On The Potential of Traffic Driven Tilt Optimization in LTE-A Networks

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***Abstract*—Performance and efficiency of a cellular network can be enhanced by properly adjusting the antenna tilt setting. Antenna tilt is one of the most important radio parameters that determines the service coverage boundary and level of inter-cell-interference in cellular systems. Moreover, tilt tuning is an effective technique in radio network optimization to effect a better load balance among cells for efficient utilization of spare radio resources. The variability of user traffic distribution makes it more challenging to operators to ensure the required service capacity and quality with acceptable capital and operational expenditures. Active Antenna System (AAS) features promise the ability to flexibly handle system capacity by adapting the orientation of the antenna beam. In this paper, the potential performance gains of tilt optimization for differently placed user traffic concentrations are investigated. Simulation results show that users at traffic hot spot areas suffering from resource sharing can achieve significant performance gains from traffic oriented tilt optimization.**

***Index Terms*—Tilt Optimization, Active Antenna Systems,**

I. Introduction

Traffic in mobile networks is not only increasing tremendously but is also rather dynamic so that high traffic peaks occur at different times of the day depending in different areas. Due to the unpredictability of user traffic patterns, operators are required to dimension the cellular network on worst case busy hour traffic statistics leading to over dimensioning and high network costs. In case of coverage or capacity issues, network parameters are then further tuned through optimization to deliver a better service quality and handle capacity demand. Antenna tilt is one of the most important system parameters in coverage and capacity optimization (CCO) as tilt determines the service coverage boundary and level of inter-cell interference in the system [1] [2]. CCO makes use of adjusting base station's radio controlling parameters like antenna tilt to perform corrective action to mitigate coverage hole and coverage over-lap problems [2] [3]. [4] shows for Universal Mobile Telecommunications System (UMTS) that in geographically unbalanced user load distribution situations, adjusting antenna tilt brings a capacity gain by creating a better load balance in the network.

Introducing additional small cells is commonly seen as a solution to cope with areas of users traffic concentration, but the dynamics in time and location requires a large number of small cells. Active Antenna System features are promising to enable flexibility in antenna beam orientation via adaptive beam-forming technology [5] paving the way for flexible traffic oriented deployment adaptation.

In this paper, potential performance gains of tilt optimization adapting to various user traffic distribution are investigated for 3rd Generation Partnership Project (3GPP) defined urban propagation environment. Simulations have been carried out by creating hot spot traffic situations at different locations in the network and adapting the tilt of base station antennas operating around the hot spot area to improve user throughput for those suffering from the high traffic concentration and to enhance overall system performance. Presence of high hot spot traffic load degrades user throughput due to resource competition in the congested cell. Using tilt optimization techniques, the deployment is adapted to enhance the signal to interference and noise ratio (SINR) of those users. Based on optimization results, evaluation is carried out by comparing the system performances at optimized tilt setting and at default tilt setting. The study aims at showing the potential gain that can be achieved from tilt adaptation based on the traffic situation in a network.

This paper is organized as follows. Section II briefly describes the system model and assumptions used. Optimization results are presented and performance evaluation is explained in detail along with a description of the optimization techniques used in Section III. Finally, the work is concluded in Section IV.

II. System Model

In this section, the Long Term Evolution-Advanced (LTE-A) system model utilized for simulation investigation purpose is described. The user traffic model adopted to create and simulate different user traffic distributions is explained in detail. Later on, the radio resource sharing scheme and antenna radiation pattern model used are presented.

A. LTE Network and System Parameters

An LTE network consisting of 19 tri-sectored sites, i.e. 57 cells, is considered in a MATLAB based system level simulator. In the simulation, an LTE down-link operating at 2GHz carrier frequency and with a 10 MHz system bandwidth

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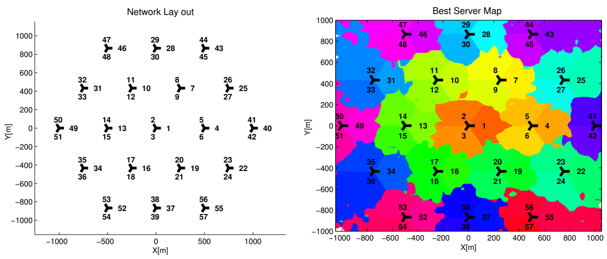

Fig. 1. Network Layout and Best Server Map Plot

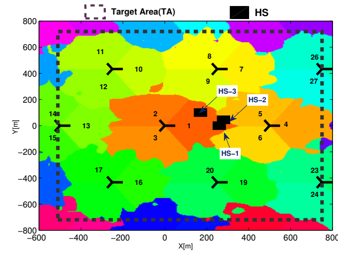

Fig. 2. HS Locations and Evaluation Target Area (TA)

with a total of 50 Physical Resource Blocks (PRBs) is assumed. Macro cell propagation parameter settings are adopted as defined by 3GPP in [6]. Thus, path loss offset and exponent are set to 128.1 and 3.76 respectively, and additional 20 dB penetration loss is considered. A shadow map of 8 dB standard deviation with a decorrelation distance of 50 m is applied. Fast fading effects are not included here as their effect will average out in long term. 3GPP defined urban scenario is assumed where the Inter Site Distance (ISD) is 500 m. Due to the short ISD, the system performance is determined by interference rather than by coverage problems. As a consequence, a change in the antenna tilt setting is predominately changing the interference situation in the coverage area and surroundings. A height of 30 m and 1.5 m above the ground is taken for the base station and user equipment (UE), respectively. Figure 1 shows the LTE network layout and the corresponding best server map plot for a uniform user traffic distribution where the antenna tilt setting for all base station antennas is set to 15°.

B. User Traffic Model

The user traffic is modeled in a pixel based approach where a pixel is defined as a potential location of UEs [7]. Accordingly, the network area is divided into a pixel grid of 5 m resolution where a pixel has an area of $A_p = 25\text{m}^2$. A uniform user density per area of β is defined for all pixels and a relative user density ρ is used to create a non-uniform traffic distribution of ρ times more at a pixel, i.e., the total number of users per pixel u_p is $u_p = A_p \times \beta \times \rho$. For a network wide uniform user traffic distribution ρ is set to 1 for all pixels and as a result, $u_p = A_p \times \beta$. In such case, simulation results have shown that 15° is found to be the optimal network wide tilt setting that balances cell loads among sectors, maximizes system SINR as well as throughput (TP) performance. Throughout this paper, 15° is referred to as a default tilt setting. The serving sector of each pixel is determined based on the strength of the reference signal received power (RSRP) at each pixel. An RSRP threshold value of -119 dBm is defined and those pixels detecting RSRP less than this threshold are declared as a coverage hole. The value of β is configured to $110/[km^2]$ so that for a uniform traffic distribution and default tilt setting the average number of users per sector is assumed to 8. The achieved UE throughput (TP) is calculated from the SINR using Shannon's formula.

Traffic driven tilt adaptation is simulated by introducing user traffic Hot Spot (HS) situations in the network where a HS area will be characterized by having ρ times higher user density per pixel than other pixel locations in the network outside the HS. The size of the HS is defined as $60\times60\text{m}^2$. In this paper, two traffic densities are considered for the HS, ρ= 20 and ρ= 60. In order to investigate the performance of tilt adaptation for various traffic situations, three different HS locations are defined where two of the HSs, HS-1 and HS-3, are located completely inside the serving area of sector 1 as shown in Figure 2. The other HS, HS-2, is located at the adjacent border of sector 1 and sector 5, i.e. part of HS-2 is served by either sectors, where those cell borders are defined at default tilt setting.

C. Radio Resource Sharing

A resource fair scheduler is employed where the available radio resources are shared among users equally in every sector. Accordingly, the resource share R_i per UE in a serving sector i with M_i number of available PRBs and N_{p_i} number of pixels having relative density of ρ_j is given by:

$$R_i = \frac{M_i}{A_p \times \beta \times \sum_{j=1}^{N_{p_i}} \rho_j} \qquad (1)$$

D. Antenna Tilting and Radiation Pattern Model

The antenna gain for a specific user location in the network depends on the antenna radiation beam pattern, the beam orientation (azimuth and elevation) and relative coordinate of the user location with respect to the base station. In a tri-sectored site deployment, it is common to orient the antennas of each sector of a site 120° apart in azimuth plane. The elevation plane orientation, i.e. tilt, is adjusted as required because it determines the best-server boundary of a cell and controls inter-cell interference. The 3GPP defined radiation pattern model is employed to determine the antenna radiation beam pattern at any given tilt setting, Θ_t [6]. Thus, the total three dimensional radiation pattern for every pixel location having an angular position of ϕ and θ in azimuth and elevation plane, respectively, is calculated from the two dimensional, azimuth and elevation pattern. as follows.

$$B_H(\phi) = -\min\left\{A_m, 12 \cdot \left(\frac{\phi - \Phi_o}{\Phi_{3dB}}\right)^2\right\} \Rightarrow Azimuth$$
$$B_V(\theta) = -\min\left\{A_m, 12 \cdot \left(\frac{\theta - \Theta_t}{\Theta_{3dB}}\right)^2\right\} \Rightarrow Elevation \tag{2}$$

$$B_{3D}(\phi, \theta) = -\min\left\{A_m, -\left[B_H(\phi) + B_V(\theta)\right]\right\} \tag{3}$$

where A_m represents the antenna backward attenuation factor taken to be 25 dB. Φ_{3dB} and Θ_{3dB} are azimuth and elevation plane half power beam widths of the radiation beam, respectively, whose values are set to 70° and 10° whereas Φ_o is the azimuth orientation of each sector antenna at a base station site, i.e, 0°, 120°, 240°, and Θ_t represents the tilt.

III. Performance Evaluation

In this section, the optimization technique utilized for simulation and evaluation methodologies employed are described. Moreover, observed optimization results are analyzed and presented in detail for various HS traffic scenarios.

A. Optimization Technique and Evaluation Methodology

1) Optimization Technique: Taguchi's optimization method based on nearly orthogonal array (NOA) is applied to find the best tilt combination of n_T number of antennas found around the HS [8]. This technique iteratively checks a number of possible tilt combinations for different number of network settings called network trials to maximize a defined target optimization function. In the experiment, the range of tilt changes Θ_t is defined from 8° to 18° in steps of 1°, where the total search space of optimization will be 11^{n_T}. Taguchi's method makes use of NOA to select a subset of tilt combinations from the full search space for every network trial with refinement for each iteration. The performance and convergence of the NOA Taguchi method is proofed against an exhaustive search (brute-force) approach for three sectors' antenna optimization scenario where the full search space is 11^3. It has been observed that Taguchi's method performed well and its performance converged to the exhaustive search result by using a greatly reduced number of network trials, 324 network trials. A detailed explanation of the NOA Taguchi's method and its performance is presented in [8].

Investigation has been carried out by changing the traffic condition in the network by creating a HS situation and searching for the optimal tilt setting of the antennas of sector 1 and the first tier of neighbor sectors found around sector 1 as shown in Figure 2, i.e. n_T = 7, to handle the change in the traffic induced by the HS and to maximize capacity of the target UEs.

2) Evaluation Methodology: Different objectives can be defined for the optimization and evaluation of system performance. One option is to look at the HS UEs' throughput as a target and to define an optimization function based on the UE TP statistics. Apparently, since the tilt optimization involves the antennas of the 7 sectors, the optimization should also consider the performance of other UEs in those sectors and neighborhood as their performance is impacted. However, since a change in tilt shifts the boundary of the best-server cell every time, it makes it not feasible to rely on a sector based UE TP statistics. As a result, a large enough area called Target Area (TA) is defined in such a way that it includes the 7 sectors under optimization and areas being served by their neighbors as shown in Figure 2. The evaluation area, i.e. TA, is kept constant independent of tilt changes. Assuming the total number of pixels in the TA is $N_{p_{(TA)}}$ and in the HS $N_{p_{(HS)}}$, the fraction of HS UEs in the TA is:

$$UE_{frac} = \frac{N_{p_{(HS)}} \times \rho}{N_{p_{(TA)}} + (\rho - 1) \times N_{p_{(HS)}}} \tag{4}$$

Thus, for HS traffic of ρ equal to 20 and 60, UE_{frac} is 4.5% and 12.2% respectively. For each HS traffic situation, optimization is carried out with the objective of maximizing the UE TP performance by using UE TP statistics from the HS area only or from the complete TA. Hence, 5%-tile, 50%-tile, and average values of UE TP distribution are utilized as an optimization metric for both cases where the TP statistics is taken from the HS (HS oriented) and TA (TA oriented), i.e., in total 6 optimization metrics are used in each HS scenario.

B. Optimization Results

In this section, simulation results are presented and performance evaluation is done in order to assess the potential gain of tilt adaptation driven by a change in user traffic situations in the network. Simulation results are discussed for different HS scenarios. The adjusted tilt values for the 7 sectors (aka target sectors), sector :{#1, #2, #3, #5, #6, #9, and #20}, which are considered in the optimization are also shown.

1) HS-1 Scenario: In this scenario, the HS is located fully inside the service coverage of sector 1 close to the cell edge as shown in Figure 2. For ρ = 20 and with the default tilt setting, 56% of the sector traffic is from the HS area whose size is 6% of the sector coverage. The optimization has been carried out targeting at different metrics defined from both the HS and the evaluation TA shown in Figure 2. Accordingly, while using the 5%-tile of UE TP distribution as an optimization metric, a significant performance gain is achieved for HS UEs for both cases where the optimization metric is taken from the HS and complete TA UE TP statistics. This is illustrated in more detail in Figure 3 where the CDFs of UE TP statistics from the HS area are plotted. As can be seen from the figure, the HS UE TP is improved at all cdf percentiles by more than 100% and 40% when using the HS 5%-tile and TA 5%-tile UE TP, respectively, as an optimization metric. The achieved TP gain at the HS is attributed to the improvement in SINR performance gained via tilt adaptation of the sectors

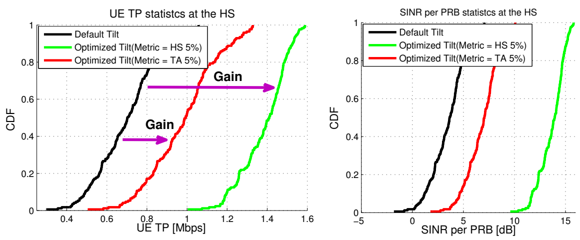

Fig. 3. UE TP Performance Inside HS

around the HS area which is performed by up-tilting (-) and down-tilting (+) the antennas of the target sectors from their default tilt setting, as seen in Figure 3. Hence, e.g. for the HS 5%-tile optimization metric, the applied tilt changes at the target sectors are: {-4°, -4°, -6°, +3°, +3°, +1°, and -1°} respectively. When the optimization is done in maximizing a target function defined from the TA, e.g. TA 5%-tile UE TP, marginal gain is observed at the TA because the HS has $\rho = 20$ and is relatively small and accounts only for 4.5% of the users in the TA, and therefore, only marginal gain is considered in the optimization process with the TA oriented metrics. Apart from 5%-tile UE TP, other optimization metrics have been applied, i.e. HS 50%, HS average, TA 50%, TA average UE TP. The performance is evaluated using the following performance indicators (PI): 5%, 50% and average UE TP for different group of UEs: UEs inside HS (HotSpot), UEs inside TA (TargetArea) and UEs inside TA excluding HS (TargetArea w/o HS). Figure 4 summarizes all results for all PIs and for different optimization metrics. In the figure, the upper performance bound shown for each PI represents the case where the same criterion is used as an optimization metric and PI, e.g. the 5%-tile TP performance at the HS when HS 5%-tile is used as optimization metric. As can be seen from the figure, a performance gain of 160% at the 5%-tile TP PI, and 96% gain at both the 50%-tile TP PI and average TP PI is achieved at the HS for all HS oriented optimization metrics. Significant gain is also found for the HS UE irrespective of the PIs when optimization is referring to complete TA using TA 5%-tile and TA average TP as optimization metrics. Interestingly, the TA 50% metric does not favor the HS as the TP of all UEs inside the HS is far below the 50%-tile TP value of the TA and therefore this metric does not consider the HS UEs. It is noticeable that the HS performance at all PIs for all HS oriented optimization metrics is almost identical. This is due to the fact that the HS size is small and the UE TP has almost the same performance for all metrics.

The performance at the TA (the middle column in Figure 4), however, is showing only moderate gain for all TA oriented optimization metrics with respect to all PIs. A minimal but acceptable performance loss can be observed at the TA for all PIs in case of HS oriented optimization metrics. This loss is a cost paid from those UEs in the TA outside the HS caused by a change in tilt setting in favor of the HS UE performance. The same investigation has been carried out for the HS-1 scenario but with 3 times higher ρ, i.e. $\rho = 60$, in order to evaluate the

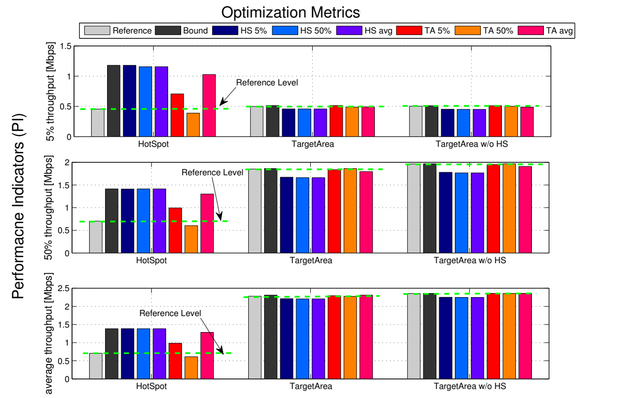

Fig. 4. UE TP Performance Comparison For Different PIs and Optimization Metrics [HS-1, $\rho = 20$]

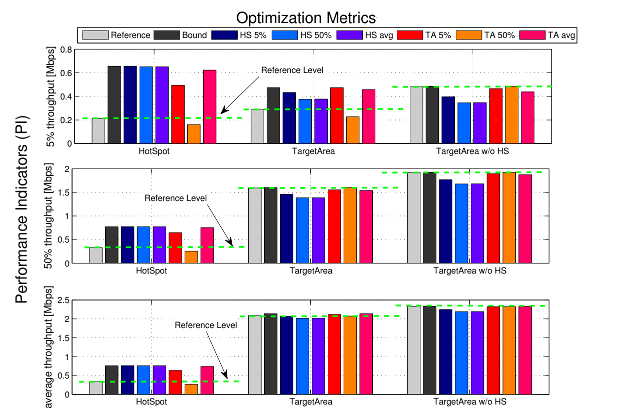

Fig. 5. UE TP Performance Comparison For Different PIs and Optimization Metrics [HS-1, $\rho = 60$]

impact if the user traffic density in the same HS location is increased further, Figure 5. In this case, with the default tilt setting, 80% of the sector 1 traffic is from the HS and the HS UEs account for 12.2% of the total UEs in the TA. With this HS traffic, the tilt optimization applied slightly different tilt adjustment to the sectors compared to the $\rho = 20$ case while using the same optimization target metrics. For example, for the HS 5%-tile optimization metric, the tilt changes applied at the target sectors on the default setting are: {-5°, -4°, -5°, +3°, +3°, +1°, and +1°} respectively. Due to the high user concentration in the HS, more than 200% gain at the 5% PI and more than 120% gain at both 50% PI and average TP PI is achieved at the HS with a cost of around 10% performance drop for the UEs in the TA outside the HS while utilizing HS oriented optimization metrics. A significant performance gain is observed at the TA for 5% PI for all optimization metrics, and moderate gain at the other PIs for the TA oriented optimization metrics.

2) HS-2 Scenario: In this scenario, the size of the HS and traffic is the same but placed on the boundary of two sectors, sector 1 and 5, as shown in Figure 2. It should be remembered

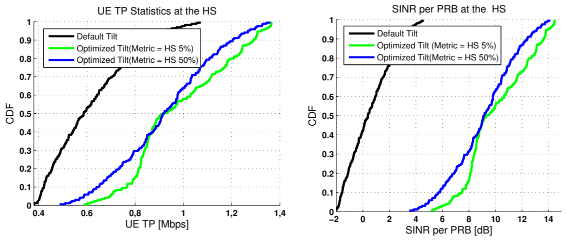

Fig. 6. UE TP and SINR Performance at the HS [HS-2, ρ = 20]

that the sector boundary is assumed with the default tilt setting before applying optimization. Due to its position, the HS traffic load is handled by both sector 1 and sector 5. For ρ = 20, tilt optimization has been applied utilizing both HS and TA oriented optimization metrics. Unlike to the previous HS scenario, the HS serving sectors at default tilt setting, i.e. sector 1 and sector 5, change their tilts in different direction depending on the optimization metric even for the HS oriented case. Accordingly, for the HS 5%-tile optimization metric, the tilt changes applied at the target sectors are: {-5°, -5°, -4°, +3°, +3°, +2°, and -4°} expanding the sector 1 coverage via up-tilting more by 5° and shrinking sector 5 by down-tilting further by 3° thereby putting the HS totally in sector 1 and creating better SINR conditions for the HS cell-edge UEs. But, for the HS 50%-tile metric which maximize the 50% PI, the tilt changes applied at the target sectors are different: {+3°, -7°, 0°, -5°, +3°, +3°, and +1°}. Hence, sector 1 now shrinks by 3° down-tilting and sector 5 is up-tilted by 5, ° thereby putting the HS completely under the sector 5 coverage. The HS UE TP and corresponding SINR performance is shown in Figure 6 for the HS 5% and HS 50% metrics where the PIs are maximized via adjusting the tilts in different directions.

The performance of the other target optimization metrics is also evaluated for the HS-2 scenario. Simulation results are presented in Figure 7. A rather significant performance gain is achieved for the HS UEs for all optimization metrics except for the TA 50% for the reason mentioned before. Gains of 70%, 60% and 55% are obtained at 5%-tile, 50%-tile and average TP PIs, respectively, at the HS for the HS oriented optimization at the expense of a minimal performance degradation at the UEs in the TA outside the HS. Moreover, marginal gain is observed at the TA for all PIs for TA oriented maximization.

Further simulation investigations have been done for various additional HS scenarios and HS traffic density assumptions, i.e. by changing the HS locations and traffic density values. For example HS-3 shown in Figure 2. All results show the same tendency and confirm the gains for traffic driven tilt optimization.

IV. Conclusion

In this paper, tilt optimization has been investigated to adapt to hot spot (HS) traffic situations in an LTE-A network. Simulation results show a significant potential gain in system performance resulting from coverage change due to tilt adaptation leading to SINR improvements of the HS area. Depending

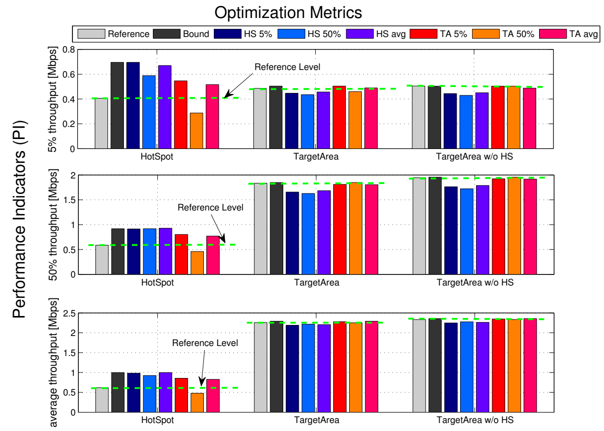

Fig. 7. UE TP Performance Comparison for Different PIs and Optimization Metrics [HS-2, ρ = 20]

on the HS location and traffic density ρ, UE throughput gains of up to 160% and 96% are recorded for cell edge and average UE TP performance, respectively. The performance gain is even more for higher traffic densities at the HS. These high gains fortunately do not lead to considerable impact in the surrounding area described as target area (TA). In all the cases, the TA statistics is found to be less harmed even though the optimization is carried out strictly to maximize the HS service performance. The gain for all UEs in the TA is observed to be moderate and depends on the ratio of the HS UE traffic statistics with respect to the complete TA. The higher the traffic density of the HS, the more gain can be seen for the complete TA even for HS oriented target metrics.

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