RFI Mitigation in Radio Astronomy

Willem A. Baan

ASTRON, Netherlands Institute for Radio Astronomy
Oude Hoogeveensedijk 4, 7990 AA Dwingeloo, The Netherlands, baan@astron.nl

1. Abstract

Changing observing strategies and the increased sensitivity of radio astronomy observatories have made radio frequency interference an important operational factor. All interference entering the data will result in data loss and observing inefficiency. This paper presents the mitigation methods to be implemented in observational systems to combat interference and to reduce its impact.

2. RFI Mitigation in Radio Astronomy

Radio interference increasingly affects the quality of radio astronomy and remote sensing observational data. The increased sensitivity of instrumentation for passive use of the spectrum and the intensifying active use of the spectrum have led to increasing data loss for the passive radio services. The avoidance of this interference and its removal if it enters the data are of great interest for the observatories. Simple excision of the affected data by visualization and accepting the data loss has been the remedy under most circumstances. However, this method becomes more cumbersome when using broadband systems and multi-station interferometry systems. Therefore, the recent advances in technology and computing must be exploited for mitigating the effects of certain classes of interference.

Avoidance of unwanted signals remains the optimal method of mitigation but such efforts depend strongly on the type of active transmissions, the environmental conditions, and the spectrum regulations that governs them. Further mitigation may thus be needed to remove unwanted signals from the observational data in and outside protected bands allocated to the RAS. The presence of unwanted signals in passive bands comes with a loss of data and band space. The ability to remove such interfering signals from these bands should thus not become a general excuse for generating more unwanted emissions by active services.

Interference mitigation is particularly needed for observational data in spectral bands allocated to other services. Partial use of these additional bands for passive observations may result in the desired high continuum sensitivity and spectral line (redshift) coverage of the observing systems. Astronomers operate in these bands using ‘dynamic access’ principles similar to those used for ‘cognitive radio’ and ‘software radio’, except that astronomers do not transmit in the empty band spaces.

Interference in allocated and protected bands always leads to data loss for the passive users of the spectrum even if interference mitigation is applied, either in the time domain or in the frequency domain. Permissible percentages of data loss in the allocated RAS bands defined in the ITU-R literature amount to some 2% for single systems and 5% for aggregate systems. Data loss for observations in bands allocated to other radio services needs to be considered accepted loss because the astronomers operate there under a no-protection principle.

3. Methods of Mitigation

There is no generic method to mitigate each class of interference. Because all methods depend on the ability to detect the interference (i.e. Interference-to-Noise Ratio, INR), a multi-layered implementation at different points in the data stream may be advisable to reduce detrimental effects of several types of radio interference. The techniques used in such a multi-layer approach cover a wide range of regulatory, technical, analog and digital means to avoid RFI and to later remove it from astronomical data. Therefore, RFI mitigation covers a very wide range of subjects and methods:

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a) measurements of the spectrum environment to identify and characterize the RFI at the telescope and identify ways to eliminate sources of interference,

b) spectrum management approaches, the regulatory methods of protecting the radio telescopes,

c) establishment of quiet zones for existing and for new generation radio telescopes,

d) methodologies for dealing with spectrum challenges for radio telescopes such as cognitive radio and ultra-wide band applications,

e) RFI mitigation methods and at which location in the detection systems they may be optimally used,

f) digital filtering and sub-space filtering using peculiar characteristics of the RFI,

g) multiple methods of pre-correlation thresholding of RFI in the time and frequency domains using wide-band spectrometers,

h) adaptive noise cancellation of specific (well-defined) RFI signals,

i) spatial filtering with array instruments,

j) statistical methods to identify RFI in the data and to remove these signals,

k) RFI mitigation algorithms built into software correlators,

l) automatic post-correlation RFI detection and flagging algorithms applied to newly build telescopes with high data rates such as the Allen Telescope and LOFAR, and

m) methods to identify and remove the signals of stationary (terrestrial) sources (at the horizon) using their fringe rate as compared with that of celestial sources during post-correlation processing.

A great variety of specific mitigation options and methodologies are already available that provide encouraging results with both on-line and off-line data processing. Since there is no universal method for RFI mitigation, the choice of the mitigation method depends on the RFI characteristics, the type of telescope, and the type of observations being done. Multiple methods should be used to remove both strong and weak RFI from the data. Because RFI algorithms generally are non-linear processes that depend on the INR and the characteristics of the RFI, a quantitative evaluation of the methods is not always possible. Furthermore, the removal of the RFI may raise the noise level and affect the gain calibration of the instrument. The cumulative effect of the implementation of RFI mitigation at subsequent stages is not a linear sum for the methods, since the RFI characteristics change after each mitigation step. This sum of what is practically possible at each step.

4. Implementation

RFI mitigation may be implemented as part of the instrumental and data processing techniques for existing single-dish and array instruments to further show the potential of each of these methods. The development of innovative methodologies is part of a forward look at applications for the next generation of radio astronomy instruments, such as the SKA and its pathfinders and LOFAR. In particular the methods that eliminate only the interfering signal from the data and may reduce the inflicted data loss. Various implementations of RFI mitigation hardware and software exist in current observing systems and some of the recent results have been described in workshops on RFI mitigation [1].

RFI mitigation has been given relatively low priority by many observatories and by their users. The new reality of increasing use of non-allocated bands to achieve increased instrumental sensitivity will likely change this situation. The large data volumes of existing and new instruments will force observatories and their users to address RFI mitigation solutions.

5. References

1. Papers in ‘RFI2010, the RFI Mitigation Workshop”, (W.A. Baan, B.M. Lewis, eds.), Proceedings of Science, 2010, http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=107