# Multi-Dimensional Radio Service Maps for Position-based Self-Organized Networks

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*Abstract*—**Increasing spectral and energy efficiency in future networks requires flexible and timely allocation of radio resources along multiple dimensions including frequency, time and space. Although this multi-dimensionality offers additional degrees of freedom, it however comes at the cost of higher complexity. To this end, it is envisaged that spatial information associated with user resource allocation will provide a means for an efficient utilization of a dense radio access network (RAN) infrastructure in a proactive and self-optimized manner. In this paper, we propose a novel approach that aims at the utilization of multi-dimensional (MD) radio service maps (RSM) for storing and exploiting position-based information. Requirements, key concepts and functions are described. The potential gains in energy consumption and efficiency of the radio service maps are shown by means of numerical results for an ultra-dense network deployment scenario.**

***Keywords-radio service maps; self-organised networks, radio resource management; fifth generation mobile networks***

## I. INTRODUCTION

In the last years new frequencies have been made available for Radio Access Networks (RAN) to meet an increasing capacity demand for wireless connectivity, and more spectrum is expected to be made available in the coming years. It is, however, widely accepted that to meet the expected increasing demand, additional spectrum alone will not suffice. To meet the 1000x capacity increase target in dense urban environments, the area spectral efficiency must increase drastically, implying a need to both densify the network grid, and increase the spectral efficiency of the air interface by means of e.g. spatial multiplexing. Furthermore, for 5G we anticipate a 10-fold increase in mobile data traffic by year 2019 and a growth in the number of connected devices to 50 billion [1]. The overall traffic is expected to reach a peak area capacity near 1 Tbps/km$^2$ and the user bit rate should not dependent on the location of the user as of today, rather it should be 100s of Mbps everywhere [2]. In addition, there are requirements on the transmission delays posed by critical data applications, e.g. required to drive a car with augmented reality navigation. With regards to the energy cost, while traffic grows exponentially, energy efficiency can only grow linearly. So in order to cope with traffic increase we need to significantly reduce the energy per bit.

In general, the development of 5G, targets to flexible solutions to address highly diverse requirements for numerous use cases and business scenarios incl. xMBB, uMTC and URLLC [3]. For the flexible solutions, a variety of enabling technologies and technology advances have been proposed ranging from the physical layer up to the network and management layer including multiple air interfaces, advanced transceiver design, non-orthogonal multiple access, massive MIMO, millimeter wave (mmW) band transmission, cloud radio access network (C-RAN) technology. All these potential technologies, when combined, will increase the degrees of freedom at hand to meet the requirements for 5G. However, the inherent increase in complexity stemming from the greater degrees of freedom will require novel approaches to RRM algorithms. We envisage that reactive multi-objective self-organized network (SON) algorithms will face a complexity growth they are not currently designed for and will consequently require guidance by more proactive correlation intelligence based on pattern recognition in time, frequency and space. As of today, patterns can be identified by means of data mining, big data analysis and AI. The mining of patterns from the operation of a complex system will allow for predictions and development of more proactive SON algorithms for 5G.

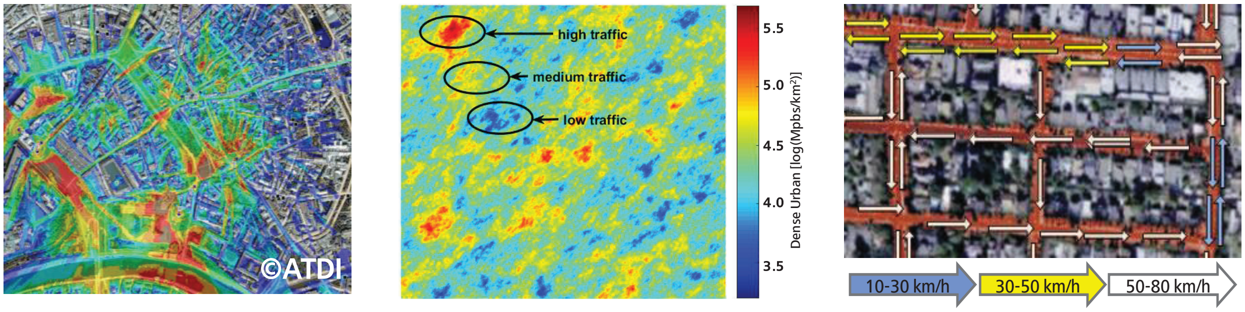
In this paper we present the notion of multi-dimensional radio service maps (MD-RSMs), which builds on an extension of multi-layer radio environment maps (REMs) [4][5] and which are used to store, identify and correlate spatial-related information of different key performance indicators (KPI) for mobile networks. With emerging technologies and paradigm shifts such as user centric networks, mmW band transmission, cloud technology, big data analysis, holistic unified traffic steering, and automated radio resource orchestration, we foresee multi-dimensional cross correlation using MD-RSM is a key enabler for an efficient 5G system effectively reducing the amount of measurements performed and reported by UEs.

An outline of the paper is as follows. In Section II, requirements and the envisaged paradigm shifts are introduced. Section III describes the main concepts and the functionality of RSM. Section IV discusses directions and challenges and in Section V RSM is numerically evaluated in an ultra-dense network scenario that compares the expected energy efficiency of a RSM-based proactive approach with a reactive approach. Section VI concludes the paper.

## II. REQUIREMENTS AND PARADIGM SHIFTS

The fifth generation of mobile networks, 5G, has been defined in terms of requirements [2] and researched in recent years [3]. The following identified 5G paradigm shifts and their requirements are expected to benefit from the use of RSM.

- "No Cell" concept, whereby the notion of cell edges is removed through advanced interference mitigation, scheduling coordination and smart network wide




(a) Example of an RSRP map (b) Example of a traffic intensity map (c) Example of a trajectory/velocity map

Figure 1. Examples of different dimensions of radio-related service maps.

utilization of multi-antenna technologies, such as M-MIMO and distributed MIMO [6]. With RSM the network can more efficiently predict and avoid coverage holes and radio environment obstacles to assist in enabling an enhanced "No cell" experience.

- mmW band transmission (~30GHz and upwards) for "last mile" fronthaul and mobile access [3], making substantially more spectrum available but also implying new challenges with more opportunistic channel properties. To increase the utilization of these bands without spending excessive time and resources evaluating alternative/additional frequencies, RSM can aid in identifying when, where, and what to measure.
- Holistic Unified Traffic Steering (UTS) [7] optimizing the usage of available radio resources given the demand and current load in the different layers of the mobile network. The ability to correlate available resources to demand with more spatial accuracy will enable better traffic steering decisions.
- Automated Radio Resource orchestration [8] enabling means to control and benefit from the mentioned degrees of freedom in future multi-layered wireless networks. With the ability to acquire and correlate multiple aspects of the radio service environment, automatic planning and optimization in future dense networks are enabled.

## III. MD-RSM Concepts and Methods

This section presents the multiple dimension examples comprising an RSM and the methods needed to process the information for the purpose of advanced SON.

### *A. Multiple dimension maps*

An RSM stores measured parameters in relation to user positions in space, time, and frequency. In principle, an RSM can be drawn based on any measurable KPI, such as radio signal strength, spectral and energy efficiency etc. Generally, RSMs may be divided into those that are network configuration and deployment dependent, referred to as radio maps, and those that are network independent, called traffic maps, such as the traffic generated by the users. In the following only a subset of RSMs are discussed.

#### *1) Radio Maps*

Radio maps provide a description of radio parameters that can be measured when the network is in its operational state. It should be emphasized that radio maps characterize a certain network deployment state. Depending on the metric various radio maps can be envisaged:

- *Capacity-related parameters*, such as maximum number of concurrent flows, maximum supportable traffic load, spectrum efficiency, percentage of satisfied users, etc.
- *Coverage-related parameters*, such as signal-to-interference-and-noise ratio (SINR) and data rate coverage, Reference Signal Received Power (RSRP) (cf. Fig. 1(a)), Reference Signal Received Quality (RSRQ), RSRP/RSRQ coverage, interference, outage, combined coverage and capacity.
- *Performance-related parameters* Quality of Experience/ Service (QoE/QoS)-based, such as admission success, setup success ratio, packet delay, transfer time, response time, throughput, uplink/downlink load/interference, packet/frame loss ratio, fairness, handover (HO) failure and outage.

In general the purpose of RSMs is to relate location information with radio information as measured either by the users or the base stations in order to identify Line of Sight (LOS)/Non-LOS (NLOS) due to obstacles, corners, moving objects and therefore to assist in optimizing beam formed radio links. In general, the choice of the radio map should be pertinent to the aspects of the network to optimize.

#### *2) Traffic Density Maps*

Traffic density maps are created by multiplying the user densities and per-user traffic intensities. An example of traffic map is shown in Fig. 1(b) representing a temporal snapshot of a 5*km*x5*km* dense urban deployment, where the traffic profiles range from high to low in different areas.

#### *3) User density maps*

In [9] mobile phone data has been used to provide snapshots of population densities. Using just call records it was possible to build population density maps for the areas covered in the study, over different dates. This allowed for identifying patterns

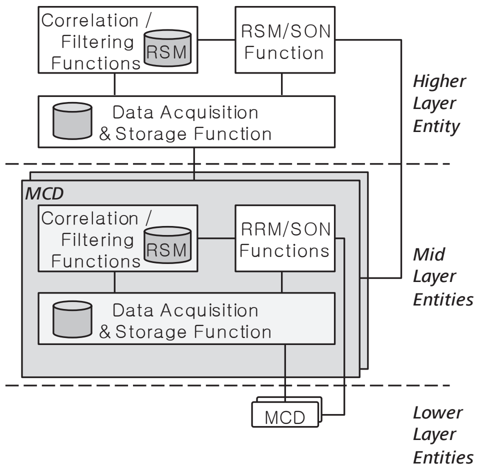


Figure 2. Example of applied recursive RSM architecture pattern.

of population location and movement, i.e., how the population travels back and forth to work during the week, and out to the countryside on the weekends.

*4) Trajectory and velocity maps*

User mobility trajectory and velocity maps relate geographical points with average user speed and/or direction uncertainty. Fig. 1(c) illustrates a simple example of such a map. Trajectory and velocity maps are useful to assist in mobility management and load balancing, or to predict when, where, and how often a user with certain trajectory and speed can be provided with a sufficiently good link given user densities, traffic volume densities and beam forming capabilities etc.

## *B. RSM Functionality*

The 5G networks are envisioned to add a dimension of complexity beyond the HetNets of the 4G era. To reduce the massive amount of data acquired from different measurement capable devices (MCDs) to a manageable size on network scale, the data may need to be pre-processed and filtered without losing spatial or temporal resolution. Assuming this can be accomplished, a recursive RSM pattern enabling a layered/hierarchical RSM solution may be feasible. Each recursive instance of this RSM architecture pattern will acquire data from MCDs on a layer below and comprise:

- *Data acquisition & storage function*, collecting- and storing data from several MCDs as tagged data structures. MCDs may be e.g., terminals, sensors, IoT devices and base stations, all acquiring different types of information about the radio environment, such as sounding profiles, link quality metrics and user behaviour.
- *Filtering/correlation functions* operating on the stored data acquired from MCDs on the layer below, effectively providing relevant *RSMs* to RSM users (i.e. various RAN functions) or RSM instances on the layer above.
- *RRM/SON functions* operating on the available RSM data. Examples of these functions include:
  - Radio resource orchestration optimizing the radio resources configuration on a larger network scale based on policies, e.g. in order to save energy, optimize spectral efficiency or service reliability etc.
  - RRM/ICIC distributing resources and coordinating user pairing and beam scheduling within and across cells based partly on RSM information.
  - Policy based UTS optimizing the radio resource usage on RAN level by utilizing RSM information.

If there is a sublevel, the RSMs on the sublevel is included as part of the tagged data structures used by the filtering/correlation functions to create a higher level RSM. An example of how such a recursive pattern can be applied on a simplified network model is depicted in Fig. 2.

MCDs in Fig. 2 may be both UEs as well as user plane processing devices in the radio access points. The mid-level entities may be a control plane for sub-network on one RAT with one or several radio access points. The higher level entity may be an aggregated network level of many sub-networks using the mid-level entities as MCDs.

*a) Measurements and MCDs*

In earlier generations of RATs, the knowledge of radio network was derived from planning tools and extensive drive tests. In LTE this was further addressed by the standardization of UE assisted measurement reports with the Minimization of Drive Tests (MDT). Although UE measurements are important when building RSMs, they risk being too sparse resulting in long convergence times for the RSMs or outdated information. UL beacons are not only aimed at being used for mobility handling or for channel estimation, but also for UE positioning [10], when received by one single or multiple base stations. The signal strength of the UL beacons and quality measurements of the data transmissions, in combination with the position determination will enable the network to obtain massive amounts of information that can be used for building the RSM.

Note that the accuracy of measurement acquisition in the system will of course have impact on the quality of RSMs and the resulting decisions taken with them as basis. These measurements may be impaired by both HW deviations and radio environment effects. But with a large amount of measurements, both made by base stations and UEs over a longer time, and in combination with relevant filtering and post decision analysis will cancel out measurement errors and ensure efficient operation.

*b) RSM acquisition and data storage*

A RSM is built based on measurements and can be generated based solely on measurement statistics or by also taking into account a model of the radio environment. With UL beacons or sounding signals, positioning estimation techniques, e.g. tri-lateration, may be applied to derive sufficiently accurate position estimates that can be stored together with other channel quality metrics in the RSM data storage. Each base station records the received signal strength at the geographical location of the UE (may involve multiple base stations to achieve sufficient position accuracy). Channel State Information (CSI) reports from UEs are also subject for RSM inclusion, but measures must be taken to assure spatial and temporal correlation. To capture the differences for different time periods of a day at a specific location requires the collection of a large amount of measurements.

*c) RSM Correlation and filtering*

The above samples can be statistically analyzed and processed by the RSM manager by means of big data analysis and machine learning, incl. neural networks (NN) based deep learning or principal component analysis, to identify patterns of usage in the radio environment and relations between the observed parameters. Benefiting from the RSM layered architecture, it is envisaged that different traffic, user and/or radio maps of different RATs, may be projected on top of each other to identify correlations between the measured parameters they are built on. Correlations will be used to automatically identify relations between the measured parameters and will be used as an input to determine the configuration of the network in the operational state. Fig. 3 illustrates an example where multiple RSMs are projected on top of each in order to identify useful correlations.

Finally, dealing with non-uniform location measurements and the existence of location holes or location inaccuracy, interpolation methods may be needed, such as inverse distance weighting [11], nearest neighbor weighted interpolation [12], etc.

## IV. Enabling Technologies & Requirements for RSM

To make the MD-RSM functionality efficient there are some requirements to be met by the network entities. Some are more challenging than others. The following is a list of high level requirements on the underlying RAN functions which are essential to enable efficient use of MD-RSM

- The RAN must have access to a large enough amount of measurements of different dimensions in the radio service landscape to build a statistical base for analysis and decisions.
- RAN must be able to command UEs to perform relevant measurements of the radio channel relative to its position in a specific moment.
- Measurements of the radio channels made by RAN infrastructure, e.g. pilot signals, BER, BLER, dropped call ratio etc. must be made available with suitably tagged properties such as time, space and frequency.
- Multi- transmit receive point (TRP) coordinated measurements by RAN or by UE across the air interface, to achieve high enough spatial resolution, must be made directly accessible for RSM.
- UEs capabilities in terms of frequency bands, number of transmit- and receive antennas, GPS performance etc. must be made available to the RAN.
- All measurements must be associated with absolute time, space and frequency properties with a relative error tolerance depending on UE speed, environment and traffic/subscriber density.

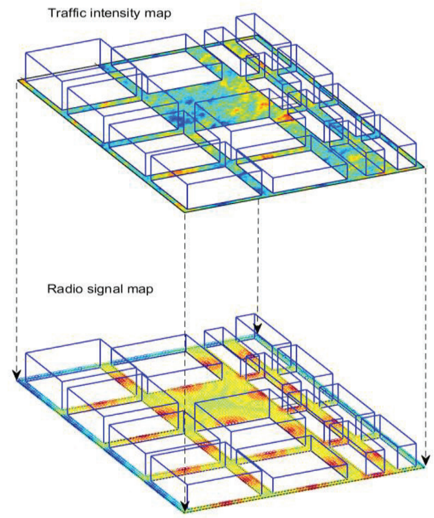



Figure 3. Correlation of multiple-dimensions of radio service maps including a trajectory velocity and a radio signal map.

Apart from the above mentioned requirements there are also other suggested technologies that would enable and enhance the performance of RSM if introduced, including:

- UL Beacon oriented network [6], whereby UEs periodically transmit narrow band beacons enabling the network to continuously track their spatial signatures. This relieves the network from transmitting costly reference signal patterns and common channels, hence most transmissions can be beamformed and thereby become more energy efficient.
- Cloud technology and big data analysis become available to the RAN domain, enabling a new level of SON capabilities we call Radio resource orchestration.
- Radio Environment Maps (REM), a technology having been in the research front for several years [13], whereby a large database of radio environment characteristics in different points in space and time is maintained to support radio resource management & orchestration functions.

## V. MD-RSM Use Case for Energy Efficiency

RSM is an extension of REM and as such it can be used to improve many functions with different characteristics. Although similar solutions have been tested in trial networks, it is clear that the gain of RSM depends greatly on the spatial resolution and the ability to correlate across different types of acquired measurements. In an optimization scenario, it also depends on the involved complexity, hence it is expected to be mostly useful for denser network deployments or in scenarios with support for many frequency carriers or radio access technologies. In this section the idea of using MD-RSM is illustrated by means of a use case that aims at improving the

TABLE I. SIMULATION ASSUMPTIONS AND PARAMETERS

| Parameters | Values | |
|---|---|---|
| Macro Cell ISD [m] | 1000 | |
| Small Cell ISD [m] | 80 | |
| Number of UEs [#] | 100 | |
| Number of Small cells/Macro cell | 1,2,4,10,20,40,100,120 | |
| Power consumption at minimum output power $P_0$ [W] | macro cell | 130 |
| | small cell | 11.8 |
| Number of TRX chains [#] | macro cell | 2 |
| | small cell | 2 |

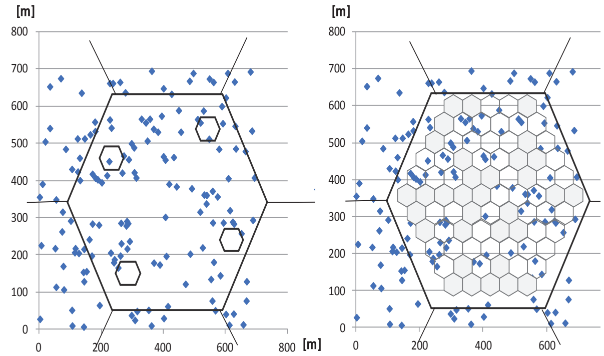



Figure 4. Sparse (left) and dense (right) uniform deployment of small cells in a macro cell with uniformly distributed users.

energy efficiency in a dense network. A reduction of the energy consumption in future mobile networks is one of the key objectives of mobile operators due to financial and environmental incentives. Technical solutions for energy savings have been suggested in the prior art [14], [15], however, these need to be revised to address the complexity that is introduced by the densification of radio resources and infrastructure in 5G. To address the complexity, enabling technologies such as M-MIMO, D-MIMO and UDN of different densities are assumed.

This use case shows the potential gains of using RSM to save energy in a dense small cell network when aided by spatial measurements in a macro cell. The evaluation scenario is based on configuration 1 defined in [16], where 100 UEs are randomly distributed in a hexagonal macro cell, with inter-site distance of 1000m. Furthermore, as shown in Fig.4, within the macro cell small cells of different densities are also evenly distributed with an inter-site distance of 80m. Further details on the network deployment and system configuration are summarized in Table I).

For the evaluation of the use case two approaches are considered: (i) a proactive approach and (ii) a reactive approach. The proactive approach assumes the usage of RSM. More specifically, in a network with RSM the UE mobility trajectories can be monitored both while served by small cells as well as when served by the macro cell, with the precondition that spatial information can be acquired by the serving base station using measurements made by the base stations and measurement reports from UEs (cf. Fig. 3). By keeping track of user density with enough spatial granularity to determine whether a user is in the coverage area of a small cell or not, and optionally mobility trajectories and velocities and correlate this against a radio coverage map for the small cells, the network can turn on the small cells proactively when needed. This implies the small cells are by default in a sleep state, but can be woken up by the RSM function in due time to serve an approaching UE.

In a network scenario without proactive intelligence, the provisioning of resources is reactively triggered by instantaneous demand. It is assumed that all small cells must be always turned on in the reactive scenario in order to be prepared to serve users when entering the coverage area of the small cells. The macro cell is always on for both the proactive case (using RSM) and the reactive case (without RSM). While the small cells in the reactive approach are assumed to be always on, the small cells in the proactive scenario are switched off intelligently whenever there are no UEs to serve. For our evaluation, it is assumed that users are uniformly distributed within the cell (cf. Fig. 4), and as a result the number of cells expected to be turned on is determined by the user density in the macro cell [17]. Based on position information, in the scenario with proactive intelligence, the network can predict and determine whether to activate or deactivate a small cell by correlating acquired position information from UEs with RSM data (cf. Fig. 3).

As the energy consumption for data traffic is assumed to be the same for both the proactive and reactive scenario, the energy efficiency gain that is considered in this evaluation study is only due to the common control channels, i.e. the energy consumption without any traffic. The applied energy consumption models defined for macro cells and small cells are according to EARTH project [18]. We assume only the energy at minimum power consumption $P_0$ which is sufficient to maintain the operation of the control channels at each base station. The supply power scales linearly to the number of TRX chains $P_{TOT}$ which corresponds to the transmit/receive antennas per cell. The total power consumption per cell $P_{TOT}$ is given by: $P_{TOT} = N_{TRX} \times P_0$. For our evaluation scenario, only one macro cell is used and different number of small cells corresponding to the different densities (cf. Table I).

Fig. 5 shows the energy consumption related to the reactive and RSM-based proactive approaches for different small cell densities per macro cell. While the performance of the two approaches coincides for the low density small cell networks, for the high density the energy consumption of the proactive approach is lower. This is attributed to the fact that the higher the density of small cells, the more small cells will be able to power off at any point in time. This is also shown in Fig. 6

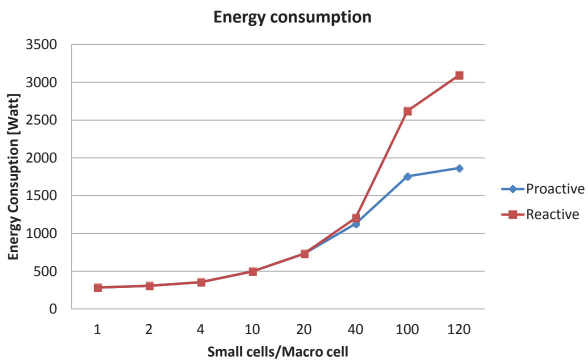



Figure 5. Energy consumption in the case of reactive and proactive energy efficiency scenarios for the common control channels.

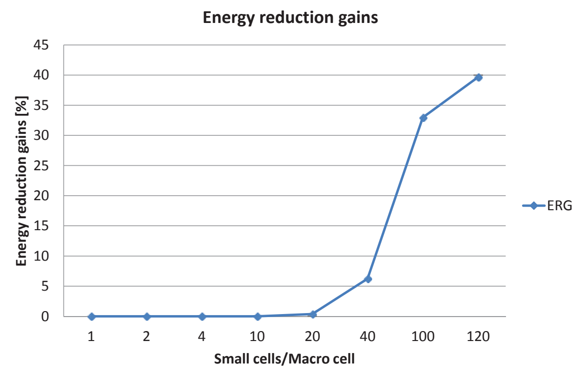



Figure 6. Energy reduction gains of proactive over reactive energy efficiency approach for the common control channels.

which plots the energy reduction gains of the proactive approach over the reactive one. Gains are visible in the higher density regimes. For ultra-dense networks there is up to 40% gain in energy consumption for common control channels.

## VI. CONCLUSIONS AND FUTURE WORK

In this paper, we have presented a novel approach to utilize multi-dimensional radio service maps (MD-RSM) for storing and exploiting position-based information. We have discussed requirements, key concepts and functionalities. The potential gains in energy consumption of MD-RSM for an ultra-dense network deployment scenario were shown to be significant.

With increased complexity in future networks, e.g. the introduction of more carrier frequencies, more radio access technologies and more base stations covering the same area, we further expect significant gains in both end user data performance and energy reduction. Evaluations of such gains are left for future studies.

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