Towards Self-Organizing Network Orchestration Management for LTE Mobile Communication Systems

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***Abstract*—Self-organizing network (SON) functions of Long Term Evolution (LTE) systems have been traditionally studied in isolation even when it is widely accepted that they need to work together to provide the next generation mobile services and applications. This paper describes a novel QoS- and resource-oriented SON orchestration SON management framework in favor of convergence to trade-offs between service level requirements and network performance targets in LTE systems. In order to orchestrate SON functions of LTE networks it is needed consider standalone optimization processes as well as QoS- and resource-aware tradeoffs between service level requirements and overall network resource performance.**

Keywords – Long Term Evolution; Orchestration; Self-organizing networks; Quality of Service

I. INTRODUCTION

Mobile communication systems are continuously evolving to provide higher data rates and to pave the way for ubiquitous, high speed broadband wireless coverage. Nowadays, the Long Term Evolution (LTE) technology [3], [4] is recognized as the most outstanding technology to meet these goals, and it is considered as the next generation mobile technology that will dominate the worldwide mobile ecosystem in the next decade and beyond.

LTE is a complex system where a large number of control mechanisms are executed at different nodes in the architecture to perform resource allocation tasks at different levels of granularity (in terms of the time-scale they operate). Algorithmic solutions for resource management operate in a highly dynamic environment where network resources (e.g., transmission power), services and applications (e.g., offered service quality), and user behavior (e.g., user mobility) experience changes over time. Those changes can degrade network performance and perceived QoS.

The research community has highlighted the need and value of LTE self-organizing capabilities, commonly referred to as Self Organizing Network (SON) capabilities. SON capabilities in the network will lead to higher end-to-end QoS and reduced churn [2] (i.e., a measurable metric of the migration of users from one service provider to another, mostly due to dissatisfaction with perceived QoS), thus allowing for overall improved network performance in terms of network quality and reliability. Finally, SON is hyped to provide higher performance from adapting the network to variations in loading and other dynamic operational conditions.

Although there is a clear definition of the most prominent SON functionalities, their implication with service quality provision and management has not been studied in the literature. The modeling and performance evaluation of SON functions are normally addressed following a standalone approach where a given function is assumed to work independently of other SON functions. The collateral effects among SON functions are neglected to make tractable the design of algorithmic solutions for LTE. As there is mutual dependency among network parameters, conflicting situations among SON functions may take place.

This paper presents a work in progress that aims at investigating novel self-optimization and management solutions to provide enhanced support for QoS of next-generation services in LTE systems. In order to address the interdependency of SON functionalities, this research will develop a coordination management framework aimed to cope with system's instabilities due to potential conflicting decisions among SON management functions. After this Introduction, Section II presents the application domain of the research. Section III presents the foreseen technical approach and Section IV presents the related work. Finally, Section V concludes the paper.

II. APPLICATION DOMAIN OF THE RESEARCH

A. LTE SON Functionalities

Self-Organizing Networks (SON) is seen as one of the main promising areas for operators to save on operational expenditures. SON is currently discussed in 3GPP standardization [3]. Furthermore, the NGMN group has made recommendations [4] and 3GPP has written some use cases into the SON standards for LTE release 8, LTE release 9, as well as in release 10 (LTE-A). However, the SON self-optimization algorithms are not standardized or defined step-by-step. Figure 1 illustrates the SON use case functionalities envisioned by the 3GPP. The interested reader can find extended descriptions of all functionalities in reference [3]. This work focuses on Mobility Load Balancing Optimization and Mobility Robust Optimization, whose main goals are briefly described hereafter [3].

Mobility Load Balancing Optimization. The goal of this use case functionality is to optimize cell reselection/handover parameters to cope with the unequal traffic load and at the same time the minimization of the number of handovers (HO) and redirections needed to achieve the load balancing.

Mobility Robust Optimization. Manual setting of HO parameters in current 2G/3G systems is a time consuming task. For some cases, RRM (Radio Resource Management) in one eNodeB can detect problems and adjust the mobility parameters, but there are also examples where RRM in one eNodeB cannot resolve problems. The objective of this use case functionality is to automatically adjust the mobility parameters in those cases that cannot be done by RRM.

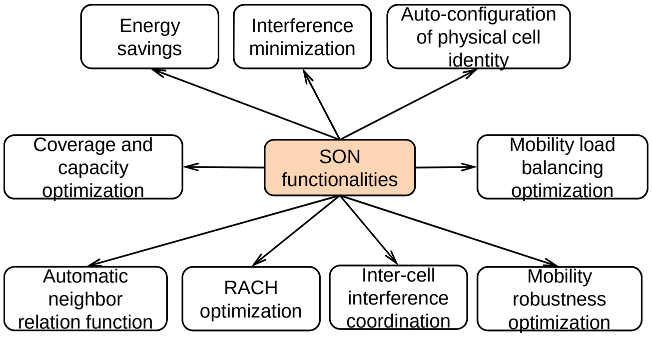

Figure 1. SON use case functionalities

Each of the SON functionalities operates at different time scales of network operation, from short-term to long-term, and each will cause changes in network configuration at different levels of granularity. SON functionalities exhibit a certain degree of interdependency and it is proven that some of them may have an impact on the configuration of the same network parameters which can result in conflicting situations.

B. *Orchestration mechanisms between SON functions*

The analysis of the different functionalities of the SON architecture and their specific characteristics has opened a big opportunity area for the implementation of optimization techniques. However, this is not a simple task, every SON-functionality has an interrelation with at least another one, therefore it may be found that an optimal solution for one SON function could be controversial for other functionalities sharing the same control parameters.

For example, SON functionalities Mobility Load Balancing and Mobility Robust Optimization shown in Figure 2 both modify inter-related parameters (Handover parameters). The Load Balancing (LB) algorithms in SON Function 1 may want to decrease the handover offset to optimize the load distribution between cells, while Handover Optimization algorithms in SON Function 2 may want to increase the handover hysteresis to reduce Ping-Pong effects, thus both would eventually change the condition on which handovers are taken [5]. The modified values of the Handover parameters that give the best performance from the perspective of the Mobility Load Balancing may affect negatively the final performance of the Mobility Robust Optimization function.

There is a need to find a way to orchestrate the different functionalities by means of a coordination management entity that can adjust the conflictive SON decisions and that can decide when to intervene in the optimization process of the SON functionalities because every process in LTE technology has a different time scale and it is important to act at the right moment. Orchestration functionalities will take advantage of the best set of values for improving the performance of the network. Moreover, there is a need for this orchestration functionality to consider the operator quality of service concerns during the SON self-* optimization process.

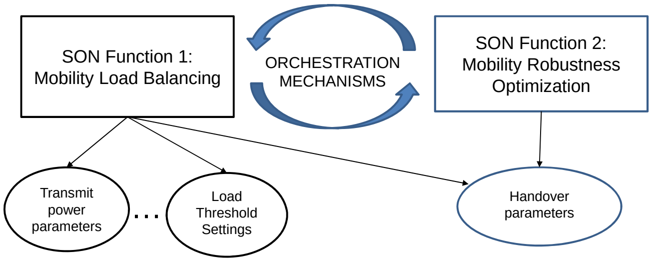

Figure 2. SON-Functionalities in the need for orchestration mechanisms

III. FORESEEN TECHNICAL APPROACH

This research aims to investigate novel self-optimization and management solutions to provide enhanced support for QoS of next-generation services in LTE systems. In order to address the interdependency of SON functionalities this research will develop a coordination management framework aimed to cope with system's instabilities due to potential conflict decisions among SON functions. This section presents the foreseen technical approach towards this complex task. Namely, we present the LTE system model and the corresponding optimization problem that we are targeting.

A. *LTE System Modeling*

This section presents the modeling of SON functions in LTE, considering the mapping of service characteristics and requirements with resource management mechanisms responsible of allocating available network resources to users. This research concentrates on the Mobility Robust Optimization and Mobility Load Balancing Optimization SON functions, since they have a high degree of dependency and rely on a common management policy (namely, handover or base station assignment procedure) to achieve their corresponding goals.

The LTE system is modeled attending to the downlink performance of an OFDMA-based cellular network. The considered system model [6], illustrated in Figure 3, consists of N eNodeBs that cover a geographical area in which there are M active users. It is assumed that each user i has a minimum data rate requirement, denoted as R^{i}_{min}, which must be satisfied irrespectively of the assigned eNodeB. The arrows connecting users and eNodeB's in Figure 3 indicate possible eNodeB assignment choices.

The overall network uses a single frequency channel with a total bandwidth *BW* that is divided into *K* OFDM subcarriers so that each eNodeB *j* can operate a subset of K_j subcarriers. Radio and transport resources are assumed to be allocated to each user in a single eNodeB, due that LTE systems do not consider macro-diversity support (i.e., only hard-handovers are allowed). The model considers that each eNodeB is constrained by a limited amount of radio resources and a limited amount of transport resources. As to radio resource constraints, each eNodeB in the LTE system is assumed to be able to allocate simultaneously a maximum of K_j subcarriers and to having a maximum downlink transmission power limitation $P_j^{\max}$. The radio channel gain between eNodeB *j* and user *i* is modeled by a vector $\overrightarrow{G_{ij}} = \{G_{i,j,1},\ldots,G_{i,j,K}\}$, where $G_{i,j,k}$ denotes the radio channel gain over subcarrier $k \in \{1,\ldots,K_j\}$.

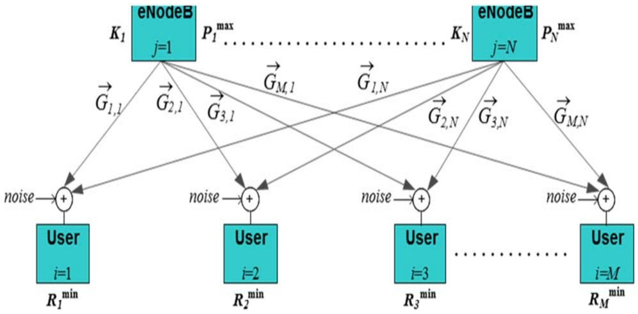

Figure 3. LTE System Model

The amount of radio resources needed to fulfill users' rate service requirements could be quite different depending on the selected eNodeB's. So, for each possible assignment, it is necessary to determine which "resource cost" it has in terms of resource consumption. To that end, we define a radio cost, denoted as α_{ij}, and a transport cost indicated as β_{ij} to quantify resource consumption when assigning user *i* to eNodeB *j*. The eNodeB assignment problem should try to find a *feasible assignment* (i.e., radio costs do not exceed their respective constraints) so that users' rate requirements are satisfied. Additionally, when several feasible eNodeB assignments solutions exist (i.e., there are several ways to allocate all the users without exceeding network resources), we are also interested in finding the "best" of these possible solutions. This can be modeled using the concept of utility function, which allows us to quantify the appropriateness of assigning user *i* to eNodeB *j* by means of a magnitude denoted as u_{ij}, so that $u_{ij} > u_{il}$ would indicate that eNodeB *j* is more appropriate than eNodeB *l* to serve user *i*. As well, $u_{ij} > u_{lj}$ would indicate that is better to assign user *i* to eNodeB *j* than user *l*. Details of utility and resource cost functions envisaged so far are provided in the following.

B. *Resource Cost and Utility function.*

Before presenting the resource cost function definition, we provide a brief review of basic concepts concerning the LTE's air interface evaluation metrics.

In a cellular OFDMA system like LTE, the computation of the signal to interference and noise ratio (SINR) achieved at subcarrier *k* in the receiver of user *i* served by eNodeB *j*, is obtained as follows:

$$SINR_{i,j,k} = \frac{G_{i,j,k} P_{i,j,k}}{I_{i,j,k} + \eta} \tag{1}$$

where $G_{i,j,k}$ is the radio channel gain between eNodeB *j* and user *i* over subcarrier *k*, $P_{i,j,k}$ is the transmit power of eNodeB *j* on subcarrier *k* allocated to user *i*, η is the thermal noise per subcarrier, and $I_{i,j,k}$ is the co-channel interference power received by user *i* in that subcarrier. The value of the co-channel interference $I_{i,j,k}$ can be computed as:

$$I_{i,j,k} = \sum_{n=1, n \neq j}^{n=N} G_{i,n,k} P_{m \neq i,n,k} \tag{2}$$

where $P_{i,n,k}$ is the transmit power of interfering eNodeB *n*, on subcarrier *k* assigned to other user $m \neq i$. Equation (1) that models the SINR denotes the channel frequency response of user *i* on subcarrier *k*, and the achievable transmission rate $r_{i,j,k}$ on this subcarrier of user *i* assigned to BS *j* is given by:

$$r_{i,j,k} = \frac{BW}{K} \cdot \log_2\left(1 + SINR_{i,j,k}\right) \tag{3}$$

For illustration purposes, if all resources of eNodeB *j* were allocated to user *i*, the maximum achievable rate would be:

$$R_{i,j}^{\max} = \sum_{k=1}^{K_j} r_{i,j,k} \tag{4}$$

In this context, considering that an eNodeB dynamically shares transmission resources between assigned users by allocating a given amount of subcarriers to user *i*, denoted as K_{ij}, being $K_{ij} < K_j$, during a given amount of transmission time, denoted as ΔT_{ij}, being $\Delta T_{ij} < T_s$, where T_s is a scheduling reference time, we could relate the achievable rate to the amount of used subcarriers and the amount of allocated transmission time to meet users' minimum rate requirements:

$$\frac{K_{ij}}{K_j} \frac{\Delta T_{ij}}{T_s} R_{ij}^{\max} \geq R_i^{\min} \tag{5}$$

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From the previous expression, the radio resource cost is defined directly as:

$$\alpha_{ij} = \frac{R_i^{\min}}{R_{ij}^{\max}} = \frac{K_{ij}}{K_j}\frac{\Delta T_{ij}}{T_s} \le 1 \qquad (6)$$

Note that $\alpha_{ij}=1$ would mean that serving user *i* in eNodeB *j* makes use of all available radio resources at the eNodeB. Attending to practical considerations, it is considered that there is a limited set of modulation and coding schemes (MCS) that must be used in each subcarrier, thus reducing the output of expressions (3), (4) and (6) to a set of discrete values.

On the other hand, to quantify the appropriateness of each eNodeB assignment, a utility-based framework is used. Different types of utility functions have been used in resource allocation problems. Commonly, a utility function is a non-decreasing function of the amount of allocated resources and its shape (e.g., step, convex, concave or sigmoid are often used) depends on the expected benefit that resource allocation can bring into a given system (e.g., a step function can be used to model a system where allocating resources below a given threshold has no utility at all but the maximum utility is just achieved when reaching this threshold). In our case, we formulate the utility function to reflect the bit rate efficiency of the allocated resources to supporting the data transfer of a user assigned to a given eNodeB. Hence, as to the air interface, the efficiency is directly obtained according to Shannon's law from expression (3) as $\log_2(1+SINR_{ij})$ (the bigger the SINR, the less amount of resources are needed to fulfill user's requirements). Hence, the utility function can be defined as:

$$u_{ij}(SINR_{ij}) = \frac{\log_2(1+SINR_{ij})}{\log_2(1+SNR)} \qquad (7)$$

where SNR is the signal to noise ratio achieved in case of no co-channel interference.

C. *Optimization Problem Formulation*

Using both the resource cost function and utility-based function, it is possible to formulate the base station assignment problem as an optimization problem aiming to maximize the utility of the assignments while not exceeding radio capacity limits at each BS. Defining the BS assignment matrix $B = \{b_{ij}\}_{M\times N}$, with $i\in\{1,\ldots,M\}$ and $j\in\{1,\ldots,N\}$, where the assignment indicator variable b_{ij} equals to 1 if user *i* is assigned to BS *j*, or zero otherwise, the BS assignment problem can be formally written as:

$$\max_{ij}\left(\sum_{i=1}^{M}\sum_{j=1}^{N} u_{ij} b_{ij}\right) \qquad (8)$$

$$s.t. \quad \sum_{i=1}^{M} \alpha_{ij} b_{ij} \le 1 \qquad j = 1,\ldots,N \qquad (9)$$

$$\sum_{j=1}^{N} b_{ij} = 1 \qquad i = 1,\ldots,M \qquad (10)$$

$$R_i \ge R_i^{\min} \qquad (11)$$

$$b_{ij} \in \{0,1\} \qquad (12)$$

The above optimization problem aims to maximize the total welfare utility, as defined in (8), of the assignments in the system. Under the considered objective function, the assignments that lead to have a most efficient connection, in terms of the bit rate efficiency of the allocated radio resources, are preferred. The set of constraints considered in (9) assures that no more resources than available are assigned to each BS. The second set of constraints (10) is used to indicate that all users need to be assigned to a single BS, while constraint (11) indicates the individual rate required by each user. Moreover, to avoid splitting or partial assignment of users, constraint (12) is used, which however leads to the combinatorial nature of the problem with exponentially growing complexity in the degrees of freedom.

Problem (8)-(12) is a non-linear combinatorial optimization problem since entries in the assignment matrix *B* can only take integer values. Notice that utility and resource cost functions are non-linear functions that depend on the SINR values, which in turn depend on the eNodeB assignment solution because of the co-channel interference, resulting in a mutual dependency. So, both utility and radio resource cost function values are coupled with the assignment of the users in the system, making the eNodeB assignment problem very hard to tackle.

The above optimization problem formulation resembles the behavior of the Mobility Robust Optimization functionality, where the underlying idea is to find the base station assignment for each mobile user so that the overall system's utility is maximized and network constraints and users' requirements are satisfied. This problem formulation is valid whenever a standalone implementation of a single SON function is performed.

As a result, in order to analyze both the Mobility Robust Optimization and the Mobility Load Balancing Optimization in a coordinated framework, a multi-objective optimization should be defined. This latter type of approaches has not been addressed in the literature to simultaneously perform different self-organizing management tasks. With this regard, Figure 4 illustrates the case where two SON functionalities co-exist and work together in an orchestrated manner. More specifically, the Mobility Load Balancing Optimization aims to distribute traffic among the cells in the LTE system, so that unbalance conditions are, at some extent, prevented or mitigated. For instance, this can be achieved by controlling the amount of resources allocated to mobile users (i.e., transmit power that is related to constraint (9) in our system model), and/or manipulating the load threshold values used to trigger appropriate load balancing actions in LTE. In any case, notice that actions performed by SON function 1 indirectly impact on control parameters been directly reconfigured by the SON function 2. With this regard, direct influences can be seen as a controllable behavior, whereas indirect impacts are actually uncontrollable behavior. Therefore, management solutions encompassing orchestration mechanisms are required to allow a seamless integration and coordination of two different SON functions, and particularly to prevent any potential conflict among considered objectives. The orchestration mechanisms can be realized by having a feedback loop between both functionalities, so that the actions taken by a given function are properly send to the input of the other function.

IV. STATE OF THE ART

Zhan et al. [7] proposed an algorithm for the Mobility Load Balancing where load balancing actions are triggered by cells experiencing a relatively low load. In practice, the objective of this approach is that an underutilized cell anticipates to an eventual congestion situation in a neighboring cell. Although it is clear that a handover mechanism is used to steer users to the lightly loaded cell, this work does not provide details about the selection choice of uses that are likely to be handed over by the proposed approach.

Sas et al. [8] analyzed the problem of dynamic admission control threshold settings and handover parameters. In this sense, the admission procedure is assumed to have a reserved amount of resources that can be allocated to users for which a handover has been performed. Depending on the perceived network conditions, the proposed solution is able to modify admission control thresholds. The main drawback of this approach is that the policy used to set threshold values does not consider minimum QoS requirement as our research proposal.

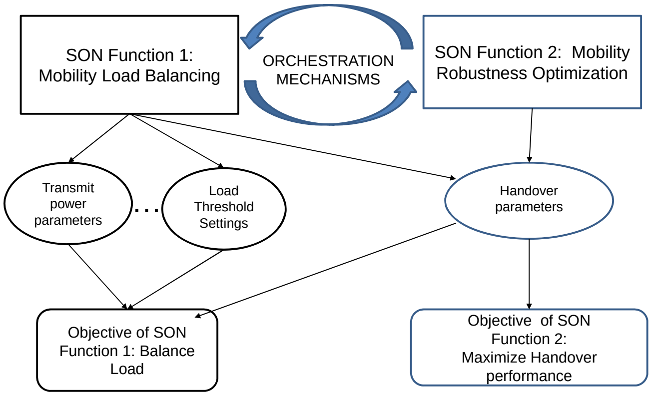

Figure 4. Interdependencies between two SON functions

Hu et al. [9] aim at improving the functionality of Mobility Load Balancing by introducing a handover penalty function in the handover decision making process. Ewe and Bakker [10] proposed a handover optimization procedure performed distributed to base stations of the radio network. However, none of these previous works evaluate or address the combination or analyze the performance of their solutions together with other LTE SON function, e.g. Mobility Robust proposed in this work.

Zhang et al. [11] detected the load conditions of eNodeBs by making use of the sizes and shapes of cellular coverage. Coverage can be adjusted automatically according to load conditions, so as to balance load. However, this work does not take into account quality of service and does not consider the impact that their methods will have on other functionalities that our proposal does.

Handover parameter optimization algorithms are commonly used in the literature in order to tune handover related parameters, namely, hysteresis and time-to-trigger. The work presented by Jansen et al. in [12] falls into this category. However, the work lacks from a formal analysis on how the proposed solution could be integrated with other SON functionalities, which are the advantages of our proposal.

V. EXPECTED CONTRIBUTIONS AND CONCLUDING REMARKS

In order to orchestrate SON functions of LTE networks it is needed consider standalone optimization processes and overall network performance to drive their decisions. It is also needed to find QoS- and resource-aware tradeoffs between service level requirements and overall network resource performance. We have presented a work in progress towards a novel QoS- and resource-oriented SON orchestration management framework to drive the optimization procedures of the Mobility Robust and Load Balancing SON functions, that exploits computational intelligence algorithms in favor of convergence to trade-offs between service level requirements and network performance targets in LTE mobile communication systems environments.

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