Design of Layered Radio Environment Maps for RAN Optimization in Heterogeneous LTE Systems

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Abstract — **In this contribution a layered radio environment map (REM) architecture is designed and applied in the framework of radio-access network optimization for heterogeneous LTE systems that comprise both macrocells and femtocells. We define layer as the hierarchical representation of a geographical area. In each layer, different instances of the same architectural block will have different spatial/temporal granularities, associated with network functionalities. The effectiveness of the proposed architecture to support LTE functions like automatic neighbor relation (ANR) and minimization of drive tests (MDT) is discussed. In addition, we present the benefits of using such architecture in the implementation of these functions along with its potential to bring performance gains.**

I. INTRODUCTION

The management and optimization of radio resource usage in wireless communication systems are becoming complex, due to the increasing complexity in network composition and the desire of managing them with as little human intervention as possible.

Traditional *radio resource management* (RRM) techniques and planning tools are not capable to efficiently manage the radio networks anymore. New paradigms, proposed during the last decade, address this complexity either through new RRM approaches or developing tools that RRM techniques can use, such as the radio *environment map* (REM) [1].

A REM can be thought of as a knowledge base used to store information related to the radio environment of wireless systems in a dynamic way. This information is then used either by the resource management to maintain and optimize the whole system directly or as input to modeling processes that generate more efficient representation of collected data such as statistical behavior description. Statistical representation not only reduces the necessity to frequently update the information used by the RRM techniques (thus reducing signaling overhead), but it also facilitates the development and implementation of context-aware RRM techniques that enhance network performance.

In contrast to existing static databases for wireless networks, REMs can provide wireless networks with a comprehensive and up-to-date representation of the radio environment. This reduces the OPEX of an operator by reducing the need for drive tests and measurement campaigns, hence contributing to the attractiveness of REMs. The EU-funded project FARAMIR (Flexible and spectrum-aware radio access through measurements and modeling in cognitive radio systems) [2] aims at developing such REMs and REM-related techniques that increase the awareness of future wireless systems about radio-environmental and spectral activities.

One of the core work items in the FARAMIR project is the development of extendible REM architecture. In contrast to existing solutions and proposals regarding REM design [1] FARAMIR develops REM technologies that can be used by cognitive radios [3] as well as conventional cellular networks. By taking a broad approach and avoiding focus on limited scope, FARAMIR's scenarios explicitly include the use of REMs in cellular networks or femtocell deployment for improving the coverage and capacity of the networks.

Motivated by the above, we propose in this paper a layered REM architecture for the scenario of 3GPP's heterogeneous *Long Term Evolution* (LTE) networks [4] comprising macro- and femto-cells. We study the application of this architecture with various LTE functions such as *autonomous neighbor relation* (ANR) [5] and *minimization of drive tests* (MDT) [6]. The proposed architecture design allows construction of flexible hierarchies of REM instances, based on the locality and time scales of the relevant particular radio environmental data. It also allows much greater diversity of information to be stored and applied especially in resource management and network optimization.

The paper is organized as follows. Section II presents the functional REM architecture as proposed in the FARAMIR project followed by the specific design of layered REM architectures for heterogeneous LTE systems. Sections III and IV discuss the effectiveness of this REM architecture in the implementation of ANR and MDT functions, respectively, along with the benefits it can bring. Finally, Section V gives concluding remarks.

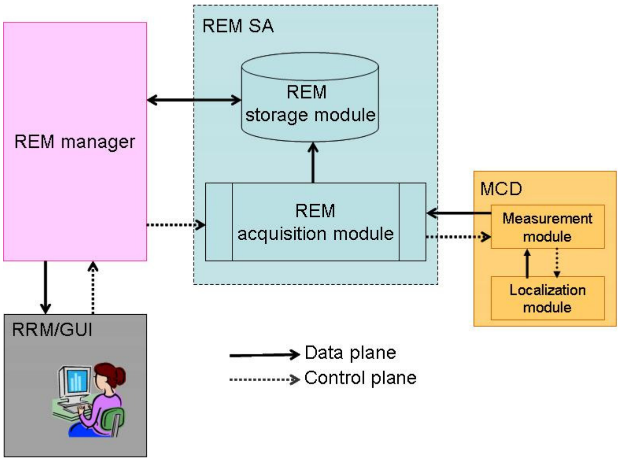

Figure 1: Functional REM architecture.

II. FARAMIR'S LAYERED REM ARCHITECTURE DESIGN

A. *FARAMIR's functional and system-level REM architecture*

Figure 1 shows a high-level functional architecture of FARAMIR's REM, composed of the following main components: *measurement capable devices* (MCDs), *REM data storage and acquisition* units (REM SA) unit and a *REM manager*. The REM architecture also involves the definition of interfaces that connect the REM to applications such as RRM modules or user interfaces to monitor system performance and track error causes.

MCDs are network entities responsible for environment observation activity through active measurement functionalities; they are responsible for acquiring the measurement information from the environment.

The REM SA unit has two functions: data storage and data acquisition. The data acquisition module is responsible for the communication with the different measurement modules in the MCDs. It gives measurement orders to MCD modules, receives measurement reports and stores data in the storage module. The storage module is basically a database that stores the REM information: either the raw data reported by the MCDs to the data acquisition module or processed data in the form of *maps*.

The REM manager is the brain of the architecture and is responsible for generating and maintaining the REM. It is the unit responsible for deciding which measurements should be done, by which nodes and at what time instants. The REM manager uses the raw data stored in the REM SA storage module, processes it and gives as output the resulting maps that are stored in the REM SA storage module. The REM manager decides also whether further measurements are needed for REM generation and/or REM update. Then the corresponding measurement requests are sent by the REM manager to the REM SA data collection module.

For most application scenarios, the REM system architecture that describes the physical locations of the REM functional blocks requires a *layered* REM structure. A layered architecture may be needed because of the limited capabilities of some nodes in terms of computation power and memory. Alternatively, some data may be needed only in some elements of the network and its dissemination to other elements would be a waste of capacity. In the layered structure we present here, instances of the same functional architecture component are found at different hierarchical levels of the system architecture. For instance, REM SA instances at terminal levels will store different information than those on base station levels.

Many important aspects in this structure must be paid attention to, from the creation of the REMs to their dissemination in order to support RRM decisions inside the system. Creation, modification or dissemination of REMs is unavoidably associated with signaling overhead. The architecture is focusing more on reducing the signaling traffic over the air interface, which is one bottleneck of the network. In some cases, this overhead is small. The user of the REM may be co-located on the same node that hosts the REM that contains the required data. For instance, a base station may host a local REM that contains information (cell load, position of the base stations and user activity patterns) about the corresponding cell and neighboring cells. In other cases, where the amount of relevant data is large and/or the connection to the hosting REM instance has limited capacity, the overhead can, however, be substantial. In either case, an operator deploying a REM in its network should conduct an analysis comparing the overhead incurred against the performance improvement achieved by applying that information when making, for example, RRM decisions.

The basic considerations arising from such analysis are related to the time of validity of the information, the aggregation of REM information either over time or space, and tuning the strategy for dissemination of such information.

Time of validity. Different REM instances at different architectural levels require different update rates. Therefore, one of the most important principles of a layered REM architecture is the time of validity of REM information. Raw measurement data on radio environmental characteristics, which are changing extremely rapidly, would only usually be made available through highly localized REM instances if at all. Statistical characteristics of such data on the other hand usually have higher time of validity, and make for much more realistic candidate for sharing through REMs.

Aggregation of information. The estimation of such statistical characteristics is closely related to the aggregation of information over time and space. For example, estimating the distribution of the shadowing coefficient and sharing that through REM will yield accurate results only if the spatial region the distribution is estimated over is in some sense homogeneous. Increasing the size of the region further reduces the overhead, but at the cost of the accuracy of the model or statistical characterization. Similarly, in time domain caching of results obtained from REMs locally using simple aggregation techniques, can be very effective in reducing the overhead provided that the validity of the cached data is selected carefully.

Dissemination strategy. Finally, the pros and cons of different dissemination strategies should be carefully considered. For information that is needed only rarely a pull-based on-demand model might be most appropriate. However, for commonly needed data that has significant dynamics, a push-based, proactive model might result in better performance. One example of the first type of information is the position of cellular network base stations and the used frequency allocation that are crucial information for some dynamic spectrum access mechanisms. This type of information does not change normally and can be pulled by a node when it is activated or in periodic way. However interference statistics and sub-channel allocation has to be pushed by the network in each frame in scenarios, for

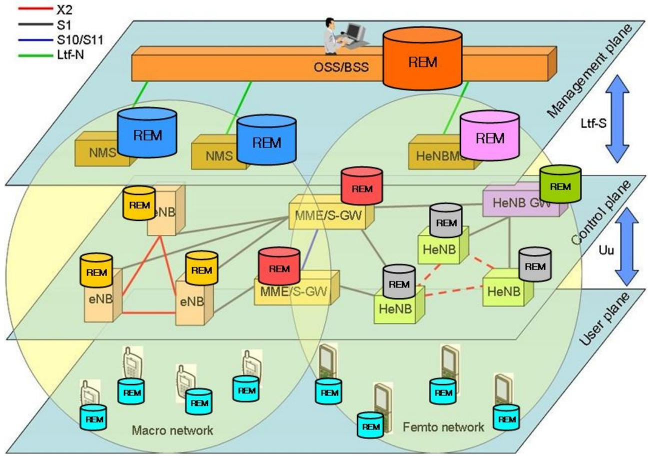

Figure 2: Layered REM on a heterogeneous LTE architecture including macrocells and femtocells, different REM colors represent different layers with different characteristics.

instance, where femtocells are sharing the same channels with macrocells.

B. *Layered REM design for heterogeneous LTE networks*

Figure 2 shows how we map the high level functional architecture of the REM to the heterogeneous LTE cellular network architecture that encompasses both macrocells and femtocells; also we provide some general guidelines for implementation. We propose a generic layered REM architecture where different functional REM components, including REM SA and REM manager, can be placed in a stand-alone database, operator's management system, eNB/HeNB, HeNB Gateway, and, if necessary, in terminals. In this architecture, LTE eNB/HeNB and user terminals will constitute the main MCD hardware.

Different REMs can be distinguished by their update rate; the higher the REM is placed in the hierarchy, the slower its updating rate shall be. For example, a REM can be updated in the order of milliseconds, seconds and minutes or, alternatively, in the order of hours, days and weeks. For the former, fast updating case, the REM SA as well as the REM manager must be typically deployed in the eNB/HeNB because of the direct connection and relatively low latency of communication between the MCDs and the eNB/HeNB. For the latter, slow updating case, the data collection module of the REM SA must be deployed in the eNB/HeNB, and the data storage module of the REM SA and the REM manager can be deployed in the operator's management system, because of the relatively high communication latency involved in the associated network entities.

Layered REMs are foreseen to be used for scenarios like spectrum sharing between macro- and femtocells and/or some other typical RRM use cases like mobility management, interference management, admission control, offloading. These use cases are based on some form of femto-macro coordination for different RRM optimization purposes. Femtocells are mainly envisioned for private use and coordination with the macrocells is necessary in order to control interference levels and maintain the required QoS in the macrocells. Coordination can be made by consulting a REM database that contains information on frequency allocation of the eNB as well as path loss estimation. The layered REM is therefore very useful as the femtocell needs to know locally in which eNB influence zone it belongs to. In the layered REM, the coverage maps of those eNBs are stored in the eNB, where also the related measurements and power configuration can be found. The REMs of these eNBs also will have information about other macro-/femtocells in the same zone. This information, which is not necessarily stored in femtocells REMs, can be used by the eNodeB to manage more efficiently its resources.

Table 1: Three-layered REM implementation in macro- and femtocells.

	National REM	Operator national REM	Operator local REM
Node locations	**X**	**X**	**X**
Node resource capacities	**X**	**X**	**X**
List of eNBs/ HeNBs		**X**	**X**
General user date/price plan		**X**	**X**
Location based user service		**X**	**X**
User behavior/traffic statistics		**X**	**X**
Local interference statistics			**X**

In such cases, a three-layered REM architecture with different spatial/temporal granularities can be designed. The intended content for different layers of such a REM is illustrated in Table 1. In this architecture, the highest layer is a national level containing cross-operator REM database and its REM manager. The second layer is a national/metropolitan level intra-operator REM and the lowest layer is a local, neighborhood-level REM. One such neighborhood-level REM can be co-located with the HeNB Gateway [4].

The exact mapping of the layered REM architecture is closely related to the specific application. In the next sections, detailed system architectures will be described for two example use cases: ANR and MDT. For these two use cases, the functional components and their placement, as well as the information exchange mechanism are designed to facilitate the management of the specific radio resources that lead to an optimal network performance.

III. LAYERED REM SUPPORTING LTE ANR FUNCTION

A. *ANR features and 3GPP specification*

ANR is one of the first *self-organizing network* (SON) [5] functionalities standardized in 3GPP for LTE. Its purpose is to relieve the operator from the burden of manually managing *neighbor relations* (NRs). Accurate identification of neighbors is vital for RRM procedures like mobility and interference management. The neighboring concept includes intra-frequency, inter-frequency as well as inter-RAT neighboring eNBs. Neighboring relations are based on downlink *user equipment* (UE) coverage measurements on the *received-signal reference power* (RSRP). In this context, a layered coverage REM can facilitate the ANR functionality as it will be shown in the following for a heterogeneous system with macrocells and femtocells.

The current execution of the ANR function is carried out as follows: downlink terminal coverage measurements on intra-frequency, inter-frequency and inter-RAT neighbors are communicated to the eNBs/HeNBs where the neighboring eNB/HeNB information is extracted for each eNB/HeNB. Thus, every eNB/HeNB has a local *neighbor relations table* (NRT) containing the identities of its own neighbors. This local neighboring information is communicated to the *mobility management entity* (MME) (and to the HeNB

Gateway for femto-cells) in order to solve possible conflicts between local neighboring information and to have a more global and coherent neighboring relation of the radio access network. The ANR function allows the operator to manage the NRs. It is possible to add and delete NRs via commands sent from the operator's management system. It is also possible to change the attributes of the NRs. The operator's management system is informed about changes in the NRTs through control plane reporting.

B. Layered REM-based ANR function

A layered REM structure based on downlink RSRP coverage maps helps enhancing the accuracy and precision of the ANR functionality. By placing REM coverage maps that have different temporal and spatial characteristics at different hierarchical levels, it is possible to obtain and maintain more precise, up-to-date and reliable neighboring information. More precisely, downlink terminal coverage measurements reported to the eNBs/HeNBs are used to construct a low-level, local and quasi-real-time REM coverage map at the eNBs/HeNBs. Using extrapolated geo-localized coverage information stored in these REM coverage maps, the eNB/HeNB can verify the coherence between this information and the information of the neighboring eNBs/HeNBs already stored in the radio access network. It should be noted that the existing geo-location information is static for eNBs, but due to the dynamic deployment nature of femtocells, it changes more frequently for the HeNBs. Thus, a first-step reliability check for the neighboring relations can be provided at the eNB/HeNB level.

Using the coverage measurements reported by the eNBs/HeNBs to the higher architectural layer (MME for the eNBs, MME and/or HeNB Gateway for the HeNBs), upper-layer REM coverage maps are constructed at the MME (a middle-layer map can be constructed at the HeNB Gateway for the femto-cell network). Note that the presence of HeNB Gateway is not mandatory in the LTE standard. Its presence is foreseen for dense femto-cell deployments. Otherwise, the eNBs are connected directly to the MME. In such cases, the femto coverage measurements reported by the HeNB to the MME are integrated to the REM coverage map found at the MME. Equipped with a global geo-localized coverage information, the MME does not need to resolve conflicting neighboring information coming from the eNBs/HeNBs/HeNB Gateways. It will have a more precise and realistic information on coverage, and thus, on the neighboring relations.

The proposed layered REM architecture described above implies the following mapping between the radio access network entities and the REM functional architecture components:

1. For REM-based ANR functionality, the UE coverage measurements on the serving cell as well as on the intra-, inter-frequency and inter-RAT neighboring cells can be satisfied by existing UE capabilities; therefore the MCD role is carried out by the user terminals and it is sufficient to have UE measurements.
2. The storage component of the REM SA, containing the coverage map composed of the raw and the processed measurements, has a three-layered structure for femto-cell networks and a two-layered structure for the macro LTE networks. For macro- and femtocell networks, there is a low-level REM coverage map at the eNB/HeNB and a high-level one at the MME. For femtocells a middle-level REM coverage map exists at the HeNBs Gateway.
3. The acquisition part, responsible for the data acquisition for constructing the map, is also found at the same two (resp. three for femto-cells) architectural levels.
4. Since the REM manager is the unit that decides to make measurements, and also on how and when, all the two (three for femto-cells) architectural levels are responsible of measurement decisions required for the coverage maps at their respective level.

An operator's management system does not intervene in REM construction and neighbor relation derivation in the control plane (eNBs, HeNBs, HeNB Gateways, MMEs etc.). However, the *key performance indices* (KPIs) found at the *network management system* (NMS) can be used as a feedback on the accuracy of the neighboring relations. An important issue to point out is that the operator verifies/approves the control-plane ANR decisions thanks to the *operation, administration, and maintenance* (OAM) functionality found in the *element manager* (EM).

IV. LAYERED REM SUPPORTING LTE MDT FUNCTION

A. MDT features and 3GPP specification

Drive tests are the major method used by network operators to collect performance metrics for the purpose of network deployment and operation. They are used to identify coverage problems after, for instance, a new building is constructed. They are also used to help in improving user experience and optimize network capacity on regular basis.

Drive tests are done periodically or triggered by customer complaints. As an example, Orange Romania schedules drive tests once a year for the top 60 cities and twice for the top 25 ones. There are also drive tests for main roads scheduled once a year. The subsequent actions undertaken are new site deployments in case of coverage holes, and optimization of the power configuration, antenna tilts and azimuth for QoS improvement. Drive tests are not only costly but also negatively impacting the environment through additional CO_2 emission. Therefore, it is desirable to develop automated solutions (e.g., assisted by terminals) to reduce the number of drive tests. MDT functionality is an LTE Release 10 feature, which is currently being studied/specified by 3GPP [6][7].

The main functionality of MDT is to enable terminals to carry out various radio network measurement including cell identity information (*physical cell identifier* (PCI), *cell global identifier* (CGI)), received power and quality information (RSRP and *reference signal received quality* (RSRQ)). In addition, at application layer, for example *perceptual evaluation of speech quality* (PESQ) for voice services and the throughput for FTP traffic can be measured. All these types of information are tagged with available location information, as well as stamped with time information. They are then aggregated into an MDT measurement report. The MDT measurements can be done and reported back to the network immediately when the terminal is in connected mode. This is called `Immediate MDT'. In another type, `Logged MDT', the measurements are done by the terminal in idle mode. The MDT measurements are stored/logged in the terminal and are retrieved by the network at a later time through signaling [6].

Table 2: Estimated UE memory size needed for logged MDT measurement (modified from [7], with restriction on number of neighboring cells[6]).

Parameters	Size
Location (Latitude / Longitude / Altitude)	63 bits
Time (Month/Day/Hour/Minute/Second)	40 bits
CGI of the serving cell (PLMN-id/Cell-id)	52 bits
PCI of neighbor cells (x 18)	162 bits
Radio environment measurement (RSRP/RSRQ) for serving cell + neighbor cells (x18)	247 bits
Total number of bits per log	564 bits
Total size of logs collected every 2 seconds for 12 hours	1.5 MB
Total size of logs collected every 2 seconds for 24 hours	3.0 MB

B. *Support of MDT through layered REM architecture*

In general, the operator needs to ensure the user that logging of the MDT measurements and reporting them will consume limited/minimum terminal energy and data storage capacity. The proposed layered REM architecture is suitable to support the MDT under such constrains and, moreover, it can help to optimize MDT functionalities through environment awareness and network-wise coordination in heterogeneous LTE systems.

Within the REM architecture, the MCD's role is carried out mainly by the user terminal for MDT. Table 2 shows the needed storage size of one exemplary MDT report comprising periodic logs. This will put very high requirement on terminal memory for log storage. The current specification for the 3GPP MDT feature has a buffer size requirement of minimum 64kB [8]. In addition, as explained before, application layer measurements are of interest for operators. If QoS measurements are to be included, it is clear that the memory usage will increase and it might become a burden for terminal. The impact on terminal memory can be mitigated by lower logging frequency and higher reporting frequency, which has to be done in a coordinated way, taking into account of other aspects as MDT performance and terminal power consumption for reporting.

In the layered REM architecture, the terminal memory can be managed as the lowest level of REM storage. The intelligence embedded in the layered REM (REM manager) allows efficient distribution of MDT data storage at different hierarchical levels of the system architecture. The optimization can be done dynamically to balance storage capacity available at different network nodes (either eNB/HeNB or terminals). The REM manager can choose when to retrieve MDT measurements report from terminal, based on evaluation of terminal memory, traffic load in the system, as well as energy consumption for reporting.

For example, during rush hours and due to high traffic demand, the logged MDT data can be stored at the UE REM level for optimized periods and then can be reported back to the network in a scheduled manner to alleviate possible uplink signaling congestions.

Further the REM manager can decide to which network node the terminal reports the MDT data. By utilizing the environment aware coordination provided by the layered REM between macrocells and femtocells, the terminal can send the logged MDT report via a HeNB instead of an eNB even if the MDT measurements are done in macrocells. This will result in reduced uplink transmission power (as depicted in Table 3) which leads to terminal energy saving and hence to the extension of terminal battery life.

Table 3: Power consumption comparison for UE uploading MDT measurement reports to HeNB or eNB (5dB SNR at uplink receiver).

RAT	Typical distance to Base station	Power	Bandwidth
HeNB	10 m	0.04 mW	10 MHz
eNB	100 m	129 mW	10 MHz

Similarly the REM manager can decide where to store MDT measurements depending on how these measurements are to be used. MDT data related to local coverage holes (e.g. coverage holes within one cell) can be stored in local REMs (eNB and HeNB Gateway) to be used in localized and very often relatively fast optimization algorithms. These algorithms are performed by RRM modules connected to local REM manager. MDT data concerning larger area coverage problems, which involve more than one cell and/or are related to handover, are stored in higher level REMs (preferably at the OSS/MMS level). Various optimization algorithms can then be operated and guided by higher level REM manager, based on the MDT measurement data.

V. CONCLUSION

In this paper, we have presented a layered radio environment map architecture and discussed how it can be applied to radio network optimization in heterogeneous LTE systems comprising macro- and femtocells. We have focused on two self-organizing network functionalities standardized by 3GPP for LTE networks: automatic neighbor relation and minimization of drive tests.

In summary, our study shows that the proposed layered REM architecture is not only effective in supporting ANR and MDT functionalities, but also has other advantages such as decreasing power consumption and memory constraints on LTE user terminals.

VI. ACKNOWLEDGEMENTS

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