Frequency Robustness Optimization with Respect to Traffic Distribution for LTE System

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Abstract. The Long Term Evolution (LTE) cellular network is based on Orthogonal Frequency Division Multiple Access (OFDMA) to meet several services and performance requirement. This paper shows the interest of robustness approach due to the uncertainty of traffic distribution while evaluating some antenna parameters. We use a greedy algorithm with different variants to show how a frequency parameter setting can impact the coverage performance indicator based on the SINR metric. The well-known frequency reuse schemes 1x3x3, whereby the entire bandwidth is divided into 3 non-overlapping groups and assigned to 3 co-site sectors within each cell, have been used in our model. Further work must be done on algorithmic approach.

Keywords: LTE; Robustness; SINR; Interference; Frequency; Optimization

1 Introduction

The Long Term Evolution is a new air-interface designed by the Third Generation Partnership Project (3GPP) [6]. Its goal is to achieve additional substantial leaps in terms of service provisioning and cost reduction. OFDMA has been widely accepted as a promising technology for new generations [9]. This technique provides orthogonality between the channels [7]; it reduces interference and improves the network Quality of Service (QoS). Resource allocation in radio networks essentially depends on the quality of some reference signals received by the user equipment (UE). In LTE, they are the Reference Signal Received Power (RSRP) and the Reference Signal Received Quality (RSRQ) corresponding respectively to Received Signal Code Power (RSCP) and *Ec/No* in (UMTS Universal Mobile Telecommunications System). Each user is assigned a portion of the spectrum depending on RSRP and RSRQ. The more complex optimization of reference signal is the RSRQ which is based on SINR [8] [12]. SINR is an important performance indicator to estimate the achievable throughput from the interference received by the neighboring cluster of first-tier cells. The estimation and optimization of the SINR are well-known problems in radio communication systems such as 802.11, Global System for Mobile Communications (GSM) or UMTS [4], [1], and LTE needs also a good estimation and control of SINR.

Optimizing antenna parameters configuration is one of main targets. It can significantly improve the coverage and the capacity of the network dealing with the lack of available bandwidth in eNB (evolved Node Base). Several studies have been done in this direction to understand the impact of parameters on antennal QoS offered by the network [12], [10] and [3]. In [3] the authors study the impact of azimuth and tilt inaccuracies on network performance considering three main quality parameters: service coverage, soft handover and the ratio of chip energy to interference *Ec/No*. The approach of simulated annealing or evolutionary computation is used in [10] [1] to study network configuration parameters (CPICH power, down tilt and antenna azimuth) effects toward coverage service in UMTS network. Other approaches for frequency assignment are available at http://fap.zib.de/biblio/.

In LTE various combinations of antenna have been studied in term of SINR and throughput performance [12] [2]. However, there is no work on robust optimization for LTE. In this paper, we study the influence of the frequency as preliminary study on some performance metrics (e.g. SINR, coverage) and also, the interest of robust optimization for LTE network. The choice of the robust approach is mainly due to the uncertainty of the traffic distribution and its advantage is to tackle this uncertainty among several traffic scenarios. For this aim, the paper is structured as follows. Section II introduces the system model and basic assumptions. Section III extends this work and shows the performance metrics and test assumptions. Section IV presents some results to highlight utility of robust optimization toward the uncertainty of the traffic demands with LTE online optimization. Conclusions are drawn in section V.

2 Case study and System Model

2.1 Case study

The considered network for this study consists of tri-sectors sites in one real city. The service area is a 40kmx20km area with industrial zones. For our model the service area is divided into a grid of equally sized test points. A test point is a 25x25 meters. Due to the very small size of the test point, we assume the same signal propagation conditions within a test point. It is characterized by its number of users and the category of required services for each user (e.g., voice, data). Each sector in the network is equipped with one directive antenna and each antenna is characterized by its parameters: radiation pattern, azimuth, tilt, frequency and output power in downlink. Due to the dynamic aspect of the network and changes in traffic demand, we use the concept of traffic scenarios. A scenario is a given distribution and load of the traffic demand at a given time for each test point. Then the scenarios allow us to compute different situations of network performance to study the robustness problem.

2.2 Basic Assumptions

In this paper, we consider the downlink transmission and illustrate the interference schemes using a theoretical model of seven-cell hexagonal layout as shown in Fig. 1. Three sectors are considered in each site with three eNBs. In Fig. 1 we see the frequency reuse 1x3x3 pattern where one site with three sectors uses three frequency sets. In our real network, cells are not hexagons; the sub-band assignment depends on the azimuth orientation of the sectors. The features of our computational model are the following: 1) Intra-frequency interference is avoided due to the use of OFDMA technique in downlink transmission. In LTE the orthogonality between subcarriers insures that the interference inside the cell can be ignored. 2) The basic resource element in OFDMA is the physical resource block (PRB) which spans both frequency and time dimensions. Here, we do not take into account PRB to estimate the inter-cell interference because it needs huge simulation; we only focus on the frequency sub-band reuse scheme. Two adjacent cells are scrambling each other if they are using the same sub-band to transmit data. It gives a worst but fast estimation of SINR.

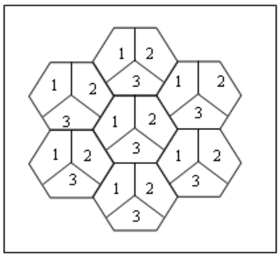

Fig.1. Reuse 1x3x3 seven-cell hexagonal layout.

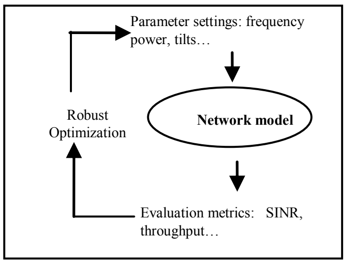

Fig.2. Online optimization process

2.3 Problem Formulation

The global objective of this study is to propose a methodology to change automatically some antenna parameters settings (power output, tilts, frequency allocation) so that the network will be more responsive to changes in traffic and the environment. The online optimization process is depicted on Fig. 2, where the overall optimization process is presented. The system operator acts on it via the antenna parameters. These parameters are called decision variables of the problem. From the input data, the network model provides an assessment of service quality using endpoints such as the level of interference and the bandwidth required to absorb the flow required by the users. The calculation in this level needs to know the real state of the traffic. Thus the decision variables depend on the considered traffic scenario. The proposed global objective of robust optimization is to minimize the lack of bandwidth of the network for all traffic flow requested. For the deployment of the network, each test point is associated with the eNB according to the quality of the received SINR. The interference model based on SINR is thus calculated as defined in Eq. (1). The detail on the production of this Eq. is given in [11].

$$\gamma_{b,t,s} = \frac{p^R_{b,t} f_b}{\sum_{b' \neq b, f_b = f_{b'}} p^R_{b',t} f_{b'} \delta_{b,s} \delta_{b',s} + n_0 w} > \gamma^{MIN} \qquad (1)$$

Where, $\gamma_{b,t,s}$ is the SINR received by the test point *t* and issued from the eNB *b* in scenario *s*; f_b and $f_{b'}$ are the frequencies used by eNB *b* and b' respectively; $\delta_{b,s}$ and $\delta_{b',s}$ are the load factors corresponding to eNBs *b* and b' in scenario *s*. The term *w* represents the total bandwidth used by all eNBs and n_0 is the thermal noise over the considered bandwidth. The terms $p^R_{b,t}$ and $p^R_{b',t}$ are the end power received by UE located in test point *t* from respectively *b* and *b'*. The right part of Eq. (1) γ^{MIN} is the SINR threshold required for the test point to establish a communication; below this value, the users within the given test point are considered as non-covered users. The full problem formulation is given by the following sets of data, parameters and functions. Let: $B=\{1,\dots,n^B\}$ the set of n^B eNBs of the network; $T=\{1,\dots,n^{TP}\}$ the set of test points of the map; and $c_{t,s}$ the number of users located on the test point *t* in scenario *s*. We need to use the network return to determine the values of the following decision variables.

Decision variables (parameter settings):

p^E_b is the output power of the eNB *b* : $p^E_b \in P_b$; t^E_b is the electrical tilt of the eNB *b* : $t^E_b \in T_b$; $f_{b,n}$ is the variable for carrier assignment to eNB : $f_{b,n} \in \{0;1\}$

Where, P_b and T_b the sets of possible values of the power output and tilt respectively.

Fitness functions for robustness: we aim at minimizing one of the following:

Mean: $\sum_{s \in S} (p_s \times \Delta_s)$	Standard deviation: $\sum_{s \in S} p_s \left[\left(\sum_{s' \in S} \Delta_{s'} \right) / n^s - \Delta_s \right]^2$
Absolute robustness: $\max_{s \in S} (p_s \times \Delta_s)$	Absolute deviation: $\max_{s \in S} \left(p_s \left(\Delta^*_s - \Delta_s \right) \right)$

Where, Δ^*_s is the optimum of Δ_s in the scenario *s*. This measure therefore requires solving n^s problems in advance. p_s is the probability of using the scenario *s*.

Where, Δ_s is the lack of bandwidth expressed in Hz required by the network to drain all traffic flow in scenario *s*.

$$\Delta_s = \max_{b \in B}(\max(0, \Delta_{b,s})) \qquad (2)$$

Where, $\Delta_{b,s}$ is the difference between the necessary bandwidth of the eNB *b* to drain the requested flow of data in the scenario *s*, and the total available bandwidth *w*.

$$\Delta_{b,s} = w^S_{b,s} - w \qquad (3)$$

The term $w^S_{b,s}$ is the necessary bandwidth to satisfy all the users in scenario *s*. and *w* is the total available bandwidth in each eNB. If $\Delta_{b,s} < 0$, then all users associated to the eNB *b* are satisfied. If $\Delta_{b,s} >= 0$, some users are not satisfied (lack on bandwidth).

Constraints: The main constraints of our model are:

(C1) $\forall s \in S,\ n_{0,s}^{C} \leq n_{0}^{C}$: the number of non covered users in scenario *s* should not exceed the threshold n_{0}^{C}.

(C2) $\forall b \in B,\ v_{b}^{MIN} \leq |V_{b}| \leq v_{b}^{MAX}$: minimum and maximum number of neighbourhood cells for *b*.

(C3) $\forall t \in T,\ \sum_{b \in B} u_{b,t} \leq 1$: a test point is associated with exactly one eNB.

Where, $u_{b,t} = \begin{cases} 1 \text{ if test point } t \text{ is associated to eNB } b \\ 0 \text{ otherwise} \end{cases}$

(C4) $\forall b \in B,\ \sum_{n \in N} f_{b,n} \leq 1$: one eNB *b* can use only one carrier *n*.

In the current work, we will not consider all the parameter settings of the antenna. We limit our study to the impact of the frequency parameter on the number of clients not covered by the network in the service area. Other parameters will be added later. The robust approach uses the mean robustness over three different demand scenarios in a traffic day. The proposed evaluation methodology aims to show the effect of the antenna frequency parameter on non covered users with respect to traffic distribution. For the study presented in this paper, the overall problem is reduced to the following.

Decision variable (frequency assignment): $f_{b,n}$: frequency assignment of the carrier *n* to the eNB : $f_{b,n} \in \{0,1\},\ n = 1,2,3$

Constraints: We keep the constraints (C3) and (C4).

Fitness function: Let $n_{0,s}^{C}$ be the number of non covered users in scenario *s* where $n_{t,s}^{C}$ is the number of non-covered users in test point *t* for scenario *s*.

$$n_{0,s}^{C} = \sum_{t \in T_{0}^{C}} n_{t,s}^{C} \qquad (4)$$

Robustness function: $f^{Rob} = \sum_{s \in S} n_{0,s}^{C}$ (5)

Where, f^{Rob} is the sum of non-covered users in all scenarios.

3 Assumptions and Performance Metrics

We aim at evaluating the SINR model to identify where the assigned frequency presents a remarkable increase of covered users with respect to traffic distribution. The main parameters and assumptions we used are those selected by 3GPP for LTE as shown in Table1. Evaluations are performed by a static snapshot of the network level. In addition to Table 1, we assume that the antennas are grouped by site and stored on the basis of an index in ascending order of the x-axis. Two intermediate performance metrics are used for the deployment of the network:

Table1. Test assumptions for LTE downlink

Parameters	Simulation setting	Parameters	Simulation setting
Network layout	35 sites 88 sectors	TX power range	[36 dBm, 46 dBm]
System frequency	1800 Mhz	Mechanical tilt range	[0°,-6°]
System bandwidth	20 Mhz	Electrical tilt range	[0°,-10°]
Required service/user	2 Mbps	Azimuth range	[0°,360°]
Frequency reuse factor	1x3x3	Horizontal HPBW	+70°
eNB heights range	[17m, 46m]	Vertical HPBW	+10°
UE height	1.5 m	Antenna gain range	[14dBi , 18.9dBi]
Propagation loss model	Hata model [5]	Traffic distribution	Distribution in proportion to UMTS traffic load

Signal-to-Interference plus Noise Ratio: The SINR, expressed in Eq. (1), is an important indicator to evaluate cellular networks. It is motivated by the fact that it takes into account all the parameters of the antenna, it depends on the traffic distribution of the network, resizes the network and determines which eNB controls each user and also, allows us to estimate the total throughput of the network.

Load factor: The Load Factor of the sector/cell is the ratio between the total allocated bandwidth to the cell and the maximum bandwidth available in the cell. Let $\delta_{b,s}$ be the load factor, then: $\delta_{b,s} = \frac{w_{b,s}^{S}}{w}$ where, $w_{b,s}^{S}$ is the total allocated bandwidth to the eNB *b* in the reference scenario *s*, and *w* is its maximum available bandwidth. It is worthwhile to mention that load factor is one of the main key indicators. The downlink cell load for a stable network should not exceed 70% [10]. Huge loaded cells are those for which $\delta_{b,s} > 0.7$, and overloaded cells are those for which $\delta_{b,s} > 1$.

4 Simulation Results & Analysis

The basic network we used is the city of Belfort described in section II.2. The UE are randomly dropped in each cell in proportion to the existing UMTS traffic load. We present a methodology to evaluate robustness taking into account traffic data of the considered network. A cell is defined as a set of test points of the map which are assigned to the same eNB; a test point is assigned to the eNB which provides the best SINR. The collected traffic data come from a real UMTS network. The tests consider three different scenarios originating from the traffic of one day, as shown in Fig. 3.

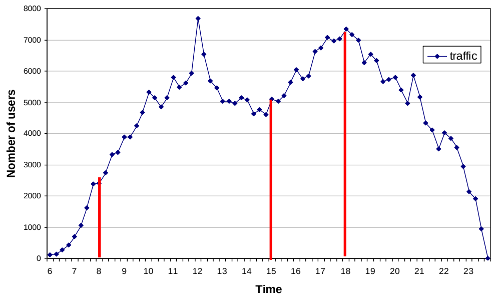

Fig.3. Example of day traffic with three chosen scenarios

Three scenarios were selected at different times of the day as follows: a first scenario at 8am with low traffic and 482 users dropped randomly in the network; a second scenario at 3pm with medium traffic and 1,019 users; and a third scenario at 6pm with high traffic and 1,471 users. We are considering that all users are accessing the network at the same time (saturated traffic condition). Fig. 4.a) and 4.b) show the concentration of the traffic in the 1st and 3rd scenario at 8am and 6pm respectively. The traffic is represented by a colour gradient. The light colour shows a low traffic, while the dark colour shows higher traffic.As we can see, there is more dense traffic at 6pm than at 8am. The objective is to test different traffic loads in the day. The program implementing our model is developed in C++. We run the program 10 times to get stable results; different tests are presented in the following to show the interest of robustness in a real network design and traffic load.

Fig.4. Example of traffic concentration at: a) 8am. b) 6pm

Our study focuses on the interest of robust optimization for LTE online optimization and shows that optimizing a number of network configurations helps considerably to meet variant services respective to traffic uncertainty. Furthermore, we use a greedy algorithm on frequency assignment where sites and sectors are explored firstly one by one ranked from the input file and secondly randomly. The reuse scheme used here is the 1x3x3 knowing that it presents better results with respect to the number of covered users [11]. We look how the solution of the antenna configuration, especially the frequency parameter, behaves under realistic scenarios.

4.1 Algorithm description

It can be proved that this problem is NP-hard as it is a graph-colouring problem. For such problems, guaranteeing optimum requires, in the worst case, an enumeration of all possible configurations. The number of possibilities is enormous; for 35 cells, 88 antennas and 3 frequency groups, the number of possibilities is $6^{35} = 1.71 * 10^{27}$. In order to show the interest of robust optimization, we present an algorithm able to quickly find a good solution. An iterative algorithm is used; the purpose is not to find an optimal solution but to get the benefit of robust optimization for 3 scenarios in comparison with local solution based on single scenario. The algorithm with several variants is proposed and we measure the performance toward the network coverage. The robust optimization function takes into account the three scenarios considered above. We run the optimization with different conditions varying: the scenarios of traffic (several traffic hours); the procedure for the initial frequency assignment to the eNBs (deterministic or stochastic per sector from the same site); the sites neighbourhood search to test the permutation of frequency: sites ranked from the input file or randomly chosen during optimization. The algorithm starts with one solution using the reuse scheme 1x3x3. The optimization algorithm is run for each scenario to show the best configuration of the frequency parameter setting with respect to the performance metric given by the Eq. (4). For each explored site, we evaluate the 6 (3! =6) possibilities of permutations for each sector of the site. The algorithm evaluates 6x88 permutations at each iteration. If a frequency permutation improves the evaluation function of the current solution, the algorithm keeps the last modification and goes through the next sector configuration. The algorithm stops once the current iteration brings no improvement. This is achieved by the following algorithm which was used for all cases.

Algorithm

Input parameters: Set B of n^B eNBs; Set T of n^T test points; Set S of scenarios: s_1=8am, s_2=3pm, s_3=6pm; Frequency reuse scheme 1x3x3 (3 groups of frequency to assign to eNB)

Variables: Frequency assignment to eNBs

Fitness function: Fitness(F) = Number of outage users for the frequency plan F with $Fitness(F) = n_{0,s}^{C}(F)$ in s for non robust optimization and $Fitness(F) = f^{Rob}(F)$ in s_1, s_2 and s_3 for robust optimization.

```
Algorithm:
Initialize F // F is the initial frequency plan
F*:= F // F* is the current best frequency plan
Repeat
Improve:=False
  For each site b of the network // Testing all the sites
    For each permutation j:=1..6 //Testing all the permutations
            of frequency on b
        Generate the new frequency plan F from F*
        If  Fitness(F)<Fitness(F*)  //Evaluation of the current
                                     configuration
            F*:= F // Store the new best solution of frequency plan
            Improve:=True
        End IF
    End For
  End For
Until Improve=False // Stopping criteria if there is no improvement.
```

4.2 Results with non robust and robust optimization

The results of optimization are shown in the Fig. 5. We emphasize that for the non robust (each scenario tackled alone) and for the robust optimization (the 3 scenarios together) we use the same algorithm but in case of robustness the evaluation function is the Eq. (5) and takes into account the configuration of the frequency considering all the scenarios simultaneously. It means that, for each frequency of the network, we evaluate the non-covered users in the three scenarios. So, we run the same algorithm 4 times (one run for each optimization), we use the evaluation function Eq. (4) to optimize the 3 scenarios separately; then we use the evaluation function Eq. (5) for the robust optimization using the 3 scenarios at the same time. The *x*-axis represents the starting solution and the optimization of scenarios 1, 2 and 3 separately and the robust optimization at the end. The *y*-axis shows the number of users in outage for scenarios 1, 2, 3 and totally. We can note that scenario1 optimization has the smallest number of non-covered users when evaluating *s1* (4 users) comparing to the other cases (8, 7, 9). The same analysis can be done for the scenario s_3 and it is a different for s_2 but not far away from the best one. After 20mn runs there is no guarantee on the solution quality. We observe that the result of the robust optimization is a trade off between the three scenarios, the best for s_1 and s_2 but not the best for s_3. Finally, the fitness function value $f^{Rob} = 22$ of non-covered users for all cases corresponds to the global best solution (blue colour in the right part), while in other situations, starting solution and non robust cases, the global function values are 43, 25, 27 and 29 respectively from left to right part of the Fig. 5a. The robust optimization does a better compromise between all scenarios. This result shows how the robust approach is important for the remaining of this study.

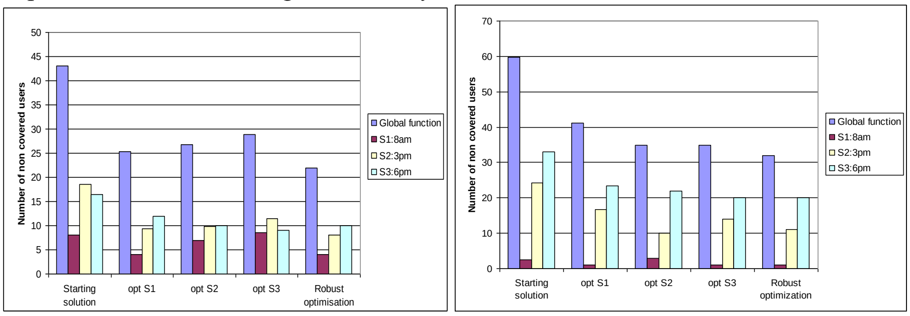

Fig.5. Three non robust cases and one robust optimization. (a) Test 1 with deterministic initial frequency plan and site ranked from input file during optimization. (b) Test 3 with random initial frequency plan and site randomly processed during optimization

Different variants of the algorithm have been tested by varying several parameters. We run the program 20 minutes for each optimization in Test 2 and Test 3, and keep the best solution for the considered fitness function. In Test 1 (Fig. 5a), the initial frequency plan is deterministically assigned and the sites are processed from their rank in the input file. In Test 2, the initial frequency plan is deterministically assigned and the sites are randomly processed during optimization. The results are similar to the test 1 so we do not plot it. In Test 3 (Fig. 5b) the initial frequency plan is randomly assigned to the co-site sectors and the sites are randomly processed during optimization. The Fig. 5 plots one execution but the ten executions provide results that are in the same direction, the robust optimization gives the best trade off between the different scenarios and this is the requirement for LTE online optimization.

5 Conclusion and perspectives

In this paper, the impact of frequency parameter setting and the interest of robust approach with respect of traffic distribution in LTE downlink system have been discussed and simulations were presented. The analysis has been carried out using model radiation pattern 1x3x3 and simple model of system performance. With respect to coverage, our case study demonstrates the benefit of the robustness approach and how the frequency parameter setting affects the coverage of the macro-cellular scenario. We aim in further studies at analyzing the influence of the load factor throughout the capacity performance metric to show the overloaded cells which represent the bottlenecks of the network and the impact of other antenna parameters like tilts. Variable Neighbourhood Search and Tabu Search are under development for robust optimization.

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