EMC AND RFI ENVIRONMENT ASPECTS FOR WIDE AREA SENSOR NETWORKS

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ABSTRACT

The propagation of disturbances requires substantial attention in order to increase our insight in complex distributed measurement processes. In particular, EMI and RFI propagation in the next generation of radio telescopes (LOFAR, SKA) will significantly affect processing quality and architectural design. In this paper we discuss aspects of RFI and EMI from the perspective of distributed computation- and measurement networks. Future design and development of a mitigation strategy is expected to increase insight in disturbance propagation in distributed systems in general.

INTRODUCTION

Large area networks of sensors and computing nodes are emerging in communication, multimedia, industrial automation, law enforcement and security, environmental monitoring and last but not least radio astronomy. Another trend is the emergence of monitoring systems [2] in heavy industry and complex infrastructures [3], e.g. the power grid, telecom and the Internet. These complex systems are monitored with sensors on data-streams, processing backbone, routers, cables, power consumption and environmental conditions, enabling early detection and remote diagnosis.

In recent years substantial progress has been made in the field of digital electronics and transmitter/receiver RF components, leading to a vast increase in industrial communication applications. These developments enable a leap in the sensitivity of new large-scale radio telescope systems. The development of the next generation large-scale radio telescopes proceeds from the Low Frequency Array (LOFAR, www.lofar.org), towards the Square Kilometer Array (SKA) [1]. LOFAR consists of more than ten thousand sensors clustered in about one hundred antenna stations, distributed over an area of 360 km. It will operate in the frequency range 10-250 MHz. The main application will be deep space imaging. The primary processing steps are: (1) transform measurements to high resolution channels; (2) spatial combination of antennas via beam forming; (3) correlating station beams in time thus, using Earth rotation, sampling the wave pattern of celestial sources (UV-plane sampling), (4) inverse 2D Fourier transformation to get a sky image.

Reliability and availability are crucial requirements for distributed adaptive measurement processes. LOFAR specific requirements are sensitivity and availability. Due to the crowded RFI environment in the LOFAR band and the large amount of analog and digital hardware, run-time RFI/EMI monitoring and mitigation is an integral and required part of this next generation sensor array. The complexity of EMI/RFI effects has no precedence in radio-astronomy, neither in modeling nor in mitigating these effects. This is identified as a risk in the development of the instrument. This paper provides an overview of the balances in viewpoints related to critical EMC and RFI issues and some recommendation for future studies, thus contributing to the attention for and mitigation of risks in the preliminary design stage of LOFAR.

PROBLEM DEFINITION

EMC and RFI Specific Problems

There are three problem areas related to the required sensitivity that can de identified for passive sensitive large-scale radio frequency sensor arrays such as LOFAR. The first area is the occupancy in time and frequency of the spectrum, filled with active spectrum users. Driven by technical advances and commercial opportunities, the spectrum tends to get more crowded. These transmissions have impact on the linearity of the receivers, on the number of required ADC bits and signal transmission speeds, and on the sensitivity and dynamic range of the instrument. The required techniques for detection and filtering of these transmitters increase the complexity of system. The second issue is an EMC issue: radio emissions self-generated or generated by nearby equipment (for example cars, personal computers in homes). This problem especially needs attention for LOFAR, as the telescope will operate in the range 10-250 MHz, where the emissions from equipment are relatively strong. As an example figure 1 shows the theoretical RFI power flux density of equipment complying with the EN55011 standard, located at 10m and 1km distance to a (future) SKA telescope. This clearly illustrates that EMI/RFI mitigation measures are needed.

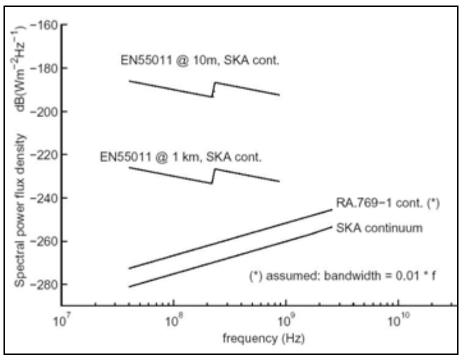

Figure 1. Equipment emissions.
Emission levels from equipment (worst case) according to the EN55011 standard w.r.t. the sensitivity level of the SKA telescopes, according to the SKA straw man specs and 8 hours of integration. Included is radio astronomy protection criterion ITU-

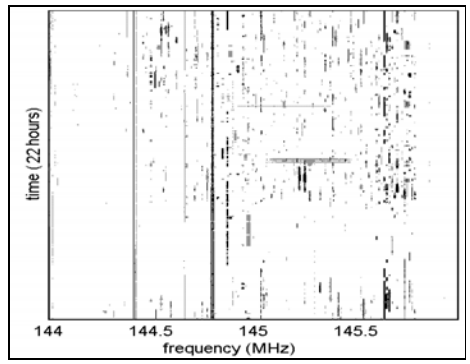

Figure 2. Occupancy, spatial correlation.
Spectrum occupancy correlation between seven monitoring sites, observed with the Dutch IVW-VMN stations. Number of simultaneous detection is indicated in gray (white: 0, black: 7). Maximum separation between the sites is 360 km.

Wide Area Observation and Computation

Although an instrument for wide area observation and computation differs from a stand-alone instrument with a single monitoring and control unit, both will suffer from disturbances. However, due to the distribution and hierarchical processing, the impact of disturbances for wide area instruments is more severe than in stand-alone instruments [2]. Disturbances are differences between expected and observed behavior. Hence an *instrumental behavior model* is required to adequately identify and suppress the effects of disturbances and instrumental errors. A large number of autonomous and adaptive processing nodes, called stations and sub-cores in LOFAR, performing several processing steps, each prevent straightforward identification of the instrument's behavior, even if the processing steps are known from design. Consequently the propagation of disturbances caused by RFI and EMI through the instrument is obscure.

In contrast with a single instrument at limited scale, wide area observation instruments need to take into account the local effects of a shared environment as well as the similarity of the processing elements and differences in processing at different locations. A certain RFI/EMI source can affect multiple stations, causing an artifact in the UV-plane or raising the system noise. Self-generated EMI will be similar for all processing nodes, due to similarities in the used hardware, but the propagation may differ due to differences in processing. It cannot be assumed that EMI-coupling has no significant impact on the quality of the processing, therefore this requires further study. Figure 2 shows an example of spectrum occupancy correlation between sites separated up to 360 km. It shows in gray scale the number of simultaneous detections of transmissions in a frequency band during a day. The impact of the simultaneousness of these transmissions influences the system performance. Obviously, the scaling and the hierarchical structure are very important factors in the propagation of the disturbances. The bottom-line is that we cannot properly monitor and mitigate propagating disturbances as long as we lack a model of the instrument's behavior and the instrument's EMI and RFI environment.

MITIGATION APPROACHES

A general starting point for RFI mitigation is that it is easiest to mitigate RFI signals in those domains where they are most localized and where they differ most from the desired signals of interest (time, frequency, location, direction, polarisation). Another general point is that RFI usually can only be mitigated down to the level at which it can be detected. Three RFI-source separation methods can be distinguished: filtering, cutting (excising) and subtracting (cancelling). Filtering is removing RFI signals in regions outside the regions of interest (e.g. spectral filtering and array-beam forming); cutting is removing the RFI in partially overlapping regions (e.g. time blanking of intermittent RFI signals, or spectral notch filtering in continuum observations), and subtracting is removing RFI by estimation and subtracting (e.g. side lobe cancelling, spatial filtering or parametric methods). Note that here spatial filtering (projection) also is considered a subtracting technique. A description of these techniques can for example be found in [5]. A practical approach for self-generated RFI and EMI from equipment in the surrounding area of the sensor network is to use EMC limits from standards (e.g. EN55011). This gives an indication of the levels to be expected, assuming a certain distribution of equipment. This gives, with the sensitivity requirements, an estimate of required RFI attenuation.

CONSIDERATIONS FOR COST-QUALITY BALANCING

Engineering Considerations. At the sensor inputs the risk of EMI is most prominent. The analog circuitry has to be as localized as possible. These circuits may experience mutual influences and can pick up digital noise. Good engineering practices like partitioning, shielding, powering, and connecting require space, add weight and volume and come at a cost. Having a large number of modules in a restricted volume, taking shortcuts in these engineering practices come naturally. The danger of these shortcuts is not to be underestimated however, as unacceptable performance will be very hard, time consuming and expensive to repair. The digital circuits, notably transmission and memory circuits, have their own fault risks. Bit errors can be corrected using fault tolerant schemes, at the cost of increased complexity.

Dynamic Range. The current two-bit phased arrays (WSRT) have a limited number of choices for coding; the next generation telescopes require a larger number of quantization levels, for sensitivity and RFI mitigation. Modifying the coding scheme may be required for optimal use of transmission bandwidth and compression, given the non-stationarity environment. Calibration requires a certain dynamic range to achieve accuracy in a fixed limited observation window. All the coding adaptations need to be known to get the absolute power, at the central processor which de-normalizes the locally applied normalization, complicating the processing. Last but not least the required statistics and windows for adaptive coding are yet unknown. New techniques are required.

Sensitivity: UV Plane Coverage and Blanking, Mitigation measures that effectively remove sky noise data from the data stream – by blanking – result in loss of sensitivity of the instrument as a whole. For this reason alone the mitigation detection and suppression mechanisms should operate only on the affected data as much as possible. Leaving out samples at certain time intervals, frequency bands and positions, disturbs the sampling of the UV plane, leading to reduced image quality and sensitivity, image artifacts and additional problems in image calibration. The trade off is improved RFI/EMI suppression by elaborate blanking mitigation methods on the one hand and reduced UV coverage and sensitivity as a result of this on the other.

Response time vs. detection limit. Any mitigation system that is able to recognize and suppress RFI the moment it occurs has an advantage over systems that have to integrate the signal to a sufficient level first. The latter case is more realistic however, because a confident recognition of the RFI needs sufficient signal to background noise. Thus the response time is inversely proportional to the achieved detection limit. Mitigation methods that need large chunks of data generally can do a better job in suppressing the RFI, at the cost of reduced response time.

Achievable Mitigation. In applying RFI mitigation there is a tradeoff between achievable mitigation and cost. The effect of the mitigation measure should be significant; if the improvements of the RFI situation are minor, then the same improvement usually can be reached by longer integration times. If the improvement is large, then at some point the improvement – cost ratio will reduce to an unacceptably low level.

Required Spectral Resolution vs. Processing Capacity. The choice of the frequency resolution of the LOFAR sensor array of 1 kHz is to a large extent determined by the RFI occupancy. It turns out that many transmitters in the LOFAR frequency band transmit in order 1 kHz wide frequency bins, often lined up in rasters with a spacing of order 5 to 10 kHz. If the time-frequency occupancy of these bands is not too high, the LOFAR telescope could operate in these bands if proper band selection and blanking algorithms are applied. The 1 kHz resolution is optimal down to about 40 MHz. In the range below this frequency, the availability of sparsely occupied 1 kHz bins decreases [12].

Distributed-ness: central, local and hybrid. As long as the RFI mitigation measures are linear and the effects on the desired signals are also linear, it is not advantageous to split a mitigation measure into two at different locations in the system hierarchy. The reason is that RFI can be suppressed down to the detection/system noise level and does not change this, it only makes the system more complex and expensive. A central location in the sensor network for the RFI mitigation usually is preferable. Other design considerations, operational requirements, or nonlinear effects involved, may suggest splitting RFI mitigation into two or more distributed stages. RFI mitigation measures operating on different sections of the parameter space may be stacked. Assuming an adequate model, expectations of the RFI/EMI situation and instrument conditions can be obtained. Local monitoring and filtering requires the distribution of the RFI/EMI information but also the central RFI/EMI information has to be kept up-to-date. The required infrastructure is unique for an instrument with approximately 160 processing nodes distributed over an area of 360km in diameter.

The system's complexity. The complexity of the RFI/EMI mitigation approach is perceived in terms of algorithmic complexity, system complexity and distributed-ness of the approach. These forms of complexity have to be dealt with on three levels: the (1) instrument users; (2) instrument management/operators, and (3) the maintenance. These will be measurable in terms of training times and learning curves, probability of human errors, man hours for diagnosis and maintenance. The implicated costs and development time motivate simple RFI mitigation approaches for LOFAR.

Computational platform requirements. Cost drivers are those aspects influencing the dimension of the processing platform. The first is the spectral resolution, for RFI blanking a resolution of few kHz may be required while user requirements can be satisfied with a much lower resolution. High resolution is obtained by frequency transformation with large time-windows, large buffers. The amount of channels that have to be processed scales the required hardware. The distributed-ness influences the dimensions in two ways: (1) central application of a mitigation procedures require one single platform to support the process; distributed mitigation, with local application, requires platform support at all remote sites; (2) distributed strategies have a higher communication overhead for monitoring and control, implying additional platform requirements.

RECOMMENDATIONS AND FURTHER RESEARCH

We have shown that EMC (fig. 1) will be an issue, and RFI disturbances (fig. 2) can be shared among multiple stations. Though multiple mitigation strategies exist, as discussed, there are many aspects due to RFI and EMI in a large area observation instrument, which require further analysis before the feasibility at reasonable costs can be concluded. The above aspects have some common critical issues; the risks involved can be tackled with the following studies:

- Investigate EM standards required to prevent self-generated signals, to be used for design and engineering
- Determine the criticality of applying adaptive processing to survive the non-stationary RFI/EMI environment
- Verify the feasibility of observation in a crowded RFI environment when using particular mitigation procedures
- Manage complexity with a detailed design of RFI monitoring/mitigation and beam-forming architecture

Propagation of disturbances such as EMI, RFI, and other artifacts in observations, is an issue in many types of distributed monitoring networks. The propagation of these disturbances requires substantial attention in order to increase our insight in these complex processes. LOFAR and SKA are instruments, which are well suited for studying this behavior. The monitoring-and-mitigation strategies of LOFAR and SKA are contributing to the understanding of the complex coupled distributed computing networks that are the backbone of today's industry and society.

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