Imaging in radio interferometry by iterative subset scanning using a modified AMP algorithm

Giovanni Cherubini, Paul Hurley, Matthieu Simeoni, and Sanaz Kazemi, IBM Research – Zurich, Switzerland

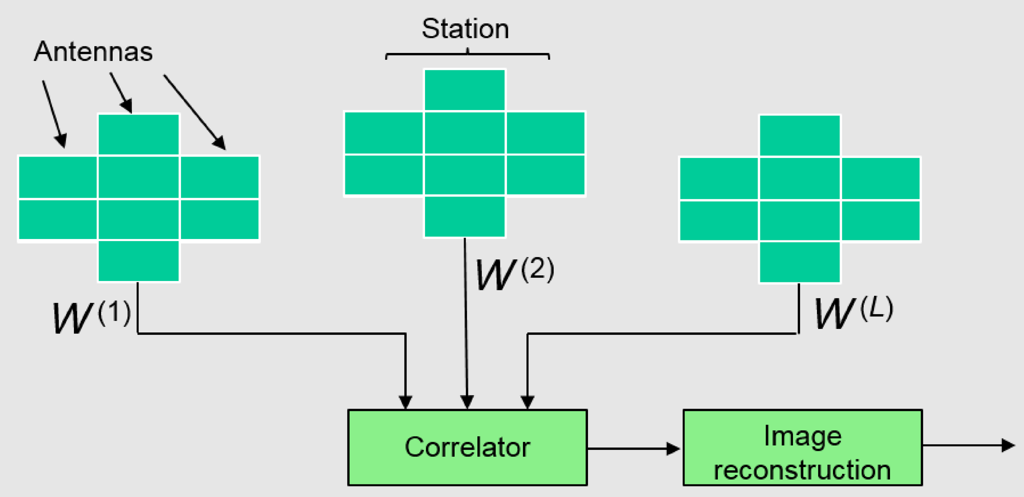
Abstract

- Imaging techniques in radio interferometry face the challenge of having to extract the image information from a huge number of antenna signals received.
- Beamforming reduces the rate required for transporting data from groups of antennas to a central site for further processing.
- We propose a novel method for image reconstruction based on the iterative scanning of a region of interest, combined with randomized beamforming.
- A modified approximate message-passing algorithm is adopted to extract relevant image information from beamformed signals received at the antenna stations.
- The method can be applied in general for image reconstruction in system getting information from sensor signals, e.g., MRI and NMR spectroscopy systems.
- The method is illustrated by simulations, with reference to the LOFAR radio interferometer, and compared with the CLEAN algorithm.

Radio interferometry

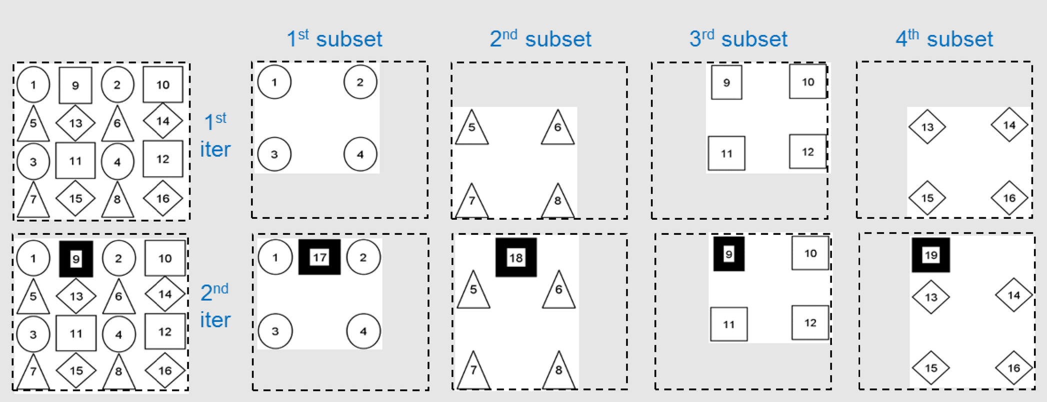
System model

- The signals received by the antennas at a station are combined by beamforming to reduce the amount of data to be processed at the later stages.
- Beamforming is usually done by conjugate matched beamforming towards the center of the field of view at all stations; randomized beamforming is used to increase diversity.
- Beamformed signals are correlated to get so called visibilities, which roughly correspond to the samples of the Fourier transform of the image.
- Image reconstruction is traditionally obtained via a Fast Fourier Transform of the visibility measurements, e.g., combined with the CLEAN algorithm.



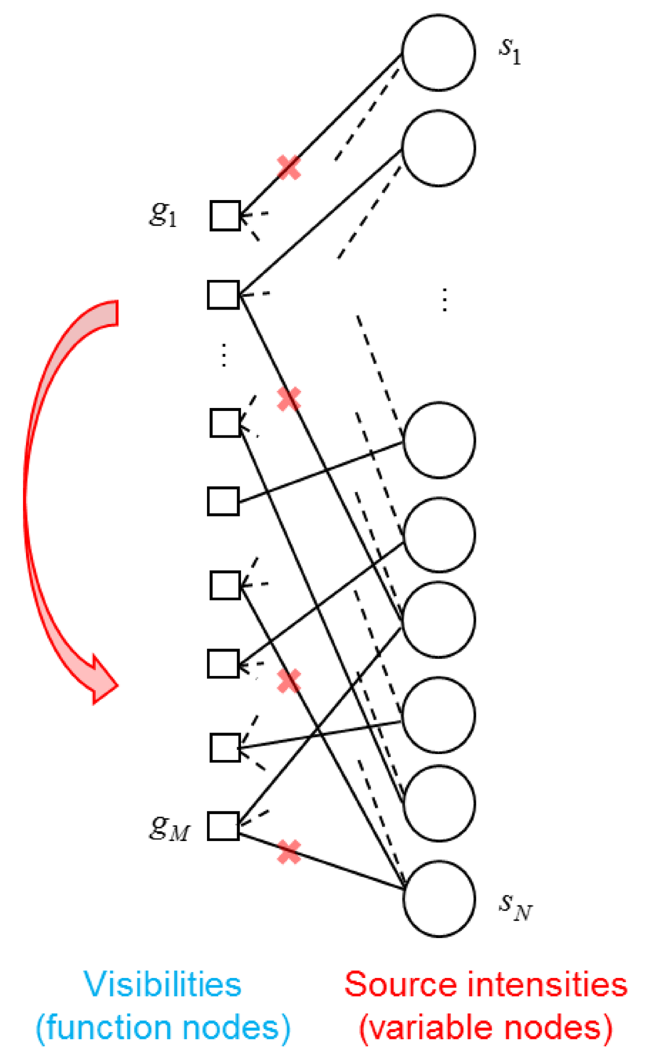
Iterative image-subset scanning

- Scan the region of interest by subdividing it into subsets of points on a grid, and estimating intensities emitted by the hypothesized sources located on each subset.
- At the end of a scan, identify those points in the region of interest that have the highest probability of "hosting" a source.
- Modify the subsets of points by 1) including in each subset the "host" points identified, and 2) changing the grid definition based on the information obtained in the preceding scan.



Modifying Approximate Message Passing (AMP)

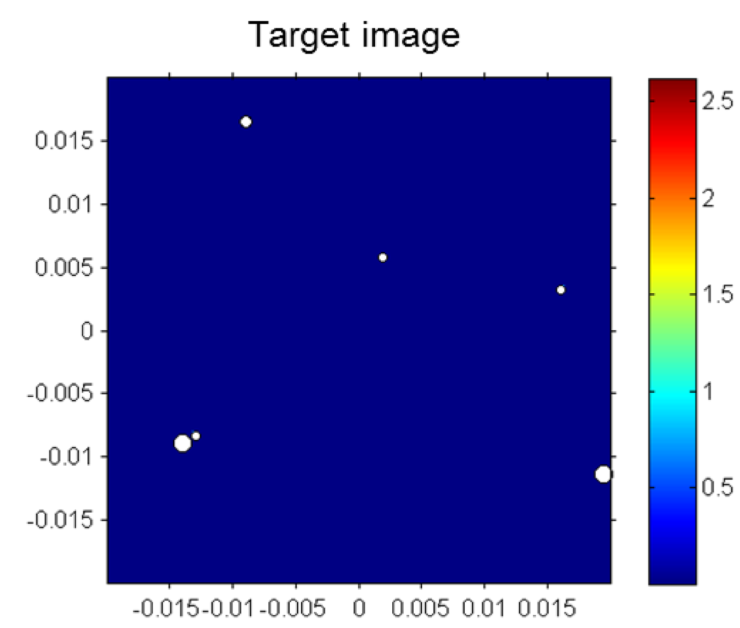
- AMP exhibits the property that its solutions yield the true posterior means, in the limit $M, N \rightarrow \infty$, with the ratio M / N fixed, assuming that the graph coefficients that express the measurements as a linear combination of variables are i.i.d. Gaussian random variables.
- In practice, however, M and N are finite, and the graph coefficients are not i.i.d. Gaussian.
- For large deviations of the graph coefficients from a Gaussian distribution, AMP does not converge.
- Solution:
  1. Randomize the order of message passing at each iteration of the AMP within the bipartite graph.
  2. Prune the messages from function nodes to variable nodes, such that the coefficients that correspond to the allowed connections in the message-passing loop approximate a Gaussian distribution.

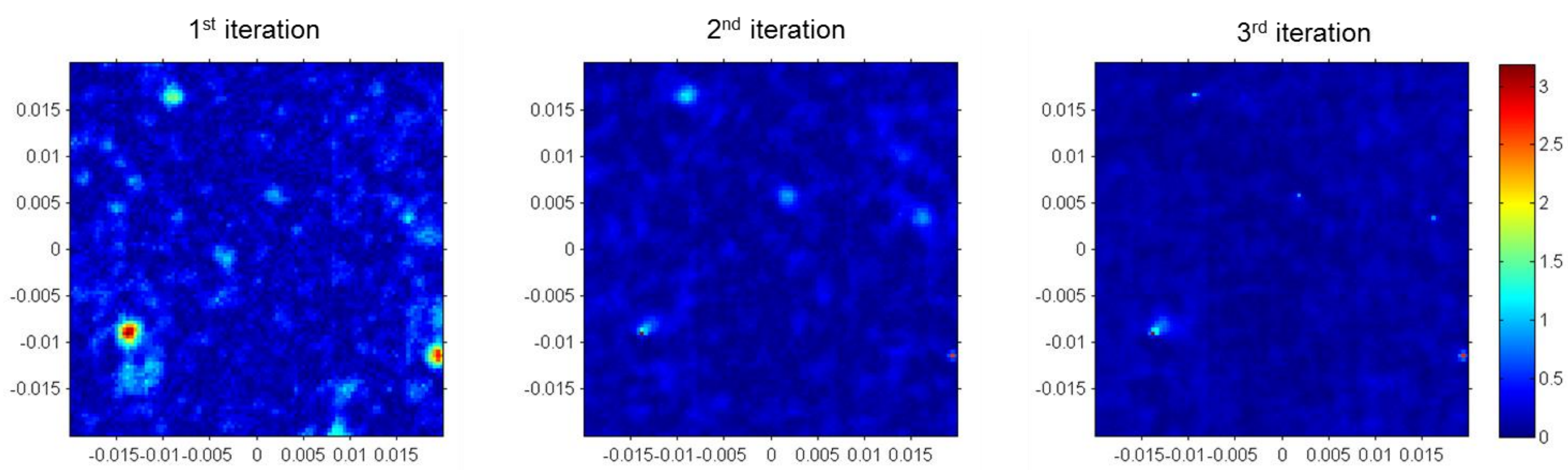


Example of sky image reconstruction

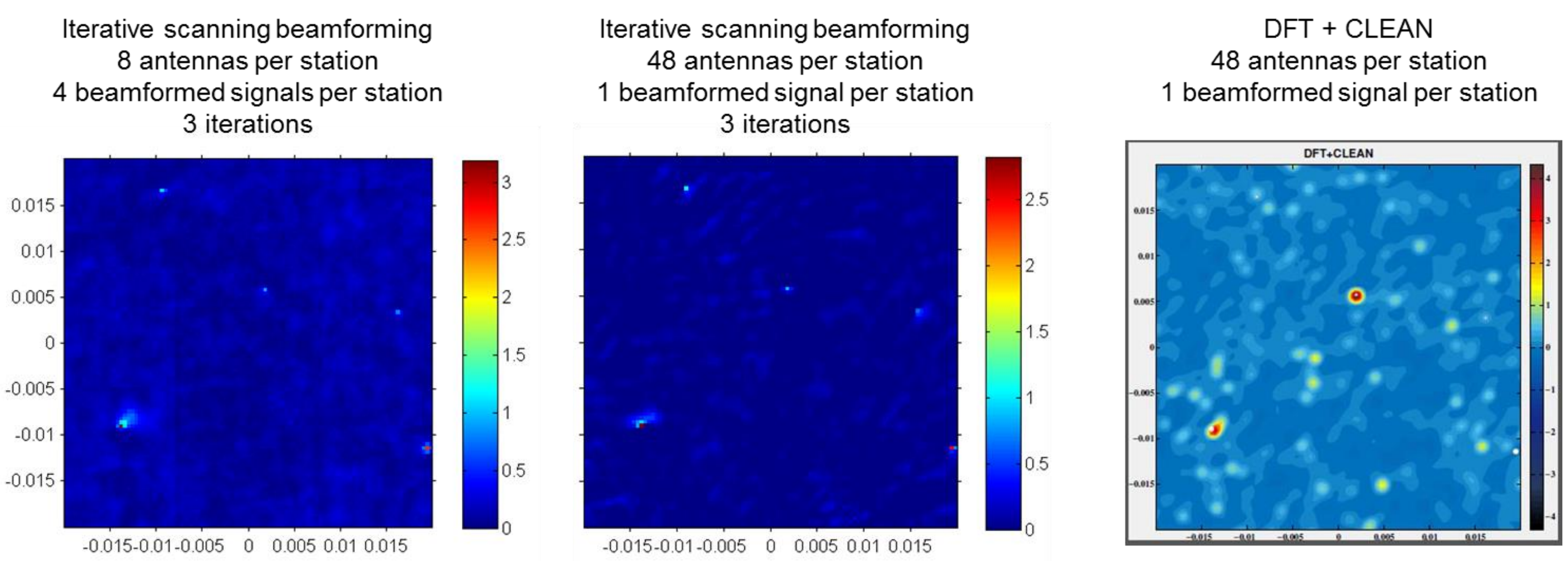
Simulation parameters to investigate convergence behavior

- Multiple sources in a field of view with radius of 0.02 rad
- Visibilities from 24 LOFAR stations using 8 antennas each
- 1 s short-time integration (STI) interval @ 768 samples/s
- Signal-to-noise ratio ~ -20 dB
- 4 beamformed signals per station
- 32 iterations of improved AMP / subset image
- 100×100 pixels





- Performance comparison with the CLEAN algorithm:
  - find strongest source in the "dirty image"
  - compute the "dirty beam" at that location
  - remove a portion γ of the dirty beam from the field of view
  - iterate until convergence



Conclusions and next steps

- A new image reconstruction method for application in several fields, including radio interferometry and medical applications, has been presented.
- The concept of iterative scanning of a region of interest subdivided into subsets has been introduced, together with a modified AMP algorithm for efficient extraction of relevant image information from sensor signals.
- Simulation results obtained with reference to the LOFAR interferometer indicate that the proposed method yields a significantly lower reconstruction error for short observation intervals than the CLEAN algorithm.
- Next steps include the extension to the case of unknown sensor gains, and the analysis of the convergence properties of the algorithm.