Self-Optimisation of Antenna Beam Tilting in LTE Networks

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Abstract—**This paper introduces a novel technique for self-optimisation of antenna down-tilting. The proposed solution consists of two phases. During the first phase, which needs to be performed quickly, a method based on the Golden Section Search (GSS) algorithm is used to find a near-optimal tilt angle. Then, in the next step, the tilt angle value is fine-tuned through frequent explorations of the near-optimal region. Additionally, the solution benefits from self-healing properties by responding to the failure of a neighbouring cell. In this case, the algorithm is adapted to find a new optimal point upon failure detection. The result shows fast convergence and close-to-optimum performance (93.8% on average) of the proposed algorithm. The overall solution is fully distributed and is 3GPP complaint.**

Keywords-component; Self-Optimisation, Antenna Beam Tilting, Golden Section Search, LTE Networks

I. INTRODUCTION

By introducing self-configuration and self-optimization mechanisms, several human interactions with respect to network operation and maintenance can be removed. These functions aim towards self-organizing behaviour within the network that ultimately increases network performance and service quality by reacting in response to network dynamics. One of the key metrics that directly impacts the capacity and the coverage of an operator's network is the down-tilt angle of base-stations' antenna. A very low antenna down-tilting results in high level of signal interference whereas, on the contrary, too much tilting might lead to coverage holes (especially at the cells borders). According to [1], as a source of coverage improvement, beam-tilt optimisation can yield 10dB signal strength increases over large areas. Currently, the antenna's tilt angles are selected mostly by considering parameters that are related to the geometrics of the deployed cells such as the cells' radius, antenna's height etc. These pre-calculated values might then be fine-tuned through measurements and drive tests.

Fortunately, modern antenna design allows influencing the antenna pattern and the orientation of the main lobe by electrical means (e.g. remote electrical tilt and beam forming). This would open new opportunities for employing algorithms that are able to autonomously self-configure and self-optimise critical antennas' parameters. For example, techniques such as the continuously adjustable electrical down-tilt (CAEDT) [2] allow for the use of intelligent algorithms for autonomous configuration and optimization of the down-tilt angles, and they remove (minimize) the need for expensive drive test measurements and statistical analysis of network performance and fault reports. During the deployment of 3G networks, there have been significant efforts to optimize the configuration of base station antennas. The upgrade to 4G would have been very swift and cost-effective if these settings could have been inherited from the more mature existing 3G networks. However, due to the fundamental differences between the technologies, this is unfortunately not possible. For example, regarding antenna down-tilting, a recent field measurement study [3] reveals that when LTE is overlaid onto Code Division Multiple Access 1x (CDMA1x) networks, independent optimization of the LTE down-tilting would result in throughput gains of over 26 percent at the cell edge, compared to the case when CDMA1x network settings are applied to LTE. Tilt-angle configuration for 3G wireless technologies is investigated in [2], [4]. Further [5] and [6] have studied the issue of joint power and tilt-angle optimisation. A number of other studies including [7] and [8] have formulated the tilt-angle configuration as a part of a multi-objective optimisation framework. Mention should be additionally made to the work in [9] where a heuristic variant of the gradient ascent method is used for optimisation of base-stations' tilt-angle.

This paper introduces a simple and yet effective scheme based on the golden section search (GSS) to dynamically adjust and optimise the down-tilt angle of a base-stations' antennas. The scheme additionally benefits from self-healing capabilities by responding to the dynamics of the environment. Since the scheme is fully distributed, it enables a cell by cell optimisation of tilt angles. For a WCDMA system, it is shown that individual optimisation of cells' down-tilting results in 20% improvement in capacity compared to applying a network wide optimal tilting to all cells [2].

II. SYSTEM MODEL

In order to evaluate the effectiveness of the proposed tilt-angle optimisation method, a fully 3GPP compliant [10] simulation framework is used. The simulation environment consists of 7 base-stations that form a hexagonal deployment. Each base-station consists of three sectors resulting in a total of 21 cells in the simulation study. Additionally, wraparound modelling is employed to simulate the effect of interference from neighbouring cells. This technique virtually replicates the simulation area six times and arranges the replications around the simulation area in its centre. As a consequence, independent of its location, each mobile device sees itself in the centre site, surrounded by the given number of hexagonal layers. The Inter-Site Distance (ISD) is considered to be 500m that corresponds to 3GPP urban deployment model [10]. Normally, smaller site distances (or higher base-stations' transmit power) requires more down-tilting of the antenna.

A widely used and accepted radio channel model is composed of three independent components: path loss, shadow fading, and fast fading. The extended Okumura Hata model [11] is used for modelling the path loss. This model defines the loss of transmission power based on the distance between the channel end points and two more parameters, commonly referred to as the A and B parameters in the Okumura Hata model. In addition, the path loss model accounts for the antenna gain of both the mobile devices and the base station. Spatially correlated shadow fading is provided for each site. The main parameters are the standard deviation of the shadow fading and the decorrelation distance of the random generation process. For the sake of computing time, all shadow fading values are pre-calculated, stored in large matrices, and loaded into the simulation environment. Fast fading is not modelled in this study since the coverage and capacity are evaluated on a much longer timescale. Two noise sources are considered in our simulations: thermal noise and receiver noise. Thermal noise depends on the bandwidth of the radio system, whereas receiver noise is relevant to the quality of the receiver. Table I summarises the simulation parameters and associated values used throughout the experiments of this study (unless otherwise explicitly stated).

TABLE I: SIMULATION PARAMETERS

Parameters	Values
Traffic Distribution	Uniform
Traffic Model	Full Buffer
Inter-Site Distance	500m
No of Sectors	3
Carrier Frequency	2 GHz
BS Antenna Azimut	0, 120, 240 degrees
BS Antenna Max Gain	15 dBi
BS Antenna Height	32 m
BS Transceiver Power	46 dBm
Channel Passloss A	128.1
Channel Passloss B	37.6
Shadow Fading Decorrelation Distance	50 m
Shadow Fading Standard Deviation	8 dB
Bandwidth	10 MHz
Thermal noise	-104 dBm @ 10 MHz
UE receiver noise	8 dB
User movement	Random Walk
User speed 3	km/h
UE's antenna gain	2 dBi
UE's antenna height	1.5 m

III. SELF-CONFIGURATION OFANTENNA BEAM TILTING

The proposed algorithm of this paper consists of two stages. In the first stage, a near-optimal tilt-angle value is rapidly found using a GSS method and then, in the second stage, the algorithm performs frequent explorations around the current tilt angle region in order to fine-tune the antenna's down-tilting. These explorations additionally enable a base-station to respond to the dynamics of the environment such as the failure of a neighbouring cell or the change of the users' distribution and quality of experience (e.g. due to deployment of new co-channel metrocell base-stations for coverage and capacity enhancement).

A. Fast GSS-based Tilt Angle Selection

GSS is a technique for finding the extremum of a unimodal function by successively narrowing the range of values inside which the extremum is known to exist. The technique derives its name from the fact that the algorithm maintains the function values for triples of points whose distances form a golden ratio. The algorithm provide a optimal reduction factor for the search interval that results in improved performance during the search process and also requires minimal number of function calls that implies fast convergence of the algorithm.

This paper considers the users' spectral efficiency as the measure of performance. Users' spectral efficiency can be derived from their Signal-to-Interference plus Noise Ratio (SINR) by applying the LTE coding schemes [12] and by measuring over a sufficiently long interval. The experienced SINR values are currently reported to the base-station frequently. Moreover, the studies show that the users on the cell boundary experience significantly poorer performance compared to the terminals in the cell interior. In acknowledgement of this reality, the specification for spectrum efficiency only requires that at least 95% of the terminals should be served at better than approximately 0.1 bps/Hz [13]. The system average, on the other hand, is expected to be 2-3 bps/Hz per user. Figure 1 shows an example where the average spectral efficiency of an LTE cell is illustrated against the base-station's down-tilt angle. The optimal tilt angle is around 15 º in this example.

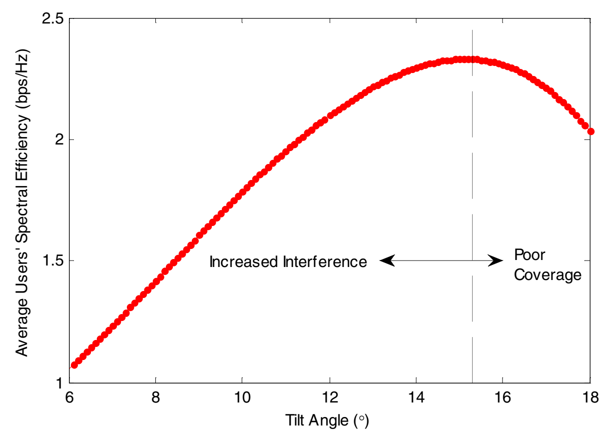

Figure 1: Average users' spectral efficiency versus base-station tilt angle

As is shown in Figure 1, aggressive down-tilting results in poor coverage and hence lower spectral efficiencies. On the contrary, a too low down-tilt angle increases the inter-cell interference. Similarly, Figure 2 shows the 5th percentile of the users' spectral efficiency that can be interpreted as the edge users' performance. As the figure shows, a similar trend to Figure 1 is observed here. However, the optimal angle is slightly lower in this case. The reason for this observation is that aggressive tilting results in coverage holes where the edge users are the main victims and hence slightly less tilting is favoured in this case. Compared to Figure 1, another interesting point is the abrupt drop of the edge users' performance when increasing the tilt angle above the optimal threshold. This is again due to the sensitivity of the edge users to the coverage holes as a result of increased down-tilting.

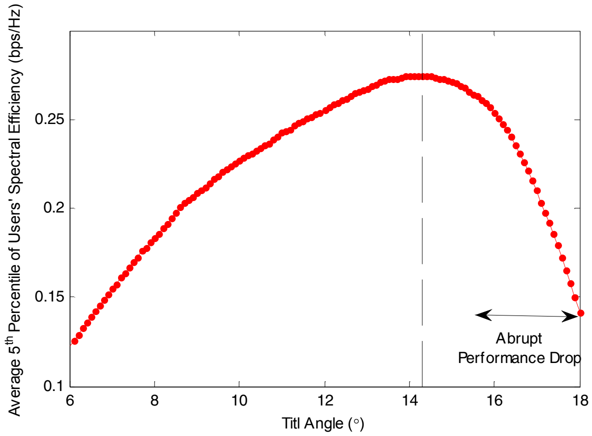

Figure 2: 5th percentile of users' spectral efficiency versus base-station tilt angle

The unimodal shape of the performance curves in Figure 1 and 2 suggests the applicability of GSS method for finding the optimal down-tilting. For a given down-tilt angle, θ, the average and 5th percentile of the spectral efficiency (denoted as $S_{ave}(\theta)$ and $S_{edge}(\theta)$ respectively) can be combined to form a fitness function, $F(\theta)$. In its simplest form, F can be a linear combination of the two metrics:

$$F(\theta) = S_{ave}(\theta)+\alpha.\ \ S_{edge}(\theta) \tag{1}$$

Where $\alpha>1$ *is* a weighting factor for edge users and it can be considered as a design parameter. Nevertheless, since the optimal down-tilt angle for edge users is relatively close to the corresponding value when all users are considered, the choice of α does not significantly affect the optimal tilt angle which maximises the fitness function in (1). Assuming tilt angle resolution of 0.1º, Figure 3 illustrates the optimal tilt angle for varying values of α.

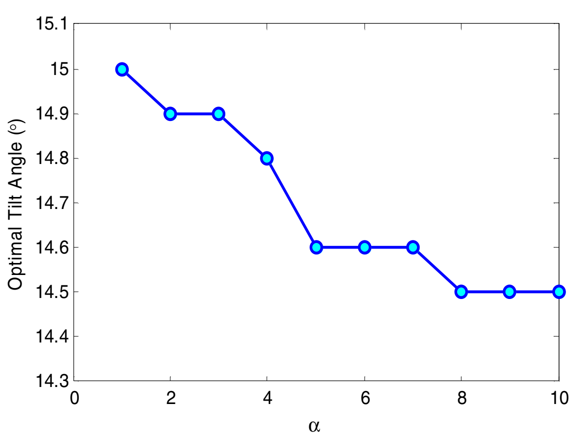

Figure 3: Optimal tilt angle for different α values

Using the GSS method, a search range consisting of an upper bound of the tilt angle (θ_u) and a lower bound (θ_l) is defined for which the optimal angle is known to be in that interval. Given the current tilt angle, θ_c, by using the GSS method the next angle to be evaluated, θ_x, is identified. The sector down-tilt angle will then be adjusted to θ_x and the corresponding fitness, $F(\theta_x)$, is evaluated. After this, a comparison is made and the upper or the lower bounds of the search space are adjusted. The update procedure in pseudo-codes is shown in Table II. The search procedure will be performed iteratively until the bracketing range is small enough ($\theta_u - \theta_l < \varepsilon$).

TABLE II: GSS BRACKETING SEARCH PROCEDURE

```
if θx > θc & F(θx) < F(θc)
        θu ← θx
else if θx > θc & F(θx) > F(θc)
        θl ← θc & θc ← θx
else if θx < θc & F(θx) < F(θc)
        θl ← θx
else if θx < θc & F(θx) > F(θc)
        θu ← θc & θc ← θx
end
```

B. *Fine tuning of down-titl angle*

The native GSS method assumes strictly unimodal function which is not normally the case in practice due to inaccuracy of measurements and more importantly uneven distribution of the users within the cell coverage area. Therefore, the down-tilt angle will be further fine tuned after the GSS search procedure. In fact, employing GSS method ensures fast convergence of the solution to a near optimal tilt angle value and then a more relaxed and fine tuned adjustment can be continuously applied to further optimise the tilt angle. As explained later, the fine-tuning stage additionally enables the solution to cope with the environment changes and to provide self-healing capabilities. During this phase, the base-station frequently alters the down-tilt angle of each sector in a small step (δ) and re-evaluates the fitness values. This exploration is performed in both ascending and descending directions in relation to the current angle θ_c (*i.e.* $F(\theta_c+\delta)$ and $F(\theta_c-\delta)$ are both subsequently evaluated). If a newly explored down-tilt angle performs better than the current choice, the base-station sticks to that. Nevertheless, in order to avoid unnecessary oscillations which can make the algorithm instable, the new down-tilt angle is not selected unless the fitness difference between the current and the new angle exceeds a certain threshold value, T.

During the study of this paper, δ was considered to be 0.2º (the same as the tilt-angle resolution) and α and T were set to 2 and 0.1 bps/Hz respectively. The length of evaluation iterations was set to 30sec. Additionally, θ_l and θ_u were considered to be 2º and 18º correspondingly. This is relatively a large search window that is used to show the self-configuration capabilities of the algorithm while in practice the operators can normally narrow this range to yield even faster convergence. Moreover, we consider a complex scenario in that all 21 sectors start with an initially random down-tilting angle θ_c ($\theta_l < \theta_c < \theta_u$) and continues to configure their down-tilt angle in a completely distributed manner. In this scenario the challenging fact is that the modification of one sector's tilt-angle will impact the measurements of users of its neighbouring sectors. Figure 4 shows the average fitness of all the sectors versus the total iteration index. To make the situation more complex, the order of tilt-angle update between different sectors was considered to be completely random and hence the accumulative iteration index showing the total of tilt-angle updating trials is illustrated. As shown, the overall fitness performance increases rapidly and starts to stabilise after a relatively few iterations. Starting from completely random down-tilt angle for all sectors, the performance is close to an acceptable region after nearly 85 iterations that means an average of approximately 4 iterations per sector. The small variations of the fitness after the steady state are due to regular explorations of the sectors to fine-tune the settings. Additionally the global optimal fitness is calculated (shown as the dashed red-line in the Figure) and compared against the proposed algorithm. As the Figure illustrates, the algorithm is capable of achieving 93.8% of the optimal performance on average.

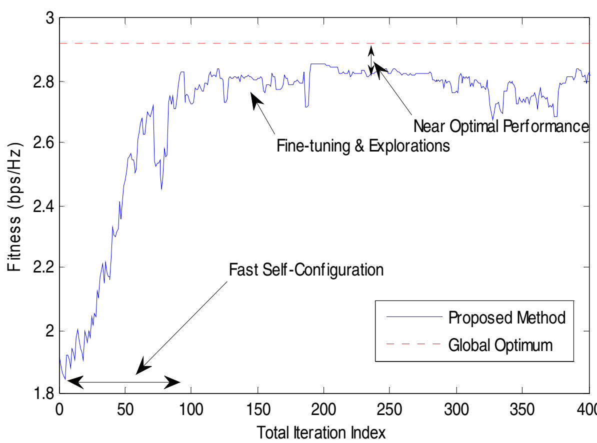

Figure 4: Average fitness versus total iteration index for 21 existing sectors

Due to the hexagonal layout of the base-stations and uniform distribution of the users, the sectors are expected to converge to nearly a same down-tilt angle. Figure 5 shows the variance and the mean of the down-tilt angle of all sectors.

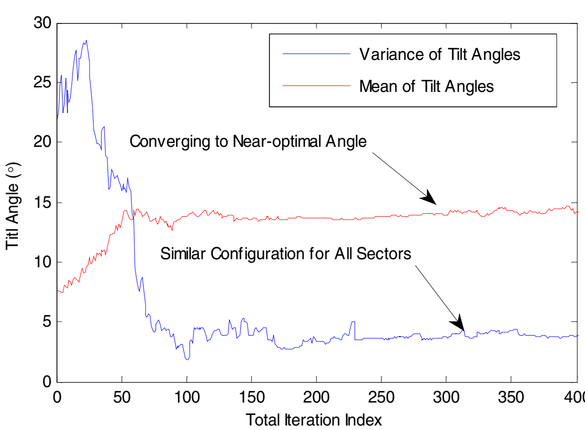

Figure 5: Variance and mean of down-tilt angle for all 21 existing sectors

As it can be verified from the figure, the variance of the tilt angles starts to decrease as the sectors continue adjusting their beam tilt. Additionally, the mean value is shown to be converging to a value between 14 ° to 15 ° that is close to the optimal setting (see Figure 3).

C. Self-healing and adaptation capablities

From the operators' perspective, it is essential to be able to maintain the availability of network services in case of partial failure in some part of the network. The frequent exploration mechanism described in the previous section can additionally provide self-healing capabilities. If a sector (base-station) fails, the expected behaviour from the neighbouring sectors with respect to their tilt-angle configuration is for them to relax their beam tilting in order to serve the users of the malfunctioning sector(s). Upon the failure of a sector, the users start to camp to neighbouring sectors (normally to sector with strongest detected pilot signal). Nevertheless, since the beam tilting of the neighbouring sectors is not optimised to serve these users, they will experience poor performance and increased drop call rates in many scenarios. However, during the explorations, when the sector slightly changes its tilting angle, some modest improved performance will be observed. This can be continued until new optimal configuration is found.

To avoid unnecessary tilt angle oscillations (that can propagate from one sector to another), the frequency of the exploration events are not very high and δ is normally set to small values. This implies that a recovery process that relies on explorations of new tilt angle value could be very lengthy. One way to address this issue is to adapt the interval between the consecutive explorations, T_e, according to dynamics of the environment. Desirably, T_e should be large during the normal operation regime but to be shrunk when an environment change is detected (e.g. failure of a neighbouring cell). This will allow prompt response and fast adaptation of the algorithm. Generally, in cellular networks there are symptoms through which a neighbour failure can be detected (e.g. abrupt increase of cell re-selection requests). While these signs can be used to further optimise the recovery process and the response time of the algorithm, here we merely rely on observation of the changes in the spectral efficiency reports.

More specifically speaking, a method based on the additive increase/multiplicative-decrease (AIMD) algorithm is used to adjust T_e. That is to increase T_e in fixed step sizes, Δ, when an exploration trial is not successful (i.e. the sector sticks to its current choice of beam angle instead of choosing a recently tested down-tilt angle) and to decrease it more aggressively by dividing T_e against a constant λ (λ>1) when the exploration trial results in improved performance. Additionally, a lower and an upper bound for T_e (T_{min} and T_{max} respectively) are applied.

$$T_e \leftarrow Max(T_e/\lambda, T_{min}) \quad \text{If exploration is successful}$$
$$T_e \leftarrow Min(T_e+\Delta, T_{max}) \quad \text{If exploration is unsuccessful} \quad (2)$$

During the simulations, Δ is set to 10s and λ is considered to be 1.5. T_{min} and T_{max} are set to 30s and 300s respectively. Figure 6 shows average fitness versus the total iteration index for all 21 sectors when the central site (all three sectors of the site) is suddenly disabled after 300 iterations. Similar to Figure 4, starting from randomly initialised down-tilt angles, the overall fitness quickly converge to a near optimal quantity after the algorithm started. The failure of the central site results in a sudden drop of the overall fitness. Using the self-healing capabilities of the algorithm, the failure is partially recovered through collaboration of the neighbouring sites. Note that the total iteration index refers to the update interval of all sectors while only adjustment of the central site's neighbouring sectors can contribute to the failure recovery.

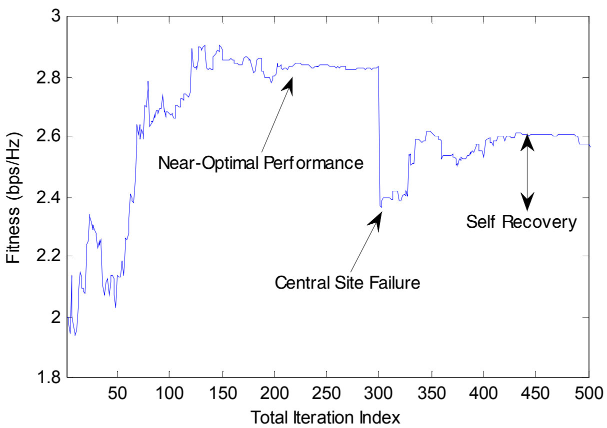

Figure 6: Self-healing capabilities of the proposed algorithm when there is a site failure after 300 Iterations

The fine-tuning and exploration of new down-tilt angle quantities does not only provide self-healing capabilities, but in a more general sense, it enables the base-stations to adapt to a wider range of network dynamics. One of the emerging trends in cellular networks is the deployment of small cell base-stations such as the outdoor metrocells. Small cells are now envisioned as effective solutions that provide improved coverage and more importantly capacity enhancement through efficient spatial reuse of resources. Considering different small cells' deployment scenarios, the shared channel mode in that small cells and existing macrocellular network use the same frequency spectrum is more efficient. However, effective co-channel deployment of small cells requires more careful management of the network or otherwise performance will be compromised due to issues such as increased interference and coverage holes [14]. Since deployment of small cells is more ad-hoc and incremental over the time (e.g. when new hotspots are formed), autonomous functionality of the macrocellular tier to appropriately respond to the changes of the network as a result of new deployments are desirable. Regarding the beam angle, it should be note that the tilt angle of a macrocell base-station has a significant impact on the coverage and capacity of the underlying small cells base-stations that are deployed within the coverage area of the own and neighbouring cells. Using the described algorithm, a macrocell base-station observes a change in the distribution of its users when a new small cell is deployed within the coverage range of the cells. If co-channel deployment is assumed, there will be a further change in the reported users' spectral efficiency values.

IV. Conclusion

This paper presents a method based on the Golden Section Search (GSS) algorithm for configuration of LTE base-stations' down-tilt angle. The proposed method consists of two phases. During the first phase, which is normally performed rapidly, a near optimal down-tilt angle is obtained. During the second phase, however, a more relaxed fine-tuning of the angle is archived via regular exploration of down-tilt angle in small steps. Such explorations enable the algorithm to respond to the dynamics of the network such as the failure of a neighbouring cell. The fitness measure used in this study is based on users' spectral efficiency with a weighting for edge users who normally experience worse performance compared to cell interior users. The overall solution is fully distributed and is 3GPP compliant.

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