Autonomous antenna tilt and power configuration based on CQI for LTE cellular networks

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Abstract

In cellular systems, antenna tilt and transmit power are two most important parameters for tuning the performance. An optimal antenna tilt has strong impact in interference mitigation which leads to a better coverage and capacity in interference limited system like LTE. Legacy optimization procedures require drive test to tune these parameters. In this paper, an autonomous configuration scheme, which works on the measurement provided by the users, is presented. The base stations constantly change their antenna tilt or transmit power to maximize their own objective functions. This heuristic approach is fully decentralized. Hence, the complexity is moderate. The simulation results show significant improvement in system performance in terms of reduced drop rate and better median SINR.

1 Introduction

In mobile cellular networks, at the planning stage, some static parameters and objectives are considered. In ongoing network optimization, system parameters are fine tuned repetitively, based on periodically collected statistics, such as key performance indicators (KPI)s. Enormous efforts, such as drive tests, are put in the coverage area to collect those data. Due to the limitation of data sampling, the collected data cannot fully represent all the characteristics of the live network. Therefore, the trend of network operating is to extract real-time parameters from user and optimize the network in a self-organized manner. This has significant effect not only on the quality of service and user satisfaction, but also comes with inherent characteristic of cost cutting, in term of initial deployment and planning capital expenditures (CAPEX) and ongoing operational expenditure (OPEX).

Antenna tilt is one of the important parameter that has dramatic impact on coverage, interference, path loss and delay spread [1]. In this paper, we proposed an algorithm of adjusting antenna tilt and transmission power, primarily based on channel quality indicator (CQI), which is a 4-bit feedback message sent from user with the information about channel condition [2]. Moreover, a system level analysis is done based on variations in the proposed algorithm. These variations are created to test use cases based on different preferences and their impact on the overall system. Additionally, the solution is kept scalable, since decision making entities do not need cooperation to govern the changes. As we are using CQI feedback mechanism from end terminal, which makes our solution agile, as it is sensitive to instantaneous changes occurred in live networks. The overall objective is to optimize the network coverage and capacity, which can be indicated by the CQI.

Antenna theory gives us freedom to change the tilt angle in two ways, mechanically and electrically. Both ways have different effects on the radiation pattern. Mechanical tilt has a relation with 3dB horizontal Half Power Beamwidth (HPBW). When downtilt angle increases, HPBW becomes wider. This effect is known as "pattern blooming" [3]. In contrary, electrical tilt gives us a uniform modification in antenna radiation pattern. Currently, the range of electrical tilt is not greater than 20 degrees. For example, Kathrein 800 10504V01 panel antenna has electrical downtilt of $0^\circ - 15^\circ$, that is continuously adjustable.

Earlier works on antenna tilt focus on the influence of antenna tilt on system performance in GSM [4], UMTS [5] and LTE [3]. Most of the existing works devote to find the relationship between antenna tilt and the system performance. Other works carried out with concrete solutions toward optimal tilt angle. Authors in [6] presented an annealing approach for tilt optimization based on user measurements. The algorithm is based on signal to interference plus noise ratio (SINR) measurements. An extended local search is performed and each solution is evaluated with respect to a certain probability. The solutions are iteratively updated until the optimum point is reached. Authors in [7] propose a joint optimization approach using a Taguchi's method for jointly optimizing antenna azimuth orientation and tilts for eNBs in LTE. Authors in [8] does not only give the effect of electrical and mechanical tilting on downlink LTE, but also provide proof that electrical tilt is optimal for cell edge users and mean throughput. Authors in [9] proposed a self-optimization of antenna tilt and pilot power based on centralized approach. A central node has global information of all the tilt angle and system information. Optimized setting are made available from this central database. There are many solutions available in literature based on information sharing or central control. The biggest problem with these approaches is, that it is contradictory to the nature of self-organization. Furthermore, they would increase the signalling overhead and complexity with the increase in number of nodes in the system. That is why in this paper we have restricted ourselves to the decentralized approach, where complexity of system

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remains constant with the insertion of new nodes.
The remainder of this paper is organized as follows. Some preliminary information is given in Section 2. The proposed antenna tilt and transmit power configuration is explained in Section 3. The numerical results are discussed in Section 4. And finally the conclusions are drawn in Section 5.

2 Preliminaries

For each evolved Node B (eNB), the local optimal tilt is not necessarily global optimal. Consider a case of inter-cell interference and non-optimized tilt. The very common problem faced during post analysis in legacy optimization procedures is over shooting pilot problem. Among other reasons, one of the key issue in this case is the tilt of the over shooting cell is not optimal, which inject interferences to many other cells. Hence, to reduce the interference region in the whole system, an optimal tilt is a handy factor to be considered. Antenna tilt has its own place as compared to beamforming. Both work in their own domain and have different impact on system. Though LTE has multiple-antenna deployment, with respect to our goal, the radiation pattern shares the same characteristics, such as beamwidth and side lobe level as in multi-antenna configuration. Some literature [3] with work done on system level simulation confirms the above statement.
The instant received SINR for user k served by eNB i over physical resource block (PRB) n is given by

$$\gamma_{ik}(n) = \frac{p_i \cdot g_{ki}(n)}{\sigma^2_{\mathrm{PRB}} + \sum\limits_{j=1, j\neq i}^{N} p_j \cdot g_{kj}(n)}, \tag{1}$$

where p_i denotes the transmission power of eNB i on PRB n, $g_{ki}(n)$ denotes the channel gain between user k and eNBi, σ^2_{PRB} represents the thermal noise power, N is the total number of eNBs in the network. Since PRB level power allocation is still infeasible in current LTE standard, p_j stays constant over different frequencies.
CQI Q is calculated from SINR by using exponential effective signal to noise ratio mapping (EESM) method presented in [10]. The target CQI $\tilde{Q}$ is a function of rate demand of the user

$$\tilde{Q}_k = f(R_k), \tag{2}$$

where $f(\cdot)$ is the rate demand to CQI mapping function.
The objective function can be written as

$$\underset{\mathbf{a}\in\mathcal{A}^N, \mathbf{p}\in\mathcal{P}^N}{\arg\min} \left(\tilde{Q}_k - Q_k\right), \tag{3}$$

where $\mathbf{a} = [\alpha_{\mathrm{el},1}, \alpha_{\mathrm{el},2}, \cdots, \alpha_{\mathrm{el},N}]^{\mathrm{T}}$ is the vector consisting of electrical tilts of all the basestations, $\mathcal{A}$ is the set of possible antenna tilts, $\mathbf{p} = [p_1, p_2, \cdots, p_N]^{\mathrm{T}}$ is the vector of transmit power and $\mathcal{P}$ is the set of all possible transmit power. The gap between user k's current CQI and target CQI is minimized subject to user k's rate requirement.

2.1 Antenna model

The eNB antenna radiation pattern can be modelled in two spherical patterns: azimuth and elevation. The standardized 3GPP antenna pattern is adopted in this work [11]. 1-D elevation pattern is modelled as Gaussian-shaped main beam with side lobe floors defined as [3]

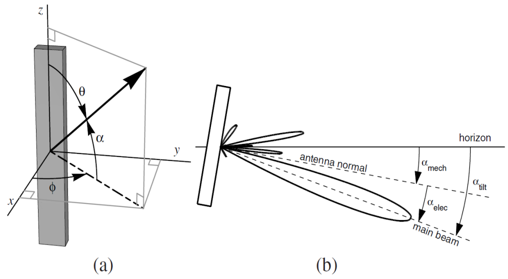

Figure 1: Spherical angles [3]

$$G_{\mathrm{el}}(\alpha) = \max\left(-12\left(\frac{\alpha + \alpha_{\mathrm{el}}}{\alpha_{\mathrm{el,3dB}}}\right)^2, A_{\mathrm{el}}\right), \tag{4}$$

where $G_{\mathrm{el}}(\alpha)$ represents vertical gain in dB, the elevation angle α has a range of $-\pi/2 \leq \alpha \leq \pi/2$. The relation of elevation angle α to polar angle θ is as $\alpha = \pi/2 - \theta$, considering that antenna is at z-axis as shown in Figure 1.

Furthermore, α_{el} is electrical downtilt, taking positive values, when the tilting is below the xy-plane. $\alpha_{\mathrm{el,3dB}}$ is HPBW and A_{el} is side lobe level, which is considered less than 0 dB.

3 Optimization Procedure

Our concept is based on the live network measurements provided by the users. In term of measurement report, users send many type of information to the base station depending upon the event that triggered this activity. CQI feedback is one of the distinct feature of LTE, which can provide us the information of channel quality.

3.1 Building a knowledge base

In the starting point, all the eNBs have antenna electrical tilt of 0°, and users are attached to the eNB, from which they receive the highest power. By observing (3), the optimization of antenna tilt and transmit power can be found as a combinatorial problem, for which the complexity of exhaustive search is overwhelming. To reduce the complexity, and also to make the solution fully decentralized, each eNB can optimize its own objective function. In addition,

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a weighting factor is introduced to make the algorithm biased to the favored group of users. The objective function for eNB i can be written as

$$\underset{\alpha_{\mathrm{el},i}\in\mathcal{A},p_i\in\mathcal{P}}{\arg\min} \sum_{k\in\mathcal{M}_i} w_k \cdot \left(\tilde{Q}_k - Q_k\right), \tag{5}$$

where w_k is the weighting factor of user k and $\mathcal{M}_i$ is the set of users that are attached to eNB i. To further reduce the complexity and make the algorithm feasible for real systems, $\alpha_{\mathrm{el},i}$ and p_i are assumed to have fixed granularity. The solution space for optimal tilt is a N dimensional vector space. To further narrow down the search range, each eNB assumes all the other eNBs have the identical tilt $\alpha_{\mathrm{el},1} = \alpha_{\mathrm{el},2} = \cdots = \alpha_{\mathrm{el},N}$. Thus, the search range will be limited to the cardinality of $\mathcal{A}$, for each eNB. After searching, a repository is created for each eNB, with information about performance of all possible tilts. Meanwhile, the CQIs of each user in different setup are also saved in this repository. Using this repository, one can find the best antenna tilt for each eNB and for each user. And the following computation are founded on this knowledge base.

3.2 Tilt biasing and Tx power optimization

According to the relationship of $\tilde{Q}_k$ and Q_k, users can be divided into two groups, where the satisfied users have $\tilde{Q}_k \leq Q_k$ and unsatisfied users have $\tilde{Q}_k > Q_k$. Based on user satisfaction, the system can be further optimized.

A weighting factor $w_k = 1$ is assigned to a user, if it is satisfied. And a weighting factor $w_k \neq 1$ is assigned to a user, if it is unsatisfied. The value of w_k for the unsatisfied user can be chosen with different criterion, such as distance and priority. Generally, if $w_k > 1$, the solution is biased to unsatisfied users.

During one iteration, based on (5), eNB i computes the best tilt for all the attached users as $\alpha_{\mathrm{el},i}^{(\mathrm{all})}$, and the best tilt for all the unsatisfied users as $\alpha_{\mathrm{el},i}^{(\mathrm{uns})}$. A deviation is calculated as

$$\Delta = \alpha_{\mathrm{el},i}^{(\mathrm{all})} - \alpha_{\mathrm{el},i}^{(\mathrm{uns})}, \tag{6}$$

which determines to which direction the antenna tilt will be changed.

Since the antenna tilt should not be changed too much, if there are only a small number of unsatisfied users, an additional threshold $\Delta_{\mathrm{threshold}}$ is applied to restrict the change in tilts. And only adjust the tilt to the harmonic mean of $\alpha_{\mathrm{el},i}^{(\mathrm{all})}$ and $\alpha_{\mathrm{el},i}^{(\mathrm{uns})}$, if $|\Delta| \leq \Delta_{\mathrm{threshold}}$. Otherwise, the tilt would be set to $\alpha_{\mathrm{el},i}^{(\mathrm{all})}$.

Furthermore, the deviation Δ also gives information about the Tx power. The Tx power should be turned up if $\Delta > 0$, and turned down if $\Delta < 0$.

As summarized in Algorithm 1, the procedure of controlling antenna tilts and Tx power bias the system towards unsatisfied group, while keeping satisfied group in consideration.

Algorithm 1 Tilt biasing and Tx power tuning

Create repository with tilt testing
Define $\Delta_{\mathrm{threshold}}$ based on percentage of unsatisfied group
for each time step **do**
  Get $\alpha_{\mathrm{el},i}^{(\mathrm{all})}$ using (5)
  Get $\alpha_{\mathrm{el},i}^{(\mathrm{uns})}$, accordingly
  Calculate $\Delta = \alpha_{\mathrm{el},i}^{(\mathrm{all})} - \alpha_{\mathrm{el},i}^{(\mathrm{uns})}$
  //Calculate final tilt and/or adjust transmit power
  if $|\Delta| \leq \Delta_{\mathrm{threshold}}$ **then**
    $\alpha_{\mathrm{el},i} = \lceil \mathrm{H}(\alpha_{\mathrm{el},i}^{(\mathrm{all})}, \alpha_{\mathrm{el},i}^{(\mathrm{uns})}) \rceil$
  else
    $\alpha_{\mathrm{el},i} = \alpha_{\mathrm{el},i}^{(\mathrm{all})}$
    if $\Delta > 0$ **then**
      $p_i = p_i + \varepsilon$
    else
      $p_i = p_i - \varepsilon$
    end if
  end if
end for

4 Results and Analysis

For evaluation purpose, two main indicators are adopted to test the results, namely, the drop rate and the CQI satisfaction rate. The drop rate is defined as the number of dropped user divided by the total number of users. The CQI satisfaction rate is the the user whose actual CQI is greater or equal than its target CQI $\tilde{Q}_k \leq Q_k$. Be aware of that, a user can still be served, even if its CQI target is not met. However more radio resources would be required for serving this user.

The reference system is the LTE network in an urban area (Munich city). The path loss is calculated using a ray optical approach [12]. Some global simulation parameters are summarized in Tab. 1. The users are divided into three groups, namely, VoIP, data and web. The VoIP users have the highest priority thus must be served first. The data rate demand of VoIP users is fixed to 64 kbps. Data users have medium priority and the data rate demand is a fixed value randomly chosen from 512 kbps to 2000 kpbs. The web users have minimum data rate demand of 128 kbps, however they should be served with the highest data rate subject to the power limit. They also have the lowest priority.

Regarding user mobility, both low speed and high speed users are considered. The low speed user (pedestrians) can walk either inside the buildings or outside. The average speed of them is uniformly distributed from 0 to 1.5 m/s. And the vehicular users move only along the streets. The average speed of them is uniformly distributed from 10 to 20 m/s.

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Identifier	Setting
Simulation area	(2.4×3.4) km, 5m resolution
Carrier frequency	2 GHz
System bandwidth	10 MHz
Physical resource block	50
Default Tx power	43 dBm
Min, Max Tx power	38.7, 47.3 dBm($\pm 10\%$)
Number of eNB	12
Number of users	300
eNB Propagation model	Ray optical, omnidirectional
Mobility model (pedestrian)	Random walk
Mobility model (vehicular)	Deterministic waypoint model
UE service types	[VoIP | Data | Web]
UE type percentage [%]	[40 | 10 | 50]
UE type priority [1: highest]	[1 | 2 | 3]

Table 1: Simulation Parameters

The antenna parameters are summarized in Tab. 2.

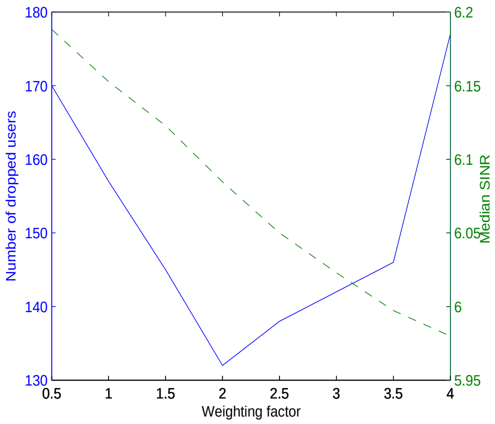

Figure 2: Weight factor fine tuning, $\Delta_{\text{threshold}} = 3$

Identifier	Numerical value
Antenna Height	Approx. 25 m
Antenna gain, G_0	14 dBi
Elevation HPBW, $\alpha_{\text{el,3dB}}$	$6.5\,^\circ$
Elevation SLL, A_{el}	-17 dB

Table 2: Antenna parameters

Three different weighting factor w_k are considered in the evaluation. (1). Distance based weights $w_k \propto d_{i,k}$, where di, k is distance between user k and eNB i. The users far from the eNB are favored in this case. (2). Priority based weights $w_k \propto \frac{1}{q_k}$, where q_k is the priority index of user k. The users with higher priorities are favored in this case. (3). The linear static weights, which are empirically calibrated by experiments. As shown in Fig. 2, different static weighting factors has different drop rate and median SINR. When the weighting factor is too large, the unsatisfied users are getting more SINR, however some originally satisfied users are getting dropped. In the evaluation, $w_k = 2$ is chosen for the unsatisfied users.

Another important factor in our simulation is $\Delta_{\text{threshold}}$. Threshold defines whether we should change transmit power of eNB. The results in Fig. 3 confirms that only with small $\Delta_{\text{threshold}}$, the overall user satisfaction can be maintained. The reason is, with a large $\Delta_{\text{threshold}}$, the system will over compensate the unsatisfied users, which are potentially at the cell edges or very close to the eNB or far away from most of the other users, and degrade the overall system performance. In the evaluation, $\Delta_{\text{threshold}} = 3$ is chosen.

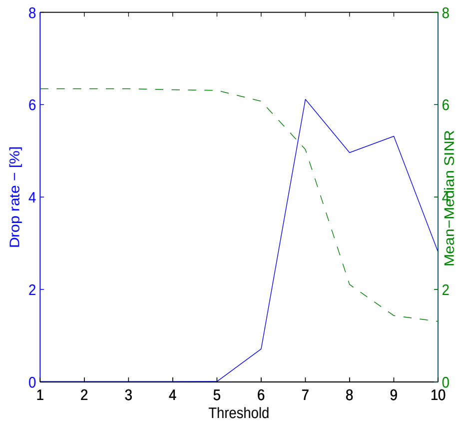

Figure 3: Comparison among different threshold values

In Fig. 4, The drop rates are compared for four different scenarios: (1). The reference system, where no optimization is done. (2). Distance-based weighting factor. (3). Priority-based weighting factor. (4). Empirically calibrated static weighting factor. Comparing to the reference system, the proposed tuning schemes show clearly superior performances, which reduce the drop rate from around 9% to less than 1%. Among all the weighting factors, the empirically calibrated static weight factor performs the best. But the gap between priority-based and static factors is very small.

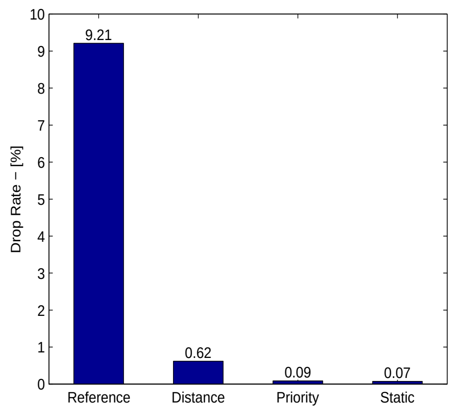

Figure 4: Comparison of Drop Rate

Similar results can be observed from Fig. 5, where only around half of the user having $\tilde{Q}_k \leq Q_k$. The performance

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is improved by a large factor by using the proposed tuning scheme. And the static weighting factor is again the best.

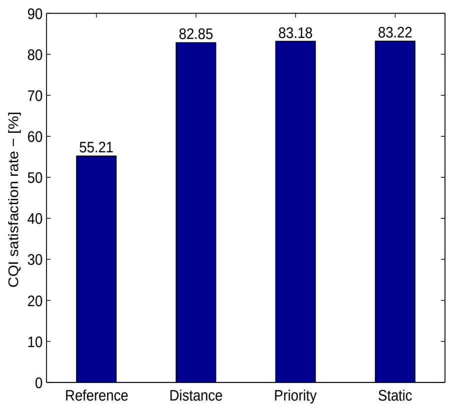

Figure 5: Comparison of CQI satisfaction rate

5 Conclusion

In this paper we proposed an autonomous optimization framework, that works on minimizing the gap between required CQI and available CQI by adjusting tilts and Tx power of eNBs. The framework works on live measurement provided by the users hence is an agile solution. A remarkable improvement can be seen in terms of drop rate reduction and CQI satisfaction, which means less resource utilization and increased capacity.

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