Impact of mechanical antenna downtilt on performance of WCDMA cellular network

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Impact of Mechanical Antenna Downtilt on Performance of WCDMA Cellular Network

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Abstract—**The aim of this paper is to evaluate the impact of the base station mechanical antenna downtilt scheme on the downlink capacity of a 6-sectored WCDMA cellular network of 33° horizontal beamwidth antennas. The effect of the base station antenna height and vertical beamwidth together with site spacing was evaluated in a macrocellular environment and observations were made based on system level simulations utilizing a Monte Carlo approach. The results show that downlink capacity of a WCDMA cellular network obviously depends on the mechanical downtilt angle and the capacity enhancements are based on reduction of other-cell interference. Moreover, the soft and softer handover areas are changed according to mechanical downtilt angle, which clearly depends on the base station antenna height and vertical beamwidth together with site spacing.**

Keywords – mechanical antenna downtilt; WCDMA downlink capacity; WCDMA cellular network

I. INTRODUCTION

Base station mechanical antenna downtilt scheme has been a tool for radio network planners to optimize their networks in sense of coverage and capacity. Mechanical downtilt is widely used in TDMA/FDMA networks (as GSM) to decrease the co-channel interference in order to achieve smaller frequency reuse factor, and hence to increase the capacity. However, improvements in the radio network quality due to tilting have traditionally not directly been taken into account in capacity or frequency planning but have been used as an extra margin to avoid serious interference areas [1]. In a (W)CDMA-based system, such as UMTS, the same frequency is utilized in adjacent (neighbour) cells, thus placing higher requirements for inter-cell interference mitigation than in TDMA/FDMA networks. A special attention should be also paid to the side and back lobes of the base station antennas, since they increase the interference level. Controlling the inter-cell interference can be carried out by downtilting the base station antennas, which is, eventually, needed in order to maximize the capacity of a WCDMA network.

Mechanical antenna downtilt has been observed to be an effective way to reduce inter-cell interference by confining the signal to its own dominance area [2]. Prior work has concluded that mechanical downtilt can increase the capacity of a UMTS network in 3-sectored sites in uplink and downlink directions [3]–[4]. However, the downtilting can be also produce a reduction in the sectorisation efficiency in the uplink (UL), as was observed in [5]. Thus, the effect of antenna downtilt ought to be studied more carefully in highly sectorised sites; especially, in a case of a mechanical antenna downtilt in downlink (DL) direction. Downlink is also more attractive since capacity of a WCDMA network is typically downlink limited. The selection of a 6-sectored network of 33° horizontal beamwidth antennas was based on the optimum radio network performance from downlink capacity point of view [6]-[7].

There exist many different downtilt schemes – mechanical tilt, fixed electrical tilt, variable electrical tilt (VET), and remotely variable electrical tilt (RET) schemes – which can be used to adjust or optimize the coverage areas of base station antennas. In order to adjust or optimize the downtilt angles, mechanical downtilt scheme requires a tower climb, hence making the adjustment process of tilt angles considerably expensive after the network is up and running. Hence, if traditional antennas are utilized, the importance of the selection of a 'right' mechanical tilt angle in the network deployment phase should be emphasized in order to guarantee the maximum capacity, coverage, and quality of service for the existing radio network infrastructure. Also fixed electrical tilt antennas require a tower climb if tilt angle is needed to change. However, if the fixed electrical tilt angle is wanted to change electrically, it requires totally new antenna element and the additional tilt angle is further increased/decreased purely mechanically (combined tilt scheme). Usage of variable and remote electrical tilt antennas removes the need of a tower climb, hence saving the funds in optimization. RET antennas even remove the requirement of a base station site visit, since the antenna downtilt angle can be controlled from network management system (NMS).

An optimum mechanical downtilt angle in a WCDMA system is obviously a trade-off between other-cell interference mitigation and coverage thresholds. The optimum downtilt angle is achieved if other-cell interference is reduced effectively still providing sufficient coverage over the cell dominance area. Clearly, this optimum downtilt angle is affected by the base station site and antenna configuration including antenna height and vertical beamwidth as well as the size of the cell dominance area.

The target of this paper is to evaluate the impact of mechanical antenna downtilt scheme in a macrocellular

WCDMA network. The effect of different mechanical downtilt angles together with different base station antenna heights, antenna vertical beamwidths and site spacings on a 6-sectored WCDMA network downlink capacity and handover probabilities have been simulated by using a radio network planning tool.

II. Mechanical Antenna Downtilt Scheme

Mechanical antenna downtilt scheme is illustrated in Fig. 1. Mechanical downtilt is achieved by directing the antenna element towards the ground. Clearly, optimum downtilt angle depends at least on two factors: geometrical factor (θ_{GEO}) and antenna vertical beamwidth factor ($\theta_{VER,BW}$). The geometrical factor takes into account the heights of the base station antenna (h_{BTS}) and mobile station antenna (h_{MS}) as well as the size of the dominance area (d). The geometrical factor is not enough to describe the optimum downtilt angle, since certainly antenna vertical beamwidth affects the optimum downtilt angle. Eventually, antenna vertical beamwidth is expected to have a great impact on the downtilt angle. Hence, the optimum mechanical downtilt angle v_m is assumed to be a function of the vertical beamwidth factor and geometrical factor:

$$\nu_m = f\left(\theta_{GEO}, \theta_{VER,BW}\right). \quad (1)$$

The geometrical factor can be calculated using the relation of the height difference between the base station antenna and mobile station antenna, and sector dominance area size as shown in (2). The antenna beamwidth factor could be easily selected as an angle between upper -3dB position in the antenna radiation pattern and zero direction. This is, in most of the cases, the same as a half of the antenna vertical radiation pattern.

$$\theta_{GEO} = arctan\left(\frac{h_{BTS} - h_{MS}}{d}\right). \quad (2)$$

The angle between base station mechanical antenna downtilt and the effective downtilt angle is the same in the horizontal plane only in the main lobe direction. The effective downtilt angle decreases as a function of horizontal angle in such a manner that the antenna radiation pattern is not downtilted from the side lobe direction of an antenna. Furthermore, as a consequence of the main beam downtilt, the back lobe of the antenna is uptilted. Towards higher mechanical downtilt angles, the horizontal radiation pattern effectively shrinks from the main direction and widens from the sides [2]. Coverage and interference reduces in the main beam direction, reducing also the overlapping between the opposite sector(s), thus decreasing the soft handover (SHO) probability in the cell border areas. The widening of the horizontal radiation pattern increases clearly the overlapping between adjacent sectors, hence increasing the softer handover probability, which is clearly dependable of sector overlapping.

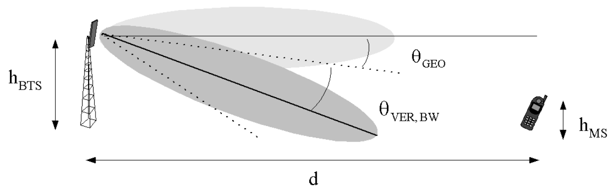


Figure 1. Mechanical antenna downtilt scheme.

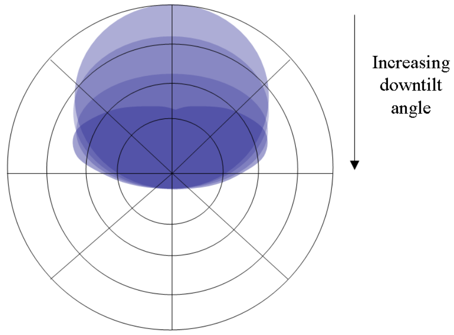


Figure 2. Illustration of the widening of the horizontal radition pattern as a function of incresing mechanical downtilt angle.

III. Simulation Parameters

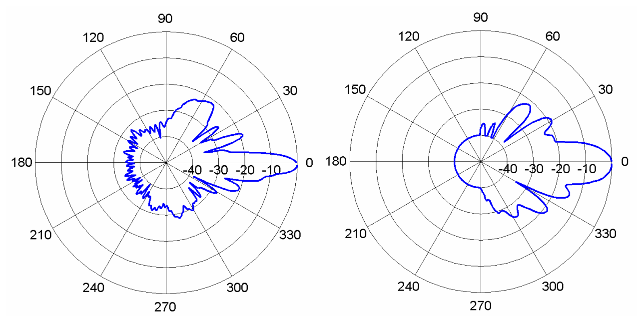
A static Monte-Carlo simulation tool was used to analyze the performance of WCDMA network under different network topologies. A macrocellular network was planned in a shape of a regular hexagonal grid of 19 base stations (3 tiers). The locations of the base stations were kept fixed during the simulations. For the simulations of different site spacings, the hexagonal layout of 19 base stations was remained and only the distance between the sites was changed. The base station antennas were oriented to have equal directions of 0°, 60°, 120°, 180°, 240°, and 300°.

Morphological and topographic information of the simulation area was defined by a high resolution digital map. The digital map included basic terrain types (water, open, and forest) and buildings of different heights in a raster form. The simulation area could be classified as suburban/light urban area consisting mainly of low-height residential buildings, but also including some higher commercial buildings. The average roof top level was well below 25 m.

For the pilot coverage predictions, COST-231-Hata propagation model was used as for a medium/small city environment with a radio propagation slope of 35 dB/dec. The mobile station antenna heights are set to 1.5 m. The prediction model was adjusted with an average area correction factor of -6.7 dB to correspond to a light urban or suburban environment. The propagation model also included a function to model diffractions. The traffic profile consisted of a homogeneous distribution of speech users (12.2 kbps). Other simulation parameters are shown in Table I. The vertical radiation patterns of the antennas used in the simulations are shown in Fig. 3. The gain of the narrower antenna (6° vertical beamwidth) was 20.7 dBi and the wider antenna (12° vertical beamwidth) 17.9 dBi. The horizontal beamwidth of both antennas was 33°.

TABLE I. GENERAL SIMULATION PARAMETERS.

Parameter	Value	Unit
Maximum BS TX power	43	dBm
CPICH	33	dBm
SCH	30	dBm
CCCH	30	dBm
DL Eb/N0	6	dB
UL Eb/N0	4	dB
BS noise figure	5	dB
MS noise figure	9	dB
MS dynamic range	70	dB
Required E_c/N_0	-17	dB
SHO window	3	dB
STD of slow fading	8	dB
UL noise rise	6	dB
DL code orthogonality	0.6	
Voice activity factor	0.5	



6 deg

12 deg

Figure 3. Antenna vertical radiation patterns.

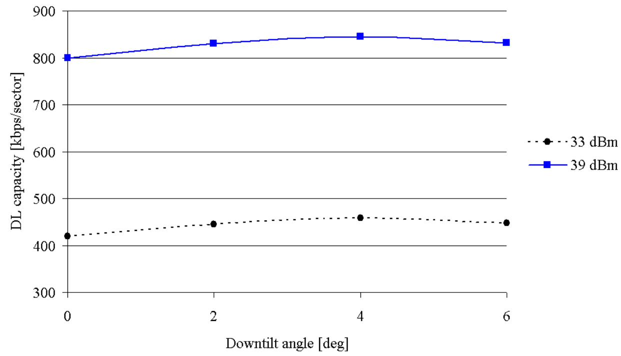


Figure 4. Capacity per sector as a function of mechanical antenna downtilt angle. Site spacing 2.2 km, antenna height 25 m, and antenna vertical beamwidth 6°.

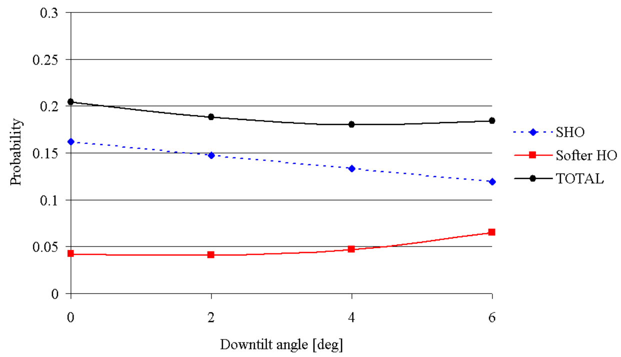


Figure 5. Handover probabilities as a function of mechanical antenna downtilt angle. Site spacing 2.2 km, antenna height 25 m, and antenna vertical beamwidth 6°.

Altogether four different network topologies and site configurations were simulated. The first three simulations were made with the antenna of 6° vertical beamwidth. In the first simulation scenario, the base station antenna height was set to 25 m and the hexagonal site spacing to 2.2 km. In the second scenario, the site spacing was reduced to 1.5 km keeping the antenna height the same. In the third scenario, antenna height was increased to 40 m. In the last simulation scenario, the antennas were changed into ones of 12° vertical beamwidth.

IV. RESULTS

Figs. 4-5 show the simulation results from the first scenario of 6° antenna, 2.2 km site spacing and 25 m antenna height. In Fig. 4, the lower curve shows the DL capacity per sector with 33 dBm average DL traffic channel (TCH) transmit power (corresponds to lower load scenario) and the upper curve the capacities with 39 dBm average TCH transmit power (corresponds to higher load scenario). As observed from the curves, downtilting is slightly affecting the capacity and an optimum downtilt angle lies around 4°. Basically, due to higher loading of the network, the optimum downtilt angle with a higher load should be somewhat at lower angle. However, the loading does not seem to have significant impact on the optimum downtilt angle. Fig. 5 shows the corresponding handover probabilities in sense of soft, softer, and total handover probabilities. SHO probability decreases fairly linearly as a function of increasing downtilt angle. On the contrary, softer handover probability curve has a slightly exponential nature and it is increasing towards higher downtilt angles. However, the change in the total handover probability is not very dramatic, since it varies only between 0.18 and 0.21.

Figs. 6-7 represent the results from the second simulation scenario of 6° antenna, 1.5 km site spacing and 25 m antenna height. Both lower and higher load capacity curves can be observed to have more changes compared to 2.2 km site spacing topology. Moreover, the optimum downtilt angle is shifted closer to 6°, and the achieved capacity with the optimum downtilt angle is to some extent larger. Similar handover probabilities can be also noticed in Fig. 7 as in Fig. 5. Interestingly, the SHO probability in non-tilted scenario is almost the same as with 2° downtilt. Otherwise, the curves show expected results, and also the changes in SHO and softer HO probabilities are more significant compared to Fig. 5.

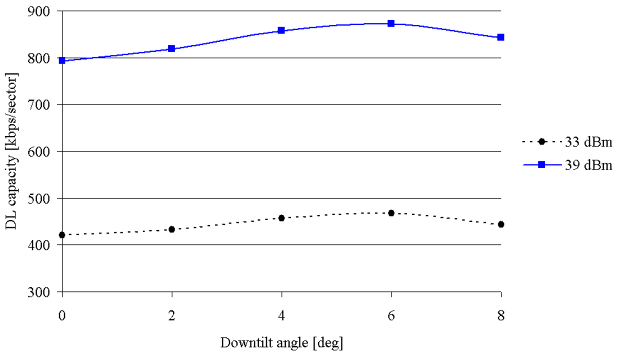


Figure 6. Capacity per sector as a function of mechanical antenna downtilt angle. Site spacing 1.5 km, antenna height 25 m, and antenna vertical beamwidth 6°.

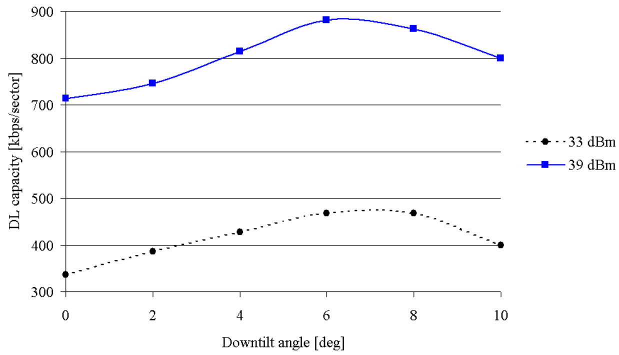


Figure 8. Capacity per sector as a function of mechanical antenna downtilt angle. Site spacing 1.5 km, antenna height 40 m, and antenna vertical beamwidth 6°.

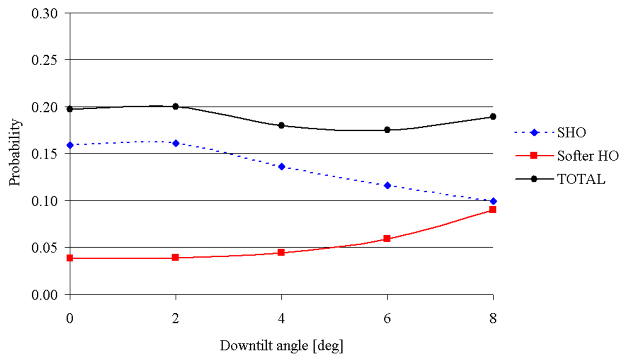


Figure 7. Handover probabilities as a function of mechanical antenna downtilt angle. Site spacing 1.5 km, antenna height 25 m, and antenna vertical beamwidth 6°.

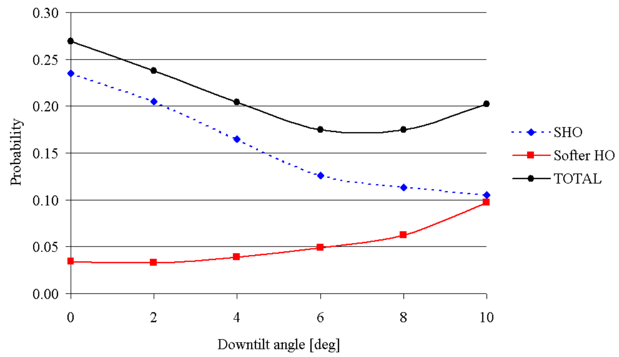


Figure 9. Handover probabilities as a function of mechanical antenna downtilt angle. Site spacing 1.5 km, antenna height 40 m, and antenna vertical beamwidth 6°.

In Figs. 8-9, the simulation results from the third scenario of 6° antenna, 1.5 km site spacing and 40 m antenna height are shown. Evidently, the gain from the antenna downtilting is more distinct between non-tilted and optimum downtilt scenarios. Higher other-cell interference level, produced by the higher antenna installation height, deteriorates the network performance (and decreases the capacity) if antennas are not tilted. The capacity can be enhanced as a function of antenna downtilt angle and the maximum achievable capacity exceeds the values of previous topology configurations (Figs. 4 and 6). The optimum downtilt angle seems to be close to 7°. The increased coverage overlapping due to higher antenna height increases also the SHO probability (Fig. 9). However, around optimum downtilt angle, the total handover probability is close to 0.17, which has been observed also in other network topologies. Furthermore, the SHO probability is starting to saturate at higher downtilt angles.

In Figs. 10-11, the simulation results from the last scenario of 12° antenna, 1.5 km site spacing and 40 m antenna height are shown. As seen from the results in Fig. 10, the capacity of non-tilted scenario with lower and higher load is initially better compared to scenario in Fig. 8. This is due to lower antenna gain, which produces also lower other-cell interference level and smaller coverage overlapping. Still, the capacity is lower, if compared to scenarios in Figs. 4 and 6. The optimum downtilt angle places expectedly at higher angles (close to 12°), and clearly, downtilting is affecting the network capacity. Again, minimum handover probability is observed with the optimum downtilt angle (Fig. 11). Due to smaller coverage overlapping, the handover probabilities behave more steadily compared to corresponding network topology with narrower antennas (Fig. 9).

Table II summarizes the DL capacities of non-tilted and optimum downtilt scenarios with corresponding capacity gains respect to the non-tilted scenarios. Although the interference level is not so high in the first network topology (2.2km/25m/6°), the achieved capacity gain with low load is around 10 % and 6 % with high load. The capacity gain is the highest in the third network topology, since the other-cell interference level is initially highest. In average, even with mechanical downtilt, a WCDMA network can gain roughly 10% in capacity. The results in Table II show also that the network capacity is larger with higher antenna height.

V. CONCLUSIONS

This paper outlines the impact of the base station mechanical antenna downtilt of 6-sectorised sites on the downlink capacity of a WCDMA network. An optimum mechanical downtilt angle exists in all simulation scenarios, and clearly this angle can be defined for each site and antenna configuration separately; depending on the base station antenna height and vertical beamwidth together with the site spacing.

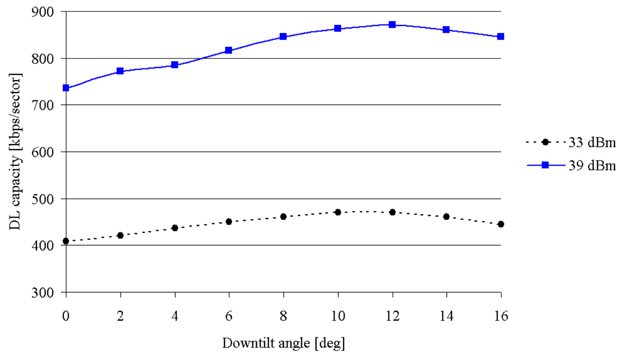


Figure 10. Capacity per sector as a function of mechanical antenna downtilt angle. Site spacing 1.5 km, antenna height 40 m, and antenna vertical beamwidth 12°.

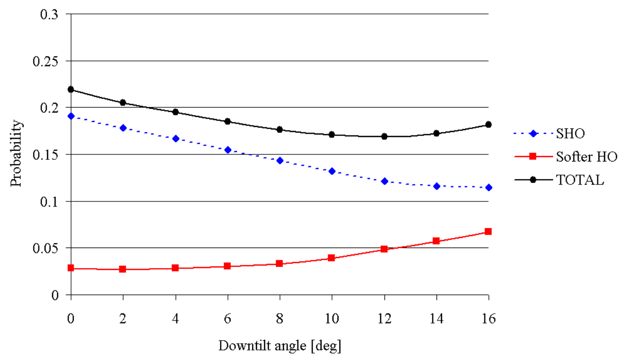


Figure 11. Handover probabilities as a function of mechanical antenna downtilt angle. Site spacing 1.5 km, antenna height 40 m, and antenna vertical beamwidth 12°.

The downlink capacity increases with downtilted antennas but also the coverage is reduced as a function of downtilt angle. Thus, an optimal downtilt should be used if coverage allows in order to maximize the capacity. Furthermore, the simulation results show that load of a network does not have significant impact on the optimum downtilt angle under homogenous traffic distribution. It was also shown that the effect of base station antenna vertical beamwidth is considerable as expected. SHO probabilities are decreasing quite linearly as a function of downtilt angles, and on the contrary, softer HO probabilities are increasing due to the changes in the antenna horizontal radiation pattern.

Although mechanical antenna downtilt scheme is not considered as the best possible for the downtilt scheme, the simulation results of this paper show the capacity gains in WCDMA network in prospect if only mechanical downtilting is utilized. Moreover, the results emphasize the fact that downtilting should be used, not only to maximize the network capacity, but also to reduce the amount of, e.g., pilot pollution.

TABLE II. CAPACITIES OF NON-TILTED AND OPTIMUM DOWNTILTED SCENARION WITH CORRESPONDING CAPACITY GAINS RESPECT TO NON-TILTED SCENARIO.

Network topology	**DL capacity [kbps/sector] (capacity gain)**			
	Low load		***High load***	
	0° tilt	Opt. tilt	0°	Opt. tilt
2.2km/25m/6°	420	460 (10%)	800	846 (6%)
1.5km/25m/6°	421	469 (12%)	793	872 (9%)
1.5km/40m/6°	336	481 (15%)	713	882 (11%)
1.5km/40m/12°	409	470 (12%)	735	870 (9%)

Further studies will concentrate on finding an equation for defining an optimum downtilt angle for macrocellular antennas; regardless of antenna height and vertical beamwidth together with the size of the sector dominance area. Moreover, the decrease of pilot polluted areas due to antenna downtilting is under interest.

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