Antenna Based Self Optimizing Networks for Coverage and Capacity Optimization

Abstract

Antenna tilt is a powerful parameter for optimization of a cellular network as it has the most direct impact on shaping the best-server boundary of a cell and hence on the coverage and interference parameters of the network. With the advent of Remote Electrical Tilt (RET) antennas, tilt optimization lends itself well to antenna based Self Optimizing Networks (SON). In conjunction with automatic monitoring of the cellular network through the Operations Support Systems (OSS), RET mechanisms enable an antenna based SON that is autonomous, continuous and closed-loop, delivering capital and operational expenditure savings to wireless network operators.

In this paper, we first explore the coverage shaping and interference impacting properties of antenna tilt settings. Then we use these properties to set up load balancing and interference reduction algorithms that are iterative based on network reactions to tilt changes and use proven Simulated Annealing principles to converge these algorithms to optimal coverage and capacity solutions. Finally, we present a network architecture for implementation of these processes that draw Key Performance Indicators (KPIs) and call trace measurements from OSS and network probes respectively and use antenna management systems to push tilt changes to the RET controllers, creating fully automated and intelligent SON systems.
1. Introduction

Coverage and Capacity Optimization (CCO) has received a lot of attention in standards bodies and in development of SON techniques. Due to the complexity and expense of optimizing network coverage and capacity manually, particularly as network operations and performance management for data networks such as LTE get cumbersome, CCO is a good candidate for automated processing. There are a number of reasons why CCO requires frequent attention by RF optimization teams; primary among them is constantly shifting traffic patterns as users are added to the networks and cell sites are added to the network to serve these users. In addition, changing seasons, changes in the physical environment such as new buildings and roadways, and changing service usage exacerbate the need for constant and frequent optimization. There are also more granular considerations for CCO such as difference in the coverage and capacity requirements between busy hours and quiet periods of the day. These considerations require more frequent changes in the network, e.g. multiple times a day to address commuting patterns and varying user concentrations, and are quite complex as they require learning and pattern recognition algorithms. In this paper we will limit our discussion to optimization processes required for gradually varying changes in the environment that require reaction to changes averaged over longer intervals of time and significant enough to impact long term network performance. We focus on antenna based CCO, since coverage and capacity is best optimized by RF parameters controlling coverage and interference. Antenna parameters such as tilt have a high direct correlation with RF performance characteristics while other parameters such as handoff thresholds virtually control coverage without actually changing cell boundaries.

As the term CCO implies, there are two main objectives of this optimization: to maximize coverage while getting the most capacity in the network. In terms of network parameters, this amounts to shaping the coverage so that the users are optimally distributed between the cell sites that serve them and maximizing the signal quality or Carrier-to-Interference Ratio (C/I) in each of the cells. These objectives motivate two corresponding processes: load balancing and interference reduction. These processes require the cell service boundaries and cell signal strength reach to be managed in a way that the two objectives – that the maximum number of users be served with the highest quality of signal – be achieved simultaneously and complementarily. As antenna tilts are the most effective settings in the network to affect both coverage and signal quality in the network, this parameter is investigated to provide the means for CCO through tilt based load balancing and interference reduction.

A network optimization process requires performance indicators to form the basis of change in the network with an aim towards improving those metrics. These performance indicators may be obtained through orchestrated campaigns such as drive test measurements and special purpose probes or may be

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1 It should be noted that the term load balancing is not used in the mobility sense where Automatic Neighbor Relations (ANR) process and Handover parameters are used to balance load between cell sites on a rapidly varying, often real-time, basis. Consistent with the previous paragraph, load balancing in this paper refers to a CCO technique in which users are shifted between cells based on actual and infrequent changes to coverage in reaction to long term performance averages.
gathered through the normal operations-based network measurements and standards-based call traces. Drive tests and dedicated probes are a necessary and integral part of pre-launch and early stage optimization when there is very little traffic on the network. In mature networks, where timely and frequent optimization is crucial in achieving optimal performance, KPIs and call trace parameters such as handover relationships and interference matrices may be collected seamlessly and continuously through the OSS and other Radio Access Network (RAN) elements such as the Radio Network Controller (RNC) in UMTS or Mobility Management Entity (MME) in LTE. CCO algorithms such as load balancing and interference reduction may use these KPIs and call trace parameters to identify critical cells, or cells that have congestion or interference issues as identified by a set of parameter values crossing preset thresholds. Subsequently, these algorithms can set up critical zones around these problematic cells, typically consisting of two tiers of radio neighbors, which are monitored for performance as well as forms the set of sites that are candidates for changes in parameters to achieve the optimization objectives. Iterative and closed-loop algorithms can then be set up to take in performance and metric changes in the network and calculate parameter changes to the network to find the optimal solution to an explicit congestion or interference problem as identified by the monitored parameters.

The attribute “Self” in Self Optimizing Networks (SON) warrants that the process is both automated in collecting the data required to identify problems and finding solutions as well as automatically outputting parameter changes to the network elements that form the solution. In this paper, we present algorithms and architecture for load balancing and interference reduction CCO processes that use continuous inputs from the network and use antenna tilt settings automatically delivered through RET controllers to achieve CCO characterized by continuous monitoring of the network, autonomous identification of congestion and interference problems, intelligent policy-based solution of the problem and automatic delivery of tilt changes to the network to form a closed-loop centralized SON solution.

2. Antenna Tilt as a Coverage and Capacity Optimization Parameter

Antenna tilt as a tool for CCO has been widely studied in the radio engineering literature [1]-[10].

Hampel et al. [1] and Garcia-Lozana et al. [2] have found that fixing antenna downtilt angle is the best solution in terms of interference and load distribution when the user distribution or traffic is uniform and equal path loss conditions apply across the network. However, when the user distribution is non-uniform and terrain renders varied signal propagation across the network, intelligent tilt adjustment can improve both coverage and capacity in cellular networks. This deduction can be intuitively predicted since unbalanced traffic conditions can lead to some cells being congested while others are left with spare capacity. Also, terrain variations, network configuration changes and seasonal changes (particularly appearance and diminishment of foliage as seasons change) can cause some cells to inject more interference into other cells than in ideal uniform cell size and uniform propagation conditions.

Pettersen et al. [3] confirm that adjusting antenna tilt angles to adapt to current geographical load distribution gives capacity gains in UMTS networks and show that the amount of capacity gain is proportion to the imbalance in the load distribution across the network.
Türke et al. [4] and Siomina et al. [5] extend the analysis to include antenna azimuth angle and pilot/common channel power in addition to antenna tilt angle for optimizing network capacity, the former more for the purpose of designing cellular networks. Both studies find that tilt adjustment is the most significant of the three parameters in impacting dynamic network optimization and in conjunction with pilot power shows exceptional performance gains.

Gunnarsson et al. [6] discuss the cell isolation effects of tilt optimization and emphasize the need for accurate tilt consideration in network performance simulation and design.


Athley et al. [8], Luketić et al. [9], and Sallen, et al. [10] all discuss the use and impact of antenna tilt on CCO for LTE networks with different emphasis such as respectively the difference between electrical and mechanical tilt on system capacity, architecture and performance of a tilt based Self-Organizing Network for LTE, and an architecture for closed-loop SON for LTE using radio and configuration parameters from the network including antenna tilts.

The premise for antenna tilt being the most effective CCO parameter is that the tilt has the most pronounced effect on the antenna pattern as seen by the mobile devices and hence on the reach, intensity and quality of the radio signal from the antenna.

![Image of impact of antenna tilt on coverage and interference](image)

**Figure 1**
**Impact of Antenna Tilt on Coverage and Interference**
As shown in Figure 1, the change in antenna pattern as a result of a change in vertical tilt has two profound effects on the network – a change in coverage of the cell and a change in the interference the cell causes to users in other cells. These two changes can then be used for two corresponding controlled effects in the network.

First, a downtilt-uptilt operation in neighboring cell antennas will cause the best-server coverage boundaries between the two cells to shift, and therefore offload users from the shrinking cell to the expanding cell. This is the basis of the tilt-optimized load balancing.

Second, an identified interferer to users in neighboring cells can have its antenna downtilted to reduce interference and improve C/I in those cells.

Both of these characteristics are CCO steps: load balancing optimizes coverage between cells while optimizing resource usage by uniformly distributing traffic, and hence increasing the overall capacity of the network; interference reduction increases overall C/I in the network, thereby accommodating more users in the cell or increasing throughput while also increasing the interference limited coverage of those cell where the interference is being reduced. By the same token, load balancing and interference reduction processes affect each other and care should be taken to jointly optimize the two to avoid detrimental effect of one on the other.

![Simulation of Effect of Tilt Change on Coverage and Interference](image)

**Figure 2**
Simulation of Effect of Tilt Change on Coverage and Interference
A graphical depiction of the effect of tilt change on coverage and interference is shown in Figure 2 using a heat map with signal strength decreasing from red to yellow to green areas. As Site 87 is up-tilted from 2 degrees to 0 degrees, its coverage area increases while its interference into Site 190 also increases, causing the areas of good C/I in Site 190’s coverage to decrease as shown by the shrinking red areas.

3. Antenna Tilt Optimization for Load Balancing and Interference Reduction

We have previously introduced the concept of tilt-based load balancing and interference reduction processes [11, [12]. In this section we elaborate the algorithms for these optimization processes describing:

- the inputs used for problem identification and critical cells,
- the process for setting up critical zones,
- the running of the iterative closed-loop algorithm,
- the justification for the frequency of iteration, and
- safeguards against coverage holes in the optimization steps.

3.1 Problem Identification and Critical Cells/Zones

The CCO has two goals:

(1) to identify and resolve load balancing issues exemplified by congestion in parts of the network accompanied by low resource usage in the neighborhood of congested sites, and

(2) to identify strong interferers and reduce their interference into victim cells through interference reduction algorithms.

Examples of configuration parameters, KPIs, and call traces that are used in identification and solution of the problems and their significance are given in Table 1 below. Collectively, these parameters identify both load balancing and Interference issues in the network, the location of these issues, and the candidate cells that can be a part of the optimization solution that the algorithms deliver. This happens when a set of these parameters cross a corresponding set of thresholds indicating that a CCO issue has been identified. The thresholds are usually set by the operator conducting the optimization and the level of these threshold settings suggest how often the optimization algorithms will be triggered vs. the tolerance to network performance degradation before action is taken to trigger the algorithm. This tradeoff is also related to hysteresis and ping-pong effects in network parameter settings, and since tilt is typically a parameter requiring longer interval averaging to determine optimal values these thresholds should be carefully determined.
Once the critical cells are identified, a Critical Zone is defined, consisting of the critical cells, tier 1 neighbors (neighbors of the critical cells), and tier 2 neighbors (neighbors of neighbors of the critical cell). The Critical Zone thus created consists of cells that are candidates for antenna tilt changes as part of the optimization process, and constitutes the area monitored for performance as the iterative algorithm makes changes, contains any effect that propagates as the CCO algorithm is executed. Figure 3 depicts a Critical Zone created around a critical cell.
3.2 Iterative Closed-Loop Algorithm

Once the load balancing or interference reduction need has been triggered and the Critical Zone has been identified, the iterative algorithm begins. This entire process is shown in Figure 4, with the problem identification and Critical Zone detection triggering the relevant CCO algorithm that runs iteratively until a satisfactory solution is found and the algorithm returns to performance monitoring mode. These processes mirror manual engineering best practices commonly used in industry.

Multiple algorithms in non-overlapping zones can run simultaneously addressing independent problems. Each algorithm in a Critical Zone follows the process shown on the right in Figure 4.

At the start, a single small\(^2\) tilt change is made to the antenna that according to the problem being solved and the inputs shown in Table 1 would have the most impact on optimizing the Critical Cell and Critical Zone.

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\(^2\) What constitutes a small tilt change and what is the period of observation between tilt changes will be discussed in Section 3.3
The tilt change is followed by a period of observation of the KPIs and call traces to study the impact of the change and keep evaluating the performance of the Critical Zone. At the end of the observation period, the change in the performance of the critical calls and the Critical Zone is evaluated particularly with respect to the performance indicators that identified the optimization problem and triggered the algorithm. If the performance has improved with respect to these KPIs, another small tilt change is made to the antenna which, according to the performance indicators gathered during the observation period since the last tilt change, would have the most impact on optimizing the Critical Cell and Critical Zone. This process of iterative tilt changes is repeated until an antenna tilt change results in performance degradation as indicated by the performance indicators gathered since the last tilt change.

In the event of performance degradation, a decision is made whether to accept the degradation or not. If the degradation occurs in the early iterations of the process and the performance of the Critical Zone is below a certain threshold, then the degradation is accepted and another tilt change is made in the Critical Zone according to the process defined above. This allows the optimization process to come out of local optimal solutions and drive towards a global solution. Conversely, if the degradation happens late in the optimization cycle and the performance of the network is above a defined threshold, then the last tilt change is reverted back, the algorithm stops for this particular CCO problem and Critical Zone and goes back to the performance monitoring mode.

It should be noted that the number of iterations of the algorithm, and hence the number of tilt changes made in the Critical Zone, is a measure of the severity of the load balancing or interference reduction problem being resolved and the threshold of acceptable performance. For examples, simulations of load balancing and interference algorithms show 12 and 6 tilt changes respectively before the problems are resolved.
The degradation acceptance step of probabilistically accepting performance degradation uses a “biased” coin toss, where the chance of accepting is higher in early iterations when the performance is low, and lower in later iterations when the performance is high, is borrowed from the well-known combinatorial optimization technique known as Simulated Annealing. This technique is drawn from the metallurgical annealing process and is aimed at avoiding local maxima or minima objectives of a cost function and helps drive to solution towards a global optimal. Simulated Annealing has been used for tilt optimization in a number of studies and simulations e.g. [2], [4], [5] and [7].

3.3 Frequency and Amount of Tilt Changes

As stated in the introduction, this paper is focused on developing intelligent rules-based CCO techniques. These optimization techniques are typically used to resolve performance issues represented by indicators and parameters averaged over long periods such as one day. Hence, changes to the network resulting from these techniques are made with a frequency consistent with the duration over which the performance parameters are averaged.
One of the most natural cycles of traffic pattern repetition, which is also the shortest end-to-end repeatable one, is the daily cycle. While there are variations in traffic patterns and performance cycles between different weekdays, making one tilt change per day and observing the performance of the network for the 24 hours is consistent with the CCO objective of using longer term averages, is suitable for a process such as tilt optimization which does not react well to non-predictable events, and hence is well suited for the algorithm of section 3.2.

The algorithm also calls for making just one tilt change in every iteration. This is also related to how the algorithm - to make tilt changes and observe the effect of that change in the performance of the cluster. By making only one change in every iteration, it is straightforward to attribute any changes in the cluster to that single change. This also helps to drive the algorithm in small steps towards the optimal tilt settings.

Another feature of the algorithm is to make small tilt changes in every step. This implies sub-1 degree changes, typically in the order of 0.5 degree. The reason for this too is the nature of the algorithm and its search for the optimal tilt settings. Larger tilt changes may make drastic changes in the network and miss the settings that lead to optimal performance. In addition, the process also aims to avoid coverage hole creation, and small tilt changes help in that safeguard as explained in the next section.

### 3.4 Coverage Hole and Interference Safeguard

When making tilt changes in an active network without off-line prediction-based verification of coverage effects, there is a concern that up-tilting of certain antennas may cause increased interference in the network and down-tilting may cause coverage holes due or compromise coverage.

The interference concern is addressed by requiring that any run of the load balancing algorithm be followed by an interference check in the same Critical Zone. This interference check calls for an Interference Matrix defined in Table 1 to be set up and examined. If issues are found with interference in the network caused by recent changes due to the load balancing process, then an interference reduction algorithm (Figure 4) should be executed. Alternatively, an algorithm that jointly accomplishes load balancing and interference reduction goals can be run. However such algorithms are complex and require arbitration and coordination between the two objectives.

There is limited risk that the attributes of the proposed tilt optimization process will generate a coverage hole in the network. This fact is based on the presumption that the network is a coverage optimized network with sufficient overlaps in coverage areas between cells. Further, in a coverage optimized network small increases in downtilt sometimes accompanied by uptilt in neighboring cells for load balancing are not likely to compromise coverage. Moreover, in the presented algorithm, a single small tilt change is followed by a significant interval of performance observation. Compromised coverage will reflect in the performance metrics, such as high drop rate not accompanied by a high handover failure, and a revert mechanism can be instated when spikes of such events are seen after a tilt change.
4. Architecture for Antenna based Centralized SON

The antenna based CCO techniques presented in this paper can be readily adopted for a SON implementation with three considerations determining the ideal architecture:

(i) The optimization process presented creates a Critical Zone, which includes the critical cells and the area around it, which are also monitored for performance antenna tilt changes made to a site affects cells around it. This process requires monitoring a wide area of the network to find CCO issues and monitor for effects of changes – a process well suited to a Centralized SON architecture.

(ii) SON function requires continuous and autonomous data gathering from the network, an attribute consistent with the Minimization of Drive Test (MDT) principle in 3GPP SON use cases. Hence for a truly SON implementation of antenna based CCO, the architecture must include data gathered automatically from network monitoring and call traces.

(iii) To close the loop with automatic push of tilt changes to RET controllers, the architecture should include a mechanism to incorporate AISG-based commands for tilt changes to RET actuators.

A closed-loop architecture for SON implementation of antenna based CCO is shown in Figure 5.

![Figure 5](#)

Centralized SON Implementation of antenna based CCO
5. Simulation Results

5.1 Load Balancing

A simulation of the Load Balancing algorithm was conducted for a Critical Zone consisting of 70 cells around two critical cells showing congestion over two distinct busy hours. The optimization criterion was a service weighted throughput for the Critical Zone.

As shown in Figure 6, the Load Balancing algorithm is triggered on Day 1 with KPIs indicating congestion in two sites during two critical hours. The algorithm follows the process outlined in section 3.2 with one 0.5 degree antenna tilt change per day. As various antennas are uptilted and downtilted in succession, traffic is more evenly distributed across the critical zone and the overall zone throughput trends upwards. Motivated by the Simulated Annealing process, small degradations are accepted in early iterations when the performance is below a threshold to avoid local optimal solutions. The tilt change on day 13 results in severe degradation of the zone throughput for one of the critical hours, down from a good performance on day 12. Hence day 12 tilt settings are accepted as the solution for this particular problem and the algorithm terminates. This optimization run results in overall zone throughput improvement of 10% for the critical hours.

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**Figure 6**
Improvement in Aggregate Zone Throughput in Load Balancing Iterations
During the optimization iterations over the 13 days, while the optimization criterion was maximization of zone throughput, the Call Success Rate for the congested cells also showed consistent and logical trends. Figure 7 shows a stable trend in the overall zone Call Success Rate.

![Call Success Rate - 24 hr. Metric Trends](image)

**Figure 7**
*Call Success Rate for Congested Cells and Zone during Load Balance Cycle*

The improvement summary for this Load Balancing simulation is as follows:

- Up to 10% improvement (zone – critical hour) observed in the overall Throughput
- Up to 6% improvement (initial congested cells – critical hour) observed in Call Success Rate
- Up to 3 percentage points improvement (zone – critical hour) observed in the Call Success Rate

### 5.2 Interference Reduction

A simulation of the Interference Reduction algorithm was conducted for the top interferer in the Critical Zone causing increased call drop and low throughput in the zone. The optimization criterion was a weighted metric between Call Success Rate and Zone Throughput.

As shown in Figure 8, the Interference Reduction algorithm was triggered on Day 1 with KPIs of low Call Success Rate and throughput indicating strong interference and a victim cell. The Interference Reduction algorithm iterations show a trend of improvement until Day 6 after which it shows a sharp decline.
following a high value for the Call Success Rate. Consistent with the principle of Simulated Annealing, the settings would be reverted to day 6 values, which would be accepted as the solution for this particular interference problem.

![Call Success Rate – Trends](image)

**Figure 8**

*Improvement in Call Success Rate over Interference Reduction Iterations*

Since Zone Throughput was also a criterion for optimization, it is expected that the interference reduction iterations would show improved trends in this metric as well. As shown in Figure 9, Zone Throughput improves consistent with Call Success Rate improvement over the 6 days of algorithm iterations. It is observed that the throughput of the interfered cell shows trends of improvement beyond the termination of the algorithm on the 7th day. However, the performance criterion is the zone throughput which shows a different trend.
The improvement summary for this Interference Reduction simulation is as follows:

- Up to 11% improvement (zone) observed in the overall Throughput for interfered cells
- Up to 4 dB improvement in C/I (C: Best server, I: Worst Interferer)
- Up to 0.5 percentage points improvement observed in Call Success Rate for interfered cells
References


http://www.reverbnetworks.com/content/benefits-antenna-tilt-based-son