Software support for NRAO RFI mitigation activities

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Abstract: *We present a plan for providing software support for mitigation of radio frequency interference for NRAO telescopes. We argue that this should be considered as an add-on to the e2e project and developed in close coordination with the other observatory RFI work. This initiative would cost roughly 6 FTE-years plus some minor computer hardware costs.*

1. Introduction

Radio Frequency Interference is becoming a bigger and bigger problem for radio astronomy. The increasing sensitivity and frequency coverage of the Expanded Very Large Array and the Green Bank Telescope will make them both vulnerable to radio frequency interference. In addition, we can expect that the use of the general radio spectrum will increase with time. In time, even ALMA will be subject to significant radio frequency interference at the lower frequencies.

NRAO has engaged RFI concerns on two main fronts: regulatory involvement (via IUCAF and WARC), and hardware-based mitigation (via the NRAO Interference Protection Group - http://www.gb.nrao.edu/~rfisher/ipg.html). Some software support work is proceeding within NRAO: for example, in the context of the IPG a database for RFI information is currently being developed, and there are plans for software for interference excision (see *e.g.* http://www.gb.nrao.edu/~rfisher/Interference/program.gbt). However, despite the criticality of RFI to NRAO's mission (as emphasized by several review committees recently), we do not have a significant software component in our observatory-wide activities for mitigating RFI. This is a notable omission, especially when considered in contrast to the initiatives at other observatories such as ATNF, WSRT, and the ATA. In this memo, we present a staged plan for augmenting our anti-RFI work with software effort.

This plan is also tailored to the specific needs of the EVLA. RFI is a particularly serious issue for the EVLA. The EVLA has a philosophy of "layered-defense" for dealing with RFI. The analog and digital electronics have been designed with RFI mitigation as a major requirement. The defense is expected to be based also in software, both in the Correlator Back End and in the post-correlator software. It is planned that most EVLA data will be processed by a pipeline in AIPS++. To make such automated processing possible, we can expect that information about RFI characteristics must be available to the processing scripts. Thus, depending on signal strength, RFI mitigation may be crucial to the success of the pipelined reduction. In addition, the large data volumes will make traditional hand-editing of observations impossible, and so even non-pipelined reduction will require similar information.

2. Requirements

The prime requirements in our work to mitigate RFI are (in rough order of decreasing importance):

1. To aid in the characterization of the RFI threat. This largely requires research and observations, but some aid can be provided in the way of software tools to store and retrieve information about RFI. Identification of RFI is a major problem, requiring some work in data analysis and some in visualization. Characterization is an important aspect of our regulatory work – our position in discussions in Geneva would be strengthened by ability to present systematic documentation of case of interference.
2. To aid in the determination of the effect of RFI on scientific observations. The effects of RFI on scientific observations have been well-established by the work of Thompson (I.E.E.E. Trans. Ant. Prop. AP-30, 450, 1982) and are established in ITU-R (1997). However, for specific cases, simulation is still useful. Some simulation work along these lines (especially in synthesis imaging) can be performed using the current AIPS++ simulator tool.
3. To develop and deploy anti-RFI tools throughout the software backend. This is an open-ended target, but much can be done with both adoption of techniques pioneered by others and straightforward automation of existing approaches. In addition, AIPS++ provides a mechanism to share anti-RFI tools not just with NRAO telescopes but with other telescopes such as ATA, ATCA and WSRT where anti-RFI research is more mature.
4. To support hardware-based anti-RFI tools. For example, the use of a small antenna to measure interference affecting a large antenna (such as the GBT) requires software support for accurate identification and removal. Specifically, the information from the wide-angle antenna must end up in the data analysis packages in a useable form.
5. To provide up-to-date information to observers during observation planning. For example, given a red shift, can a given spectral line (outside the protected bands) be observed at the VLA site or at Green Bank? What is the likelihood of interference for a particular frequency?
6. To support RFI avoidance through scheduling. Time-sharing of frequency bands is likely to become more and more important. Scheduling software must support this possibility.
7. To close the loop from operator and observer back to our knowledge of interference. The best information on interference comes from actual observations. We should harvest this information. The automated pipeline-based processing of observations planned in e2e will help here.

3. Analysis

All of the requirements above are common to all NRAO telescopes, suggesting that software-based RFI mitigation be considered to be part of the e2e project development

rather than tied specifically to one telescope such as the EVLA or GBT. For example, anti-RFI software tools developed (in AIPS++) at one NRAO telescope will almost certainly have application to other NRAO telescopes (this is already true – the autoflagger tool developed for synthesis use in AIPS++ evidently works very well for single dish data). Similarly, information about interfering sources will be of importance to all NRAO telescopes. In addition, the common database being planned for e2e will provide a natural and accessible repository for RFI information.

The deliverables required fall into the following categories:

- **Characterization:**
  - Database design and deployment: an Oracle database would be used to store information about RFI.
  - Access tools: the database must be accessible via a number of Application Programming Interfaces's including AIPS++ (for processing) and Java (for e2e interfaces).
  - Identification tools:
- **Simulation:**
  - AIPS++ simulator improvements: this tool will need some improvements to allow off-delay center simulation of time-averaged signals.
  - Simulation suite: an AIPS++-based suite of simulation tools (basically glish scripts) should be developed to simulate specific scenarios where numerical calculations are needed.
- **Backend tools:**
  - AIPS++ autoflagger improvements: this is the principal AIPS++ tool for non-interactive flagging of data. It allows many different algorithms to be plugged in and used in parallel.
  - Closure-based removal: this is the Sault-Ekers method of finding and removing interfering sources based on closure.
  - Research into new methods: who knows?
- **Support of hardware-based measures:**
  - Small antennas (or whatever else is planned in hardware). If corrections are to be made post-correlation, the data from a wide-beam antenna must be propagated into AIPS++. This requires a modest but still significant software effort.
- **Observation planning:**
  - e2e interference checker: this is a simple facility to check a proposed observation against the likelihood of interference. Tools such as this will be vital for observers using the EVLA, and will help in configuring the correlator optimally.
- **Operator and observer feedback:**
  - Reporting forms
  - AIPS++ reporting tool
  - Pipeline-based reporting

4. Straw man project plan

To scope out the resources and timeline, we have developed a straw man project plan, based on deliverables identified above. The net time taken is 1380 person-days, which with one person would take about six years. With two people, the timeline will shrink to about three years from start to finish (as is shown below). For comparison, the overall staffing budget for e2e is about 60 FTE-years, so the addition of this proposed anti-RFI program would mean a 10% cost increment.

Most of the costs are likely to be in people. Some minor computing hardware may be needed for simulation purposes but it is likely that existing computers will suffice.

Note that the ordering of activities is not carefully considered in this plan. It should be revised after close consideration of the timeliness of each deliverable.

ID	Task Name	Duration	Start	Finish
1	**Anti-RFI**	**715 days**	**Wed 10/1/03**	**Tue 6/27/06**
2	**Management**	**65 days**	**Wed 10/1/03**	**Tue 12/30/03**
3	Establishment of project	13 wks	Wed 10/1/03	Tue 12/30/03
4	**Characterization**	**325 days**	**Wed 12/31/03**	**Tue 3/29/05**
5	Database design and deployr	13 wks	Wed 12/31/03	Tue 3/30/04
6	Access tools	26 wks	Wed 3/31/04	Tue 9/28/04
7	Identification tools	26 wks	Wed 9/29/04	Tue 3/29/05
8	**Observation planning**	**130 days**	**Wed 3/30/05**	**Tue 9/27/05**
9	e2e interference checker	13 wks	Wed 3/30/05	Tue 6/28/05
10	Avoidance support in schedu	13 wks	Wed 6/29/05	Tue 9/27/05
11	**Observer feedback**	**145 days**	**Wed 9/28/05**	**Tue 4/18/06**
12	Reporting form	8 wks	Wed 9/28/05	Tue 11/22/05
13	AIPS++ reporting tool	8 wks	Wed 11/23/05	Tue 1/17/06
14	Pipeline-based reporting	13 wks	Wed 1/18/06	Tue 4/18/06
15	**Simulation**	**130 days**	**Wed 10/1/03**	**Tue 3/30/04**
16	AIPS++ simulator improveme	13 wks	Wed 10/1/03	Tue 12/30/03
17	Simulation suite	13 wks	Wed 12/31/03	Tue 3/30/04
18	**Backend tools**	**455 days**	**Wed 3/31/04**	**Tue 12/27/05**
19	autoflagger improvements	13 wks	Wed 3/31/04	Tue 6/29/04
20	closure-based removal	26 wks	Wed 6/30/04	Tue 12/28/04
21	Research into new methods	52 wks	Wed 12/29/04	Tue 12/27/05
22	**Support of hardware-base mea**	**130 days**	**Wed 12/28/05**	**Tue 6/27/06**
23	Wide-beam antenna	26 wks	Wed 12/28/05	Tue 6/27/06

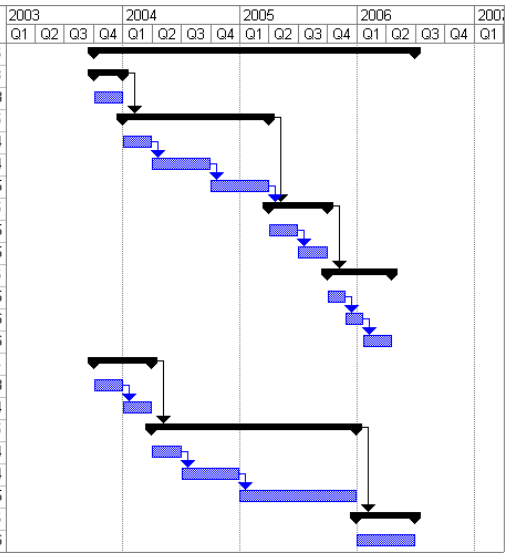

Figure 1 Straw man project plan

There are currently no resources identified for this work either within e2e or at the telescopes. An MRI proposal by Fisher and Bradley for *hardware-based* anti-RFI measures has been funded by NSF for the last several years. One possibility is to submit a proposal to NSF for this specific work. Another is to reallocate resources from existing activities. All of the work could be performed by a software-literate scientist or scientists with consultative support from other e2e project staff and telescope-based scientists. This person would then be a point-of-contact for software based RFI mitigation at the Observatory, allowing cooperation with the excellent work being pursued at other observatories.

The timeline is written to start at the beginning of FY 2004. An earlier start might be possible if resources are found internally.

Finally, it should be noted that most of the work in this plan is organizational and supportive. There is a moderate research component (mainly in requirement 3). It is not the intention of this plan to control or direct this or other similar research effort. It is important that such self-driven research continue, but with mechanisms to expedite the use of such results of astronomers observing with NRAO telescopes.

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