Demonstrating Radio Environment Map Construction from Massive Data Sets

Janne Riihijärvi, Jad Nasreddine and Petri Mähönen
Institute for Networked Systems, RWTH Aachen University
Kackerstrasse 9, D-52072 Aachen, Germany
email: {jar, jad, pma}@inets.rwth-aachen.de

***Abstract*—In this demonstration we show an approach for constructing radio environment maps from massive data sets. Unlike earlier approaches, the methods used in the demonstrator can scale to millions of measurement points, enabling coverage prediction and other spatial estimation problems to be solved at country-wide scales. The demonstrator GUI enables attendees to construct different types of simulated measurement data sets, and perform spatial estimation based on those. The framework also allows the attendees to study the accuracy of the obtained estimates, as well as the computational time required for data processing.**

I. Introduction

Measurement-based estimation of coverage regions and propagation environment is one of the key application scenarios of radio environment maps (REMs) [1], [2]. Spatial maps of, for example, received signal strengths can be used in the dynamic spectrum access context to significantly improve the accuracy of primary user protection zones, and also in cellular networks to improve network planning and discover coverage holes. Methods from spatial statistics, especially *kriging*, have been found as giving both accurate and robust results for the estimation problems needed to construct such maps [3]–[5]. However, basic kriging approaches suffer from poor scalability, requiring up to $O(n^3)$ operations for a prediction at a single location, where n is the number of measurement points from which data is available [6]. For country-wide estimation of TV white spaces or cellular network coverage in an automated fashion, n can be in the order of millions of data points or even higher. In the cellular network case the adoption of the "minimization of drive tests" (MDT) approach being developed at 3GPP [7] would effectively make every mobile phone a spectrum measurement device, resulting in unparalleled amounts of data becoming available for radio environment map construction.

In this demonstration we will showcase a prototype implementation of a highly scalable REM framework capable of dealing with such vast amounts of measurement data. Our prototype utilizes recently developed *fixed rank kriging* techniques [8], [9], with linear computational complexity, to enable processing of tens or hundreds of thousands of measurements on a typical laptop in an interactive manner, and much more when run on dedicated high performance computing server or in the cloud. The attendees will be able to generate predictions of spectrum use in real time based on simulated measurements,

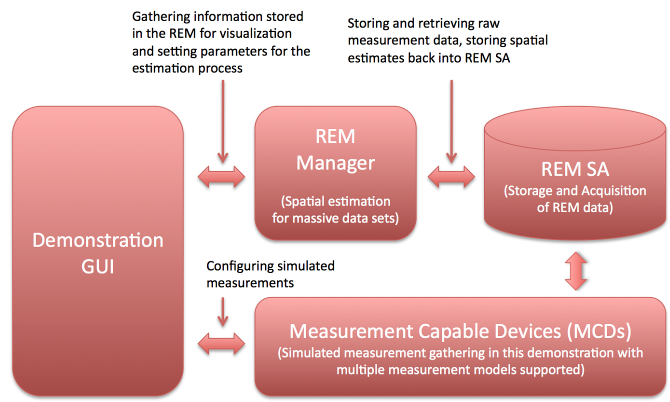

Fig. 1. The radio environment map architecture forming the basis of the demonstrator, including the mapping of demonstrator functionalities to the architectural elements.

and will also be given the opportunity to bring their own data sets for processing.

In the following section we provide a more detailed description of the architecture and the functionalities of the REM demonstrator.

II. REM Implementation and Demonstration

The demonstrated REM prototype builds upon the architecture co-developed by the authors, and demonstrated in DySPAN 2011 with a live measurement setup [10]. This architecture is shown on Figure 1, together with a mapping on the components present in the proposed demonstration. The REM Storage and Acquisition database will be seeded with different simulated data sets of varying sizes, obtained from highly realistic propagation simulations. We will include data sets corresponding both to TV white space applications, as well as for use cases involving cellular networks. New data sets can also be added during the runtime of the demonstrator. Live MCDs will not be deployed for this demonstration since very large data sets are needed. The scalable spatial estimation code runs as a REM Manager instance, performing estimates on the data sets and storing the predictions together with estimates on their accuracy back to the REM SA database. The demonstrator provides a rich GUI that interacts with the REM Manager to control the prediction process as well as for obtaining the predictions to be visualized.

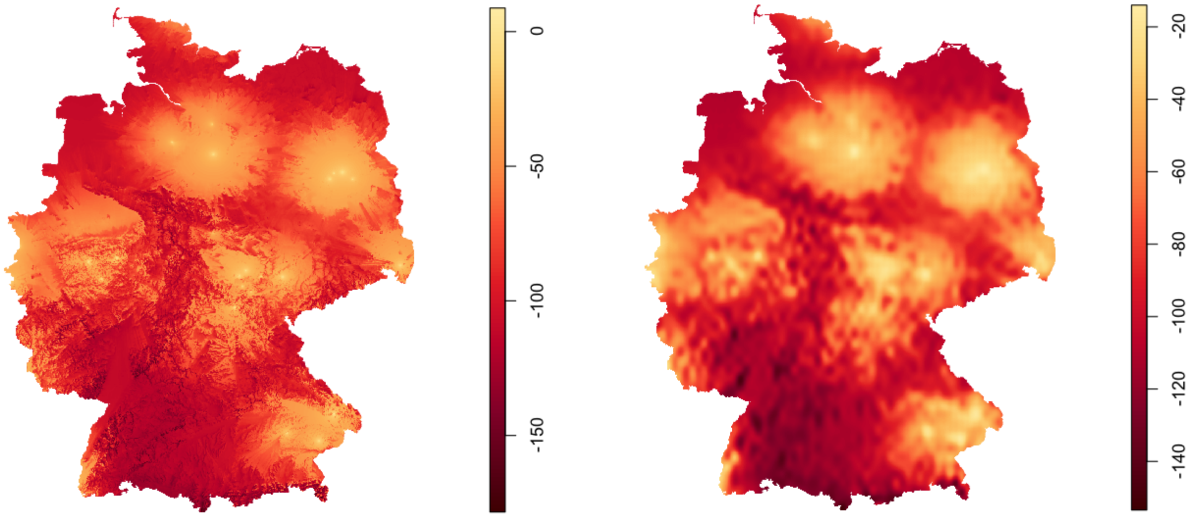

Fig. 2. The received power for DVB-T channel 27 in Germany (left) computed using the Longley-Rice irregular terrain model, together with the spatial estimate (right) constructed with fixed rank kriging techniques based on 27 000 random measurements. The global structure of the data set is well estimated by already this relatively sparse measurement setup, although local structure is, of course, somewhat smoothed out.

Figure 2 illustrates the kinds of computations the attendees will be able to carry out interactively using the prototype framework. On left panel the received power for DVB-T channel 27 in Germany is shown computed using the Longley-Rice irregular terrain model. From this a random collection of 27 000 simulated measurements has been taken, and used as a basis for spatial estimates for the country-wide coverage of the given DVB-T channel, with results shown in the panel on the right. The associated model fitting takes less than 20 seconds on a typical desktop computer, and individual predictions from the model are computed in milliseconds. Due to the linear complexity of the method employed, the fixed rank kriging approach remains computationally feasible even if the number of measurement points would be increased by several orders of magnitude.

Since simulated measurements are used for the demonstration purposes, the prediction accuracy can also be readily estimated and visualized. This will enable the attendees to compare the accuracy of MDT approach or measurement driven coverage estimation against that of traditional propagation model based estimates. In the DVB-T case for white space types of applications one can, for example, explore using the demonstrator the number of measurement points needed to exceed the accuracy of the ITU or Longley-Rice models, which for most channels turns out to be on the order of some tens of thousands of measurement points.

Finally, the demonstrator will enable the study of the impact of the measurement locations on the accuracy of the obtained results. Especially for MDT types of scenarios users themselves would be carrying out the measurements, which can be modeled by generating the corresponding locations based on the population distribution of the country. We would seed the REM database with such information on population densities for selected countries, allowing the attendees to compare the results from population based sampling against different types of planned measurement campaigns.

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References

[1] T. Cai *et al.*, "Design of layered radio environment maps for RAN optimization in heterogeneous LTE systems," in *Proceedings of IEEE PIMRC 2011*, 2011, pp. 172–176.

[2] Y. Zhao, L. Morales, J. Gaeddert, K. Bae, J. Um, and J. Reed, "Applying radio environment maps to cognitive wireless regional area networks," in *Proceedings of IEEE DySPAN 2007*, 2007, pp. 115–118.

[3] J. Riihijärvi, P. Mähönen, M. Wellens, and M. Gordziel, "Characterization and modelling of spectrum for dynamic spectrum access with spatial statistics and random fields," in *Proceedings of IEEE PIMRC 2008*, 2008, pp. 1–6.

[4] A. Alaya-Feki, S. Ben Jemaa, B. Sayrac, P. Houze, and E. Moulines, "Informed spectrum usage in cognitive radio networks: Interference cartography," in *Proceedings of IEEE PIMRC 2008*, 2008, pp. 1–5.

[5] J. Riihijärvi, P. Mähönen, M. Petrova, and V. Kolar, "Enhancing cognitive radios with spatial statistics: From radio environment maps to topology engine," in *Proceedings of Crowncom 2009*, 2009, pp. 1–6.

[6] N. Cressie, *Statistics for spatial data*. Wiley-Interscience, 1993.

[7] 3GPP, "TS 37.320 v10.0.0, "Radio measurement collection for Minimization of Drive Tests (MDT);Overall description; Stage 2"."

[8] N. Cressie and G. Johannesson, "Fixed rank kriging for very large spatial data sets," *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, vol. 70, no. 1, pp. 209–226, 2008.

[9] N. Cressie, T. Shi, and E. Kang, "Fixed rank filtering for spatio-temporal data," *Journal of Computational and Graphical Statistics*, vol. 19, no. 3, pp. 724–745, 2010.

[10] V. Atanasovski *et al.*, "Constructing radio environment maps with heterogeneous spectrum sensors," in *Proceedings of IEEE DySPAN 2011 — Demonstrations*, 2011, pp. 660–661.