Small-cells Radio Resource Management Based on Radio Environmental Maps

Daniel Denkovski, Valentin Rakovic, Marko Angjelicinoski, Vladimir Atanasovski and Liljana Gavrilovska
Faculty of Electrical Engineering and Information Technologies
Ss. Cyril and Methodius University in Skopje
Skopje, Macedonia
{danield, valentin, markoang, vladimir, liljana}@feit.ukim.edu.mk

Abstract—**Recent advances in cognitive radio have identified the small-cells among the most promising future wireless networking scenarios. Utilizing radio context information, small-cells should perform the most optimal radio resource management (RRM) to maximize performances and minimize inter-cell interference. Radio Environmental Maps (REM) data: empirical propagation models, active transmitters' locations, up-to-date interference levels, statistical channels occupancies, are especially beneficial in these scenarios. The proposed demonstration aims to showcase the benefits of using REM information in the small-cell optimization. The demonstration utilizes a modular/flexible REM prototype, performing a real-time REM data acquisition, processing and inference as input to an enhanced small-cell optimization.**

Index Terms—**small-cells, radio resource management, REMs, single/multi transmitter localization, propagation models.**

I. INTRODUCTION

Smart reconfigurable small-cells have recently emerged as potential underlay spectrum sharing approaches to improve the overall spectrum utilization of cellular bands. The small-cells aim to most efficiently exploit the macro-cell frequency bands, while tending to minimize the inter-cell interference (small-cells-to-macro and vise versa). The dynamic radio environment context information is especially crucial in these scenarios. The knowledge on the active transmitters (base stations, terminals), the propagation model parameters, as well as the available channels for secondary usage, their temporal and spatial occupancy, is a necessity for the optimal (re)configuration of the small-cells communication parameters.

Radio Environmental Maps (REMs) [1][2] emerge as a keystone facilitating technology for the evaluation and optimal re-usage of vacant/underutilized spectrum bands. The REMs can be seen as databases or knowledge bases, which can store various types of radio environment information, constantly fed with on-field real-time measurement data to track the dynamism of the radio environment. Additional REM data can be modeled or estimated based on the raw spectrum measurements, including the interference levels a certain transmission can induce to the surrounding devices, empirical propagation models, estimations on active transmitters' (and possibly receivers) locations and their communication parameters. All this REM data can be a valuable asset to the small-cell optimization scenarios, and if reasonably utilized can result in an optimal (or enhanced at least) radio resource management in these scenarios.

The proposed practical demonstration intends to show the benefits of using the REMs in small-cell optimization scenarios. The demo foundation is a generic, modular, and flexible REM prototype implementation (backend) [1][2] with on-field spectrum measurement devices to provide real-time environment data, and a rich set of statistical inference algorithms for propagation modeling [3], single/multi source localization [3][4][5], Radio Interference Fields (RIFs) estimation, temporal and spatial channel occupancy estimation, etc. The presented demo is an extension of the work in [1]-[5] in terms of addition of RRM functionalities to the developed REM backend. In particular, the output of the REM backend serves as an input to the radio resource management of the small-cells parameters in terms of frequency, bandwidth and power optimization. The synergy between REM and RRM can be especially beneficial in femto-cell scenarios due to the unavailability of clearly defined interfaces, techniques and solutions to manage the installation and the optimization of femto-cell operation.

II. INTEGRATED REM-BASED SMALL-CELL RADIO RESOURCE MANAGEMENT DEMO PLATFORM

The prototype implementation consists of a REM backend, represented by acquisition, storage and processing/inference components and interfaces, and small-cell communication devices, utilizing the optimal communication parameters coming as an output of the REM–facilitated radio resource management. The prototype architecture [1][2], as illustrated in Fig. 1, consists of four major components and three interfaces, briefly explained in the subsequent paragraphs.

Measurement Capable Devices (MCDs). The REM prototype can integrate different types of spectrum measurement capable devices [1][2], such as low-cost spectrum sensors, spectrum analyzers, mobile phones, base stations. The MCDs report measurements to the REM storage and provide options for remote (re)configuration and measurements querying.

REM data Storage and Acquisition unit (REM SA) represents the main data storage in the REM prototype implementation. Besides the raw spectrum measurements coming from the MCDs, the REM SA keeps other REM relevant information: positions and configurations on radio transmitters/receivers, propagation characteristics, as well as restituted REM processed data, in terms of empirical propagation models, RIFs estimations, dynamic transmitter locations' estimations, etc.

REM Manager is the fundamental REM prototype component performing the main processing tasks for REM data creation and evaluation. It is modularly constituted, comprising various toolboxes for single- /multi-transmitter localization, statistical analyses of the spectrum usage, assessment of propagation characteristics, estimation of RIFs etc. The *Radio Resource Management (RRM)* is one of the key toolboxes which are used in small-cell optimization scenarios: frequency, bandwidth and power allocation based on the denoted REM data.

The REM data can be utilized by different types of ***REM users***. In the proposed demonstration, there are two possible REM users, i.e. the *REM Graphical User Interface (GUI)*, for real-time presentation of the radio environment conditions and the *Communication Devices (CDs)* acting as small-cell devices using the communication parameters, as decided by the RRM toolbox of the REM Manager.

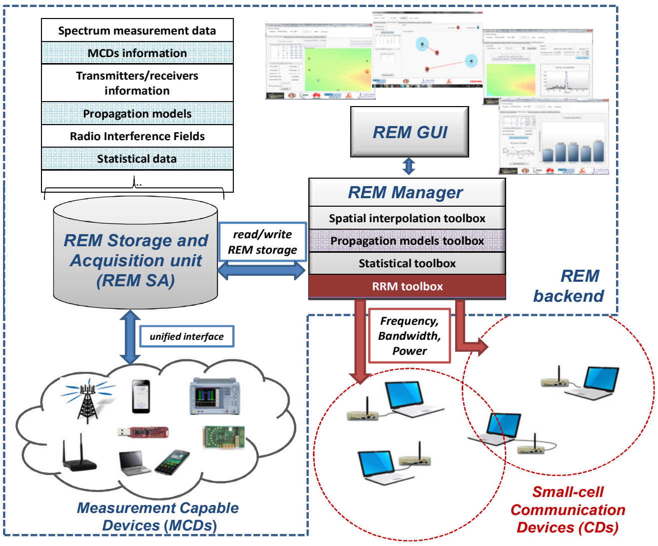

Fig. 1. Integrated REM based small-cell optimization prototype

The ***MCD–REM SA interface*** handles the measurement data reporting and the MCDs registration and (re)configuration, while the ***REM SA–REM Manager interface*** relays the communication between the related entities in terms of the measurement data extraction and processed REM data restitution. Finally, the ***REM Manager–REM User interface*** provides the REM Users' access to REM data and ability for online querying of some specific REM processing. Via this interface, the small-cell communication devices dynamically receive the communication parameters from the RRM toolbox of the REM Manager, and hence, adapt to the dynamically changeable environment conditions.

III. Demonstration Setup and Flow

The proposed demonstration of the REM-assisted RRM optimization of small-cell devices will comprise the following hardware/software components:

- Laptops to run the REM backend with the toolboxes for data processing/analysis, along with the REM GUI.
- In total 10+ spectrum sensors to perform the real-time spectrum measurements as an input to the REM processing/inference algorithms.
- At least two pairs of small cell-like communication devices (e.g. USRPx devices) which utilize the REM based radio resource management to perform real time communication (e.g. video streaming).

The proposed demonstration will show several REM and RRM related aspects, including:

- Real-time performance assessment of the REM backend, in terms of single-/multi- source localization, estimation of the propagation model parameters, estimation of the interference levels in the environment, estimations on statistical/spatial spectrum usage.
- The RRM toolbox of the REM Manager will calculate the most optimal frequency/bandwidth/power parameters of the small-cell devices, based on the estimated REM data: available channels, propagation model estimates, locations of estimated transmitters, interference levels estimations. The small-cell devices will utilize the optimal communication parameters calculated by the RRM.
- The small-cell devices will be forced to inquire a change the communication parameters via activating an interferer in their operating bands. The RRM toolbox of the REM Manager will dynamically perform a new frequency/ bandwidth/ power optimization, so the small-cell devices can adapt to new environment conditions and continue the communication.
- All of the environment changes will by dynamically monitored via the REM GUI, including appearance of new emissions, changes in propagation characteristics etc.

The demonstrated prototype is to the best of the authors knowledge one of the first fully comprehensive REM assisted small-cell optimization demo platforms.

Acknowledgment

This work was inspired by the EC project ACROPOLIS (FP7-257626) and the NATO project ORCA (SfP-984409). The authors would like to thank everyone involved.

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