DISTRIBUTED CONTROL SYSTEM FOR THE TEST INTERFEROMETER OF THE ALMA PROJECT

M. Pokorny, M. Brooks, NRAO, Tucson, AZ, USA
B. Glendenning, G. Harris, R. Heald, F. Stauffer, NRAO, Socorro, NM, USA
J. Pisano, NRAO, Charlottesville, VA, USA

Abstract

The control system (TICS) for the test interferometer being built to support the development of the Atacama Large Millimeter Array (ALMA)[1] will itself be a prototype for the final ALMA array, providing a test for the distributed control system under development. TICS will be based on the ALMA Common Software (ACS)[2] (developed at the European Southern Observatory), which provides CORBA-based[3] services and a device management framework for the control software.

Simple device controllers will run on single board computers, one of which (known as an LCU) is located at each antenna; whereas complex, compound device controllers may run on centrally located computers. In either circumstance, client programs may obtain direct CORBA references to the devices and their properties. Monitor and control requests are sent to devices or properties, which then process and forward the commands to the appropriate hardware devices as required. Timing requirements are met by tagging commands with (future) timestamps synchronized to a timing pulse, which is regulated by a central reference generator, and is distributed to all hardware devices in the array. Monitoring is provided through a publish/subscribe CORBA-based service.

1 ALMA

The Atacama Large Millimeter Array, or ALMA, is a radio astronomy millimeter and sub-millimeter array to be built in Chile's Atacama desert (at an elevation of 5000m above sea level) in the coming years. The project is an international collaboration among partners from Europe, Japan, Canada, Chile, and the USA. Current plans are for an array consisting of sixty-four parabolic antennas of twelve meter diameter, with configurations ranging in size from a compact configuration, with a maximum baseline of 150 m, to an extended configuration, with a maximum baseline of 10 km. Each of the antennas will contain from four to ten cryogenically cooled receivers, operating in the range from 31 GHz to 950 GHz. Science data will be digitized at each antenna, and transmitted via optical fiber to a central location at a rate of 3 GB/s per antenna.

2 TEST INTERFEROMETER CONTROL SYSTEM: TICS

Three antennas, one contracted by each of the high-level partners in the ALMA project, will be delivered over the next two years to the National Radio Astronomy Observatory's Very Large Array site in New Mexico. These antennas are collectively known as the Test Interferometer (TI). The TI will be used for comparative evaluations of the three products to assess which design will be used for the antennas in the final ALMA array. Simultaneously, the TI will also be employed as a test-bed for the development of technologies to be used by the ALMA array; in particular, the development of the control system software (TICS) for the ALMA project. Nonetheless, the primary goal of TICS is to provide the TI itself with a comprehensive array control system.

2.1 ALMA Common Software: ACS

The common base of all software being developed for ALMA will be the ALMA Common Software (ACS). Most of the development of ACS is being done by the European Southern Observatory, based in Garching, Germany. ACS provides a CORBA-based device management framework, system services, application services, and an application framework for all software that will be required for ALMA. TICS is the first application to use ACS, and has been developed roughly in parallel with ACS. The device management framework and system services have been the primary features used in the development of TICS to this point in time. Some of the ACS features employed by TICS include

- object lifetime management
- configuration database (devices and properties)
- naming service
- time service.

2.2 Control System Architecture

At each antenna there is an Antenna Bus Master (ABM): a VME bus Power PC based computer running the VxWorks operating system. Its principal role is to provide real-time control of the devices at the antenna based upon infrequent time-tagged commands from the center. The ABM also serves as a router for an antenna Ethernet segment.

Most devices with computer interfaces are attached to a Controller Area Network (CAN) bus, through which they are controlled and monitored by the ABM.

Each ABM is connected to the central systems via a point-to-point Gigabit Ethernet network that terminates at a switch. The switch is in turn connected to a high-speed switched network on which all central ALMA computer systems required to operate the array are attached.

Two real-time computers are situated at a central location of the array. The Array Real-Time Machine (ARTM) plays the role of the ABM at the central location, providing local real-time control of its attached devices. The other central real-time computer, the Correlator Control Computer (CCC), provides the interface for the correlator, and detailed control of the correlator hardware. Both the ARTM and CCC are VME/PPC/VxWorks based systems.

The coordination function is implemented via the Array Control Computer (ACC), which is a high-end workstation running the Linux operating system. It is responsible for controlling all hardware in the array (indirectly through the ABM, ARTM, and CCC computers) under the command of a high-level observing script. The ACC also runs various ancillary software such as model servers (*e.g.*, phase models), and data formatting.

Almost all devices will be attached to a CAN bus operating in a master/slave (polled) fashion. The bus will operate at 1 Mbps and is capable of at least 2000 polled operations per second (up to 8 bytes of data per transaction). Devices on the CAN bus will be responsible for implementing a simple in-house protocol to map CAN message IDs to internal device addresses. A few devices will have other connections, in particular Ethernet.

2.3 *Devices*

Logically, the software is partitioned so that control flows in a master-slave fashion from a central executive, which controls high-level ("composite") software devices, which in turn control their constituent parts. The lowest level software devices are referred to as device controllers, and represent a proxy for the actual hardware — that is, they communicate with the hardware. Data, both monitor and back-end, are collected from the devices by a collecting process in the real-time computer connected to the hardware, and are then buffered up for distribution, *via* a publish/subscribe mechanism, to data consumers. Standard data consumers include processes that format and archive the data. The software is distributed among the computers so that only the device controllers and software directly concerned with low-level device activities are on the local real-time computer. All higher-level software entities are concentrated on the ACC.

Engineering access to devices that are installed on the test interferometer will be implemented by access to the device controller interface, or to the I/O routines directly from engineering workstations.

Naming services provided by ACS are used by clients to obtain CORBA references to the devices. Transient servants are created and destroyed by the ACS "Manager" as they are needed by clients, but persistent servants (typically, those devices closest to the hardware) can also be created at system start-up. Device configuration, and some aspects of system configuration, are implemented using a centralized database.

2.4 *Properties*

Devices in the control system have both properties and methods. The properties are themselves complete CORBA objects; therefore, clients may get references both to properties and devices that are physically located on any computer on the network. Using features of ACS, properties may have monitors or alarms attached to them, or a client may simply poll a property at will.

2.5 *Timing*

The ALMA time system will establish synchronized switching cycles and mode changes, and provide time-stamping for the resulting measurements across the entire instrument, including the central building and the geographically dispersed antennas. Additionally, the time system must be accurately related to external measures of time to correctly determine the position of astronomical objects of interest. The fundamental time system of the interferometer is TAI time maintained in a central master clock.

While most devices do not have precise timing requirements, a timing pulse with a 48 ms period is distributed throughout the entire array to provide a time basis for those devices that do have more precise timing requirements. For such a device, the control software must arrange to have monitor and control commands sent to the device in precisely defined windows within the 48 ms timing period. Time-tagged commands from the center must be transmitted sufficiently early to account for the non-determinism in the network and general-purpose ACC. The slave clocks are given the array time of a particular timing event, and thereafter maintain time by counting timing events.

Some of the relevant time scales in the control system are as follows.

- 2 ms: The shortest time-scale at which any device will require interaction. Shorter time-scales are always handled by hardware.
- 16 ms: Fastest correlator dump time.
- 48 ms: The period of the pervasive timing event sent to all hardware with precise timing requirements.
- 1 s: The fastest time-scale for observational changes, *e.g.*, source changes or changes in correlator setup.
- >1 s: Most devices will be monitored or controlled at rates slower than 1 Hz, often much slower (300 s).

3 EXAMPLE DEVICE: FINE TUNING SYNTHESIZER

The fine tuning synthesizer (FTS) is a low-level device that is a component of local oscillators throughout the array. It provides the fine adjustment of the local oscillator phase and frequency (for the purposes of fringe tracking), and phase switching capabilities (used to remove spurious signals and for sideband separation). Like most devices, the FTS hardware is monitored or controlled *via* the antenna-wide CAN bus.

To present an example of the execution of TICS, a short description of some of the properties of the FTS is given here.

3.1 Timing

The FTS implements several timing event associated commands. All of the functionality of the FTS depends upon synchronization with the pervasive timing event. Effective phase switching requires synchronization between antennas at the start of the phase switching function. Fringe tracking depends upon tracking and pointing information to achieve the desired phase output at the proper time; therefore, updates to the phase function must remain synchronized with the timing event.

The time scales of importance to the FTS are the following:

- 250 μs: shortest phase switching interval
- 16 ms: fast phase switching period, shortest slow phase switching interval
- 48 ms: phase chirp modulation update rate
- $\sim$1 s: slow phase switching period
- $\sim$10 s: fast switching calibration
- $\sim$100 s: fringe tracking frequency update.

3.2 Properties

Fringe tracking Local oscillators will be compound devices, each containing an FTS device. A command from a high-level device to a local oscillator device to set a frequency will occur at the array network level through CORBA. Such a command will occur whenever the astronomical source or receiving frequency is changed.

The inputs required by the FTS for fringe tracking are all dynamic, depending upon factors such as the observing frequency and tracking information. A client of the FTS device, namely a local oscillator, will be responsible for setting these properties as necessary. On the other hand, the phase function needed by the FTS to provide accurate phase tracking services may be obtained by the local oscillator from a phase model server running on the ACC.

The FTS device controller will send commands to the hardware on the CAN bus just prior to the timing event on which the changes are to take effect. After setting initial conditions, the FTS device may then update a phase chirp modulation parameter at the 20 5/6 Hz rate to adjust for non-linearities in the phase function, and to control quantization errors in the phase generation.

Phase switching For phase switching, each FTS uses a four-valued step function with a minimum interval of 250 μs between changes, and a period of 1.024 s. The functions comprise a mutually orthogonal set, from which each antenna uses a single element over its “lifetime”. There are in fact two, nested two-state switching cycles, which compose the overall 1.024 s cycle; however, the functions used by the two cycles are similar, differing only in scaling on the time axis, and a shift on the phase axis. The phase switching function to be used by a particular FTS may therefore be configured using a value from the configuration database, allowing the device controller to set its own phase switching function when it is instantiated.

Because the rate of phase switching is faster than it is possible to accurately control from the ABM, the phase switching itself is implemented by the FTS hardware. The precision required of the phase switch times is ensured by an especially precise “version” of the 48 ms timing pulse that is received by the FTS hardware.

4 TICS STATUS

The first version of TICS (version 0.1) was released earlier this year, and the next release is scheduled to occur in February of next year. By mid-April of 2002, the first TI antenna will be ready for evaluation. TICS will support mount control and pointing tests by the time the antenna is delivered. As the antenna proceeds through the evaluation process, TICS will provide new capabilities to support required testing. Concurrently, further integration with ACS, and use of new ACS features (as they are developed) will also occur.

5 REFERENCES

[1] ALMA Web Site, http://www.alma.nrao.edu

[2] G.Chiozzi, *et al.*, “Common Software for the ALMA Project”, ICALEPCS’01, San Jose, USA, 2001

[3] CORBA Web Site, http://www.corba.org