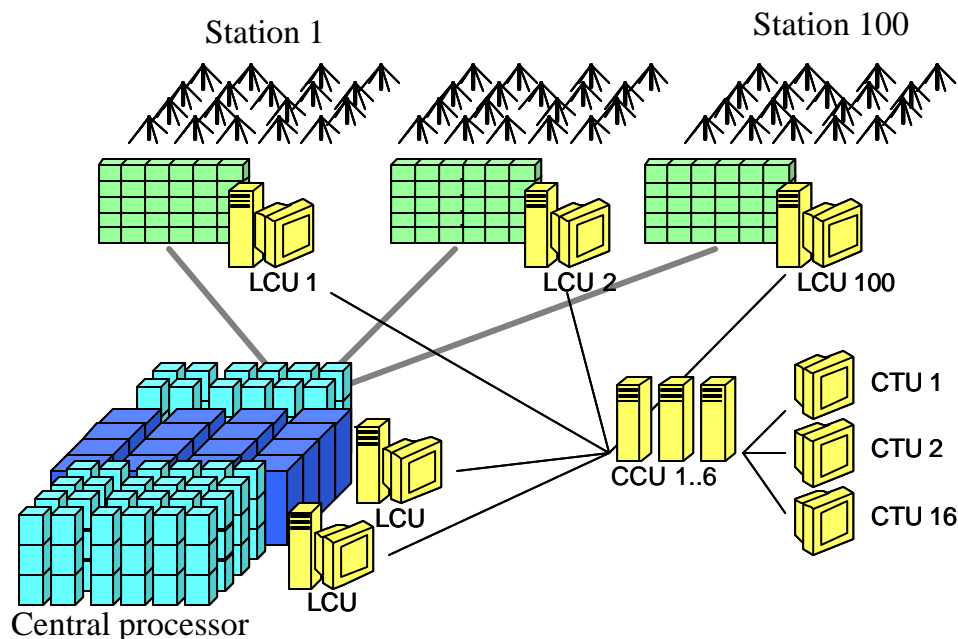


Figure 2: Instrument view of LOFAR. A total of 100 sensor stations are distributed over a wide area. Each station contains arrays of sensors and local processing resources. The pre-processed data streams are sent to the central processor. This central processor facility consists of multiple Linux clusters and a Blue Gene/L supercomputer. The Monitoring and Control (MAC) system is distributed over the station sites, the central processor and the central control site, as indicated by the yellow computer and terminal symbols.

ARCHITECTURE

As described in the introduction section, the MAC system architecture is heavily based on the concepts of an instrument control hierarchy and observation control hierarchies. Both these hierarchies consist of active software models, or object trees which are mapped to fields in the distributed real time database under the hood of the SCADA package that is used.

The use of a real time distributed database to distribute control commands and acquire monitoring data is often used, for example in the telescope management system of the WSRT radio telescope in Westerbork. A similar approach is used in the CERN LHC control system [4]. In the LOFAR monitoring and control system we extend this approach with active software models that represent the instrument and observations. These active models are the top of the MAC layers architecture, as is shown in figure 3.

The middleware layer offers a framework based on the PVSS-II system with additional functionality for hard real-time control, GUI frameworks, storage and drivers. The PVSS-II functionality is wrapped in order to allow for other SCADA packages to provide the required distributed database and user interface functionality.

Each LOFAR station site will have a local control PC running the PVSS-II software and parts of the MAC software. The local control units operate autonomously; performing the control tasked corresponding to the location. Monitoring information is gathered locally and processed locally. Instrument specific or observation specific model components associated to the local unit (station) are executed locally. This includes handling of alarms and fail-over modes. Only out-of-boundary events are reported to the central control systems. Six workstations located at the LOFAR operations centre are used to run large parts of the observation models, serve the GUI terminals etc. Monitoring information from the local sites is made available to the graphical interfaces connected to the central control units on request.

All these hardware systems for the hardware layer in the MAC architecture.

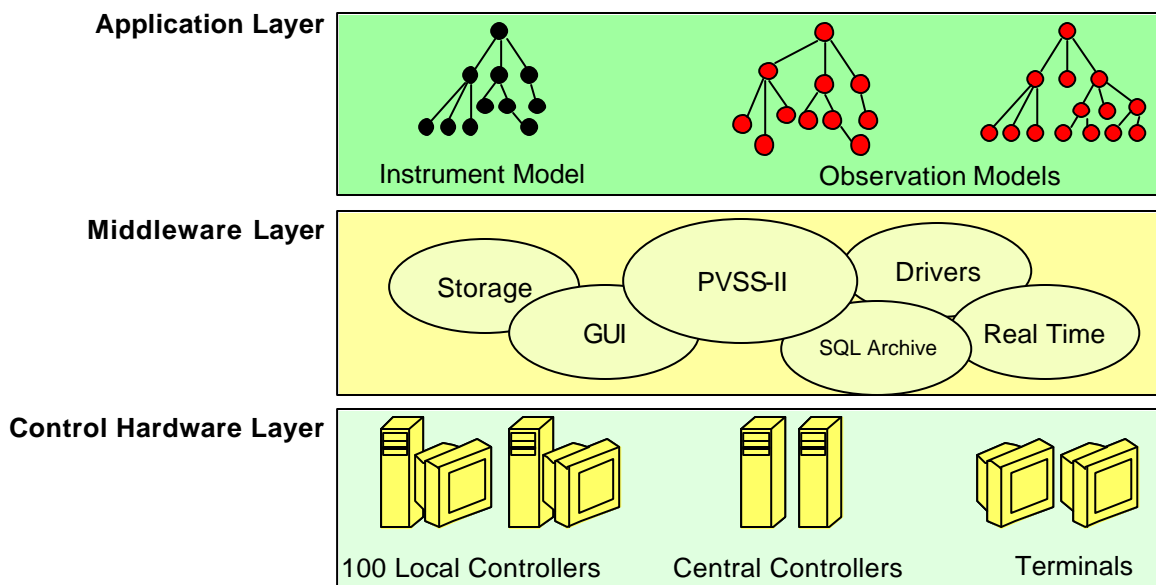


Figure 3 Layering in the MAC architecture. The core of the MAC system is a middleware layer build around PVSS-II. This layer contains frameworks for real-time control, Graphical interfaces etc. The applications specific control is built on top of this layer, based on a dynamic instrument model and a model tree per observation.

Middleware Layer

The middleware layer consists for a large part of a wrapper around the selected SCADA package. The intention is to provide a generic API to the other MAC software packages that is mostly independent on the exact SCADA package. Also, this API is optimised for the other subsystems in MAC, thus with appropriate interfaces for the models in the application layer, interfaces for the real time control library etc. Direct communication to the LOFAR devices is provided. This part of the middleware layer also provides generic facilities for data type transformations, smoothing of sampled data streams, averaging etc.

The middleware layer contains facilities for building distributed control applications, including services such as trend, alert, archive, access-control, HMI and others. These facilities are used by the higher level applications in order to implement their tasks. The middleware layer contains a few subsystems which are listed below.

Drivers implement the direct communication with the LOFAR instrument hardware devices. The drivers translate property values in hardware settings. Monitoring points are sensed and the associated database points in the SCADA system are set accordingly. Data type transformations, smoothing, averaging and data conversion are implemented in the drivers.

All communication between MAC subsystems and communication to systems external to MAC use the communication and storage library. This library provides communication and storage services for building distributed applications. Most of the communication will use the distributed database which is part of the SCADA system. Addition communication mechanisms are implemented as well, such as HTTP, plain sockets and an SQL database.

The control and services subsystem provides a framework for controller hierarchies and generic services such as alarm handling, archive handling, logging, reporting, trending, script control and access control.

The user interface subsystem provides a framework for building user interface applications; standard user-interface system tools (e.g. database browsers). Local terminal and web based user-interface support. The user interface subsystem will be discussed in the next section.

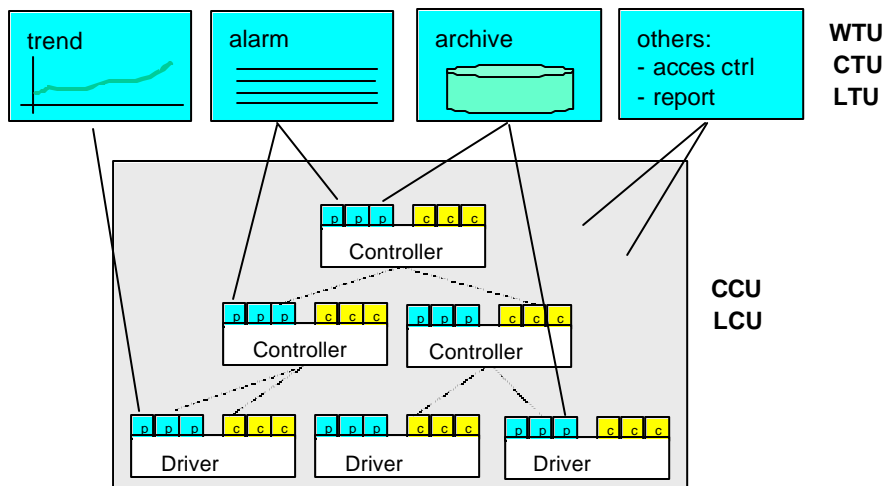


Figure 4 In the application layer of MAC control hierarchies are built to control the instrument. Nodes in those hierarchies are software objects that is linked to database fields in the SCADA database. These fields are used for monitoring (property values) and control (control values). The application layer contains such hierarchies for the instrument model and observation models.

Application Layer

In the application layer the instrument model is executed and multiple observations models are executed that map onto the instrument model objects. Each object in an observation tree is linked to an object in the instrument model. This link represents the resource usage of that part of the observation. Multiple observation model objects can share logical device.

The core concept of the application layer is the property concept. Properties represent the status of the LOFAR instrument. Examples properties are current voltage level, current beam track, and actual spectral RFI mitigation. Properties can also be used to represent the status of the observation model components. Such properties may for example be quality numbers for the ionosphere calibration component. Properties and Control settings are treated differently in the middleware layer since the control settings will also be distributed over the system, while properties may be held locally.

USER INTERFACES

The PVSS-II software package provides a large suite to develop graphical interfaces. These facilities form the basis for the MAC Navigator. The MAC Navigator is the interface application that is provided to all users of the MAC system. The navigator contains a tree browser (in the left pannel, see figure 5). This tree browser is used to navigate through the instrument model or observation models. An operator can for example select a specific station or dig into the details of a station till the level of the analogue-to-digital converter chip. Navigating through the observation model, an astronomer may select the calibration step in the processing pipeline. In the right panel multiple tabbed-pages present information on the selected model item. A few standard pages are available with all available database points for the selected item, trend plots of such parameters, trigger levels for control actions etc. Following the former example, the operator can inspect the chip temperature of the analogue-to-digital converter and set a new alarm level.

Additional tabs are available based on the selected item. Following the astronomer’s selection from the previous paragraph, the navigator may present a comprehensive view on the calibration application including a plot of the phase rotations of the ionosphere during the observation, a residual image of the observed field (with frequency selection scrollbar) and key parameters of the instrument stability. In other words, the application developer can define a specific GUI, which may even differ between the astronomer role and operator.

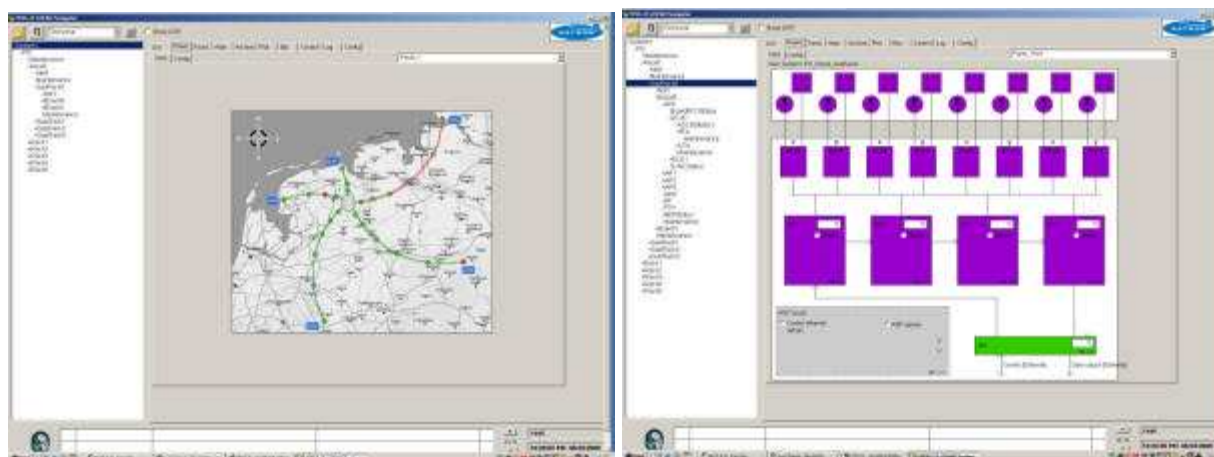


Figure 5 Screenshots of the MAC Navigator. In the left screenshot the top-level of the instrument model is selected and the system status panel is selected. This panel shows the current status of the instrument; in this example one station and one fibre arm are in error state. In the right screenshot the receiver board of a particular station is selected for which a configuration interface is selected where an operator can inspect chip temperatures and select additional monitored properties.

The presented information and available pages in the navigator depends on the user's role in the project. The goal of this user dependent representation is to minimise the amount of information given to the user. Since the LOFAR instrument is quite large, complex and serves users from multiple disciplines, we considered it very important to adapt the user interface to end-users and operations staff. On the other hand we adhered the simplicity, unified look-and-feel and reduced maintenance effort of a single graphical interface framework. The intension is to run multiple instances of the MAC navigator in a typical control room at the LOFAR operation site or at the science operations centres. We envision such a control room to contain a dozen terminals which for a large part show a pre-selected set of high-level control screens. An operator may activate his or her favourite (personalised) selection at the start of his or her shift.

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