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The comparison of methods for constructing the radio frequency layer of radio environment map using participatory measurements

Marko Pesko[1], marko.pesko@telekom.si
Tomaž Javornik[2], tomaz.javornik@ijs.si
Mitja Štular[1], mitja.stular@telekom.si
Mihael Mohorčič[2], miha.mohorcic@ijs.si

[1] Telekom Slovenije, d.d., Ljubljana, Slovenia
[2] Jozef Stefan Institute, Ljubljana, Slovenia

Marko Pesko, Telekom Slovenije, d.d.

Abstract— **Construction of the radio frequency layer of radio environment map (RF-REM) is one of the essential steps in building REM, required for the dynamic spectrum access based on geo-location and database approach. In this paper we consider participatory measurements based RF-REM construction and present performance evaluation of several existing construction methods and a novel method which takes into account characteristics of the operating environment and estimates operating parameters of the transmitter.**

I. INTRODUCTION

An efficient utilization of radio resources, investigated within the dynamic spectrum access (DSA) and cognitive radio (CR) concepts, can be achieved only by a good knowledge of the radio environment. A state-of-the-art method for describing radio environment is Radio Environment Map (REM) [1, 2], where comprehensive information about the radio environment is stored. The most important class of information in the REM is interference field information [2], which is obtained from maps illustrating the area coverage with radio signal, the RF-REM layer. Nowadays, RF-REM layer is estimated by processing the results obtained from dedicated measurement campaigns, which are performed monthly or even yearly. This essentially results in static RF-REM layer. The future radio environment is expected to be more dynamic and static RF-REMs will not present the radio environment with sufficient accuracy. The dedicated measurement campaigns are expected to be replaced by a new approach, where mobile devices will send information about their position and sensed environment to REM, where the RF-REM layer will be calculated and stored. This approach is known as a participatory spectrum sensing[1] [3] and appears well suited for collecting dynamically changing data on radio environment. However, the dynamic nature of collected data calls for investigation of suitability of existing methods for construction of the RF-REM layer, and if necessary for the development of appropriate new methods.

II. RF-REM CONSTRUCTION

The RF-REM construction can be performed with direct and indirect methods [1]. The most widely applied direct, interpolation based methods found in the literature are inverse distance weights (IDW), nearest neighbours (NN), splines, Kriging [4, 5], modified Shepard's method (MSM) [6], and gradient plus inverse distance squared method (GIDS) [7], among which Kriging is often reported to achieve the best performance. Still, none of these methods explicitly takes into account characteristics of the operating environment nor estimates characteristics of the propagation model and antenna pattern of the transmitter. Consideration of these features could further improve the construction of the RF-REM layer, as indicated in the latest research on indirect methods performed by Yilmaz et al. [1] proposing the LIvE method which statistically models the influence of the operating environment.

[1] With the term participatory we refer to the opportunity for each spectrum measurement capable device (MCD) at random location to participate in RF-REM construction.

Making a step further, we developed a new indirect self-tuning method[2] (STM) for the RF-REM construction [8] which considers the operating environment, applies received signal strength (RSS) measurements for simultaneous estimation of the transmitter parameters, including the antenna pattern, and calibration of the propagation model for the RF-REM construction.

III. PERFORMANCE COMPARISON OF METHODS

To be consistent with the latest progress in the field [1], the considered methods in this paper are IDW, IDW2, Kriging, LIvE, and the new STM method. The root mean square error (RMSE) between the constructed RF-REMs and a reference RF-REM is used as the performance evaluation basis. The reference RF-REM and participatory measurements are simulated to reflect real directive transmitter of the Slovene mobile operator. However, since the participatory measurements are randomly distributed over the area of interest, in order to depict more real comparison of the methods, the selected performance comparison metric is $\overline{\text{RMSE}}$. This is calculated from RMSEs of the RF-REMs constructed from 100 different randomly formed measurement sets of the same size, whereas the set size varies from 10 to 500 measurements.

IV. PRELIMINARY RESULTS OF THE CONSIDERED CONSTRUCTION METHODS COMPARISON

The preliminary comparison results are depicted in Fig. 1. These show that the STM method, which takes into account characteristics of the operating environment (i.e. digital elevation model (DEM) and clutter information) and estimates characteristics of the propagation model and antenna pattern of the transmitter, clearly outperforms the existing RF-REM construction methods. As can be seen in Fig. 1 LIvE still can be better than Kriging and IDW2 in scenarios with the directive transmitter, however, only if very small number of measurements is available. In addition, the results indicate that in such scenarios the direct methods still have a great potential, unless an indirect method is used that takes into account the operating environment and the characteristics of the transmitter. In such cases, the direct methods cannot compete with the latter in terms of RF-REM accuracy. On the other hand, one could argue that in terms of computing power, such approach demands very high processing capabilities. This is in general true, but in practice it does not present any special implementation restrictions, as the methods for such RF-REM construction can be integrated in parallel simulation frameworks, e.g. in [9].

V. CONCLUSION

In this work we presented the preliminary performance evaluation results for several existing methods for RF-REM construction in parallel with the new STM

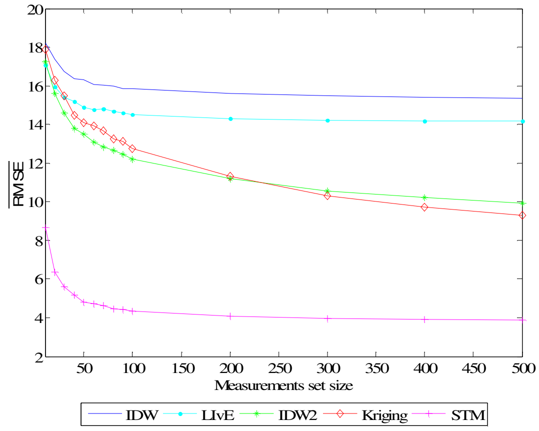

Fig. 1 *Preliminary results of the considered construction methods comparison.*

method. All methods were tested on the same sets of spatially distributed measurements used to model participatory spectrum sensing. The preliminary results confirm that the accuracy of the RF-REM layer can be notably enhanced by construction methods considering the operating environment, propagation model tuning and transmitter characteristics.

VI. ACKNOWLEDGMENTS

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[2] Described in a paper under review at IET Electronics Letters [8], subject to Institution of Engineering and Technology Copyright. If accepted the copy of record will be available at IET Digital Library.