Preliminary specifications for the MSSS

R.J. Nijboer & A.G. de Bruyn
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This document describes the preliminary specifications for the MSSS. These specifications are not final and we anticipate a final MSSS meeting in the spring of 2009 where we incorporate the results from the commissioning of LOFAR8-12 that will take place in the Nov08 - Mar09 period.

Introduction

For MSSS there are 13 core station and 7 remote stations. The HBA core stations are split in two half stations.

For the LBA stations 48 dipoles out of 96 are selected. The numbers below are based on an effective station diameter of 30 m. A reduction in sensitivity due to tapering is not taken into account.

The HBA tiles are 5 m by 5 m with a tile – tile spacing of 15 cm. This means a 24 tile core (half-) station is 30 m in diameter. A 48 tile remote station could be tapered to the same 30 m station yielding similar primary beams (but different side lobe levels). Due to the tapering it will have the same sensitivity as a core station. The precise choice of spatial taper to be used in the station beam former will probably be decided on only after extensive testing and experimentation in the Nov08 - Mar09 period when the 20 station configuration will be built up.

LOFAR20 has a longest baseline of 28 km. However, due to the bad uv-coverage at the long baselines, the uv-plane will be tapered to an effective longest baseline of about 10 km.

FWHM = 1.3 λ / D; D = 30 m

FoV = π (FWHM / 2)^2

PSF = 0.8 λ / L; L = 10 km

In order to keep up with the Roll – Out we propose to complete MSSS within 3 months. This phase is likely to take place over the summer. Doing an all-sky (24h RA coverage of the northern sky, i.e. 20626 sq. deg.) survey in 3 months in the summer period implies we have to observe a lot in daytime! This will bring many ionospheric calibration challenges, not all of which we will be able to solve.

Surveying Figure of Merit

FoM = FoV * (A_eff / T_sys)^2

	15	30	45	60	75	120	150	180	200	210	240
NL	0.02	0.07	0.34	1.06	0.24	18.1	18.5	9.80	6.72	5.62	3.49

In the LBA 60 MHz has the highest FoM. In the HBA this is 150 MHz.

Frequency-related issues

The choice of central frequency and the overall frequency span has many aspects. Not all software will be up and running so the MSSS observing specs will have to be less demanding than those in use during full LOFAR operation. Whether we choose 4 MHz (~ 20 subbands) total bandwidth per beam or 32 MHz (~160 subbands), in either case we can still decide to span the full 45-75 MHz (LBA) or 120-180 MHz (HBA) range. A wide band allows bandwidth synthesis hence will improve uv-coverage in the radial direction. However, different primary beams at very different frequencies (factor 1.5-1.7) will then cause complications. The azimuthal coverage can only be increased by extending the LST range over which the snapshots will be gathered. Since low elevations bring their own problems extending the LST range can only be done at the higher declinations (TBD).

Some numbers

The numbers below are based on 9 times 5 minute observations in the LBA and 3 times 5 minute observations in the HBA using 1 beam of 32 MHz (and 1 calibration beam of a single subband). In order to improve the UV – coverage and PSF we might trade BW for beams. In this way we can observe more fields at the same time and, hence, integrate longer on the same field. This goes at the expense of a smaller BW, but the sensitivity and total data size on that field remain the same.

	60 MHz	150 MHz
Observing time per FoV	9 times 5 minutes	3 times 5 minutes
FoV	121 deg^2	19.4 deg^2
FWHM	12.4 deg	4.97 deg
PSF resolution (10 km)	82.5 arcsec	33.0 arcsec
Correlator time resolution	1 s	1 s
Correlator freq resolution	0.76 kHz	0.76 kHz
Uv data size	760 Gbyte	680 Gbyte
Post DP^3 time res.	5 s	5 s
Post DP^3 freq res.	21.3 kHz	42.6 kHz
Post DP^3 uv data size	~ 5.43 Gbyte	~ 2.43 Gbyte
# channels per image cube	Tbd	Tbd
# pixels per image plane	Tbd	Tbd
Total image size	Tbd	Tbd

Table 1: Specifications per pointing / FoV

	60 MHz	150 MHz
Total # fields (2 pi steradian)	536	3340
Total observing time (100% eff.)	402 hr	835 hr
Total # sources	Tbd	Tbd
Total uv data size	407 Tbyte	2.27 Pbyte
Total post DP^3 uv data size	~ 2.9 Tbyte	~ 8.1 Tbyte
Total image data size	Tbd	Tbd

Table 2: “All sky” specifications

Some remarks:

- Each Field / FoV is to be observed in multiple snapshots with an overall time span of at least 4 and preferable 6 hours (depending on declination).
- For comparison, the PSF resolution of the VLSS (74 MHz) is about 80 arcsec, the resolution of WENSS (325 MHz) about 50 arcsec. Hence, from VLSS and WENSS an initial sky model can be constructed. This should be done well before April 2009.
- The current covering of the sky is based on a square grid (approximately Nyquist sampled at the central frequency within the band).
    - TBD: when the frequency span is determined the number of pointings should be recalculated using the highest frequency within the band.
    - A hexagonal coverage could also be chosen. If survey speed is an issue we could increase the grid size leading to a slight non-uniformity in the sensitivity.
- TBD: Images can be made by combining
    - 163 subbands into 1 MFS channel, or
    - 3 times 54 subbands (= 162 subbands) into 3 MFS channels, or
    - 5 times 32 subbands (= 160 subbands) into 5 MFS channels, or
    - 7 times 23 subbands (= 161 subbands) into 7 MFS channels.
    - The remaining subbands (from the total of 164 subbands) are used for clock calibration.
- The total observing time is 1237 hours or 7.4 weeks at 100% efficiency. At the more realistic efficiency of 50% this would be 15 weeks, slightly more than 3 months.

Smearing Loss

Using formulas 18.24 and 18.43 from SIRA-II. HPBW = 10000/30 * 1.3 / 0.8.

	Beta	Rf	Rt	Rf*Rt
0.5 * HPBW	0.0961	0.9979	0.9978	0.9956
1.0 * HPBW	0.1923	0.9915	0.9911	0.9826
2.0 * HPBW	0.3846	0.9669	0.9642	0.9322

At 60 MHz using 5 s samples and 21.3 kHz wide channels.

	Beta	Rf	Rt	Rf*Rt
0.5 * HPBW	0.0769	0.9986	0.9978	0.9964
1.0 * HPBW	0.1538	0.9946	0.9911	0.9857
2.0 * HPBW	0.3077	0.9786	0.9642	0.9435

At 150 MHz using 5 s samples and 42.6 kHz wide channels.

Number of sources

LOFAR CS1 images in the LBA had reached the classical confusion limit. LOFAR CS1 images in the HBA were limited (probably) by side lobes from distant bright sources. Indeed with LOFAR CS1 we never reached the thermal noise and we do not expect to reach the thermal noise with LOFAR20 / MSSS either, albeit for different reasons. We expect that the noise level in LOFAR20/MSSS images will be limited by a) poor UV coverage and resulting fundamental deconvolution errors and b) non-isoplanaticity problems due to the ionosphere. This will be especially true at LBA frequencies. The LOFAR CS1 HBA image made by Sarod Yatawatta has a noise level of 0.5 Jy, whereas the thermal noise is only 0.02 Jy. Hence, the noise in the image is 25 times the thermal noise. Similarly large discrepancies, but for different reasons, might still be encountered in the initial MSSS images.

When estimating the number of sources we expect to see with LOFAR20 / MSSS we therefore consider noise levels of 30 sigma and 100 sigma (where sigma is the thermal noise). This would correspond to the expected noise in a LOFAR20 image resp. 3 to 4 times the expected noise.

Thermal noise levels.

	σ (Jy) 60 MHz, 10 s	σ (Jy) 60 MHz, 2700 s	σ (Jy) 150 MHz, 10 s	σ (Jy) 150 MHz, 900 s
1 freq; 30 MHz	8.04 10^-2	4.89 10^-3	4.62 10^-3	4.87 10^-4
3 freq; 10 MHz	1.39 10^-1	8.47 10^-3	8.00 10^-3	8.43 10^-4
5 freq; 6 MHz	1.80 10^-1	1.09 10^-2	1.03 10^-2	1.09 10^-3
7 freq; 4.29 MHz	2.13 10^-1	1.29 10^-2	1.22 10^-2	1.29 10^-3

An effective bandwidth of 30 MHz was used in the tables below (93.75%). The effective BW was then distributed over 1, 3, 5 or 7 groups of subbands (to be used in MFS) with the indicated total bandwidths. The number of detected sources can thus be traded against information on the spectral index within the LBA and HBA frequency ranges, if that is deemed important. However, the uv-coverage aspect may be more important at this stage of LOFAR where a GSM with first-order spectral and structural information should be our main goal.

Number of detectable sources at 60 MHz

	100 σ; all sky	100 σ; FoV	30 σ; all sky	30 σ; FoV
1 freq; 30 MHz	9.17 10^4	538	2.70 10^5	1585
3 freq; 10 MHz	5.30 10^4	311	1.67 10^5	983
5 freq; 6 MHz	4.04 10^4	237	1.33 10^5	781
7 freq; 4.29 MHz	3.36 10^4	197	1.14 10^5	670

2700 s integration time.

Number of detectable sources at 150 MHz

	100 σ; all sky	100 σ; FoV	30 σ; all sky	30 σ; FoV
1 freq; 30 MHz	3.70 10^5	348	1.05 10^6	986
3 freq; 10 MHz	2.32 10^5	217	6.48 10^5	608
5 freq; 6 MHz	1.85 10^5	174	5.20 10^5	489
7 freq; 4.29 MHz	1.60 10^5	150	4.51 10^5	423

900 s integration time.

Calibratibility

In order to say something about the calibratibility of LOFAR20 the number of sources visible in the FoV in 10 s of data is computed. If we want to trade BW for beams in order to improve the UV – coverage and PSF, this will reduce the available BW for the calibration.

	100 σ; 60 MHz	100 σ; 150 MHz	30 σ; 60 MHz	30 σ; 150 MHz
1 beam; 30 MHz	17	44	94	140
3 beams; 10 MHz	6.9	24	45	84
5 beams; 6 MHz	4.4	17	31	66
7 beams; 4.29 MHz	3.3	14	24	56

sources in FoV in 10 s integration time.

It is currently expected that at 150 MHz there will be enough sources (> 10) in the FoV per 10 s for LOFAR20 to be calibratable. At 60 MHz the situation is much harder, especially in the daytime. Peeling large number of sources and using the phase information to model an ionospheric screen will have to be high on the agenda in the next 6 months.

Central processing steps after correlation

Once the data is correlated on the Blue Gene/P, they are temporarily stored on the storage cluster. Hereafter, the data are further processed on the off-line cluster. The following processing steps are currently foreseen:

- Correction for the remainder of the passband
- Flagging of RFI
- Correction for clock phases
- Subtraction of the A-team (strongest sources through the side lobes)
- Compression of data in time and frequency
- Storing the compressed data
- Self-Calibration
    - UV plane calibration
    - Ionospheric calibration using Peeling
    - Beam calibration?
- Facet corrected imaging
- Source finding and updating of LSM
- Next cycle of self-cal?
- Updating of GSM

The final data products will consist of

- Compressed UV data sets
- Image cubes
- Updated GSM
- Meta data (TBD, e.g. calibration tables)

Miscellaneous issues to be discussed

Preparing for LOFAR20

- What kind of fields to target for preparation?
  - NCP for beam validation? Possibly in combination with WSRT LFFE observations?
  - 3C196 and 3C295?
  - A strongly polarized field ('FAN')

LOFAR20 and European stations

- How to incorporate EU – stations?
- Always / sometimes?
- How many will there be?
- What is the minimum number of stations for imaging?