Electrical Antenna Downtilt in UMTS Network

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ABSTRACT

In this paper, the impact of the base station electrical antenna downtilt on UMTS network performance is studied. The effect of the base station antenna height, vertical beamwidth, and site spacing on the optimum electrical downtilt angle has been evaluated in a macro cellular environment. Both downlink and uplink performances are considered with a special attention to soft handover areas. The results are based on the system-level simulations utilizing a Monte-Carlo approach. According to the results, the base station antenna vertical beamwidth has the greatest impact on the optimum downtilt angle. A larger vertical beamwidth requires a larger downtilt angle in order to obtain an optimum system performance. Moreover, the base station antenna height affects the optimum downtilt angle. However, site spacing was observed to have smaller impact if antenna heights were kept constant.

I. INTRODUCTION

From a network operator's point of view, an economical and efficient way to increase the network capacity is attractive. Techniques proposed for increasing the capacity, e.g., additional carriers, sectoring, and micro cell deployment, may easily require additional hardware and/or software investments, and therefore increases the implementation expenses. Although, many operators are willing to invest more resources in developing their networks, some enhancement methods may require more money and also more time than expected. Nevertheless, it would be advantageous if solution for capacity enhancements was fast and flexible.

A base station antenna equipped with electrical downtilt is an attractive choice for an antenna selection. Especially, in the WCDMA-based UMTS system, where a decrease in the cell interference level is directly reflected into capacity enhancement. An optimum downtilt angle is contributed by many factors: cell range, base station antenna height, and antenna vertical beamwidth. In order to achieve the most excellent performance, the downtilting scheme has to be defined for each site and antenna configuration separately.

Electrical antenna downtilt has been studied in UMTS network in a single 3-sectored site scenario [1]. Downtilt affects clearly the network performance, since quite significant capacity increase has been observed. The results in [2] propose that electrical downtilt should be used in an urban environment as a pre-optimisation method. Since these references include only one scenario (one site spacing, one antenna height, and one antenna vertical beamwidth), it is hard to define an optimum downtilt angle with the aid of these references. In [3], optimum electrical downtilt angles have been defined using a simple algorithm, but any clear definition for it has not been proposed. However, a slight deviation in an optimum electrical downtilt angle has been observed, if the angle has been defined based on the site configuration of a typical urban environment.

The main target of this paper is to realize the impact of electrical downtilt on the network performance and to find an optimum downtilt angle for different base station site configurations for macro cellular sites in a light urban/suburban environment. The effects of the base station antenna height, antenna vertical beamwidth, and site spacing on the optimum electrical downtilt angle has been simulated by using a radio network planning tool. Moreover, both uplink and downlink performances are considered together with an attention to soft handover areas.

II. ELECTRICAL ANTENNA DOWNTILT

Electrical downtilt is carried out by adjusting the antenna elements, and hence it slightly changes antenna radiation characteristics when downtilt angle is changed [4]. Figure 1 illustrates the behaviour of the main, side and back lobes of an electrically downtilted antenna, and shows roughly the changes in the corresponding radiation pattern when downtilt angle is increased.

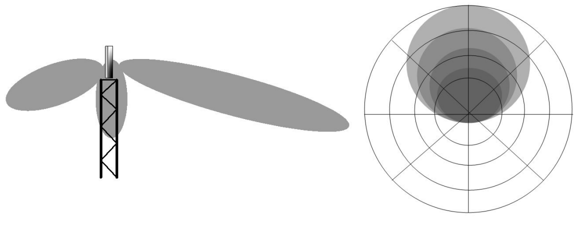

Figure 1: Illustration of electrical antenna downtilt and radiation pattern.

Since all directions are tilted by the same amount, electrical downtilt reduces other-cell interference very efficiently. This interference reduction in UMTS system can be converted straight to capacity enhancement. However, also the coverage in the main lobe direction reduces rapidly, which deteriorates the network performance if antennas are downtilted too much.

Based on the geometry, an optimum electrical downtilt angle ν_e is assumed to be a function of the antenna vertical beamwidth factor $\theta_{VER,BW}$ and the geometrical factor θ_{GEO}:

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

Obviously, the weight of the vertical beamwidth factor is quite high, which can be concluded from geometrical dependencies. If an antenna of a larger vertical beamwidth is utilized, more downtilt is required in order to point the upper -3 dB lobe towards the ground (Figure 2).

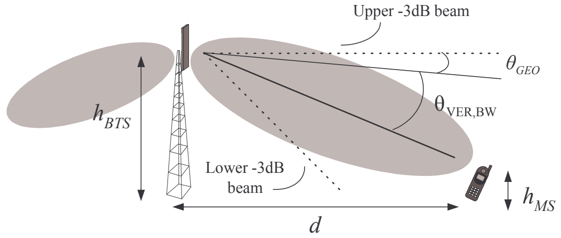

Figure 2: Electrical downtilt scheme and optimum downtilt angle factors.

Geometrical factor depends at least on the base station antenna height and the site spacing. A higher antenna position as well as a smaller site spacing yield for a larger downtilt angle. The geometrical dependence can be defined as in Equation (2):

$$d = \frac{\Delta h}{tan\left(\theta_{GEO}\right)} \quad (2)$$

where Δh is the height difference between the base station antenna height (h_{BS}) and the mobile station antenna height (h_{MS}). How d is thereafter selected, depends on the soft handover (SHO) area definitions and required coverage overlapping (indoor coverage thresholds).

In a certain situation, soft handovers give additional gain to the link budget due to macro diversity [5]. If handover areas are widely spread, the signal level differences between SHO links become larger and the observed gain decreases. The signal field strength near the base station becomes better, if antennas are downtilted and directed more precisely towards the intended serving area (dominance area). Therefore, these sector dominance areas become clearer. Since the coverage overlapping is reduced as a consequence of downtilt, also SHO areas become more distinct.

III. SIMULATION SCENARIO

Monte-Carlo simulations were utilized to verify the performance of UMTS network under different downtilt simulation scenarios. An accurate digital map (including morphological and topographical data of the simulation area as well as the building information in a raster form) was given as an input for the simulator. In the simulation, 19 3-sectored (with 65° antennas) sites were located in a regular hexagonal grid. Okumura-Hata propagation model was chosen for the simulations, and an average area correction factor was set to -6.7 dB (light urban/suburban). The user profile consisted only of speech users (12.2kbit/s), and moreover it was homogenous. Other general simulation parameters are gathered in Table 1.

The selected antenna vertical beamwidths were 6° and 12°. The base station antenna heights (25 m, 35 m and 45 m) were selected based on practical considerations for a suburban macro cellular network. The site spacings (1.5 km, 2.0 km and 2.5 km) were chosen in order to realize the effects of antenna downtilt in a noise sensitive network (1.5 km site spacing) and in a coverage sensitive network (2.5 km site spacing).

TABLE 1: GENERAL SIMULATION PARAMETERS.

Base Station	
Maximum power	43 dBm
CPICH	33 dBm
CCCH	30 dBm
SCH	30 dBm
Maximum power per connection	38 dBm
Noise figure	5 dB
Required E_b/N_0	5 dB
Mobile Station	
Maximum transmit power	21 dBm
Dynamic range	70 dBm
Power step size	0.5 dB
Required E_c/I_0	-17 dB
Noise figure	9 dB
Required E_b/N_0	8 dB
Other	
Slow fading standard deviation	8 dB
UL noise rise	6 dB
DL orthogonality	0.6
Handover margin	4 dB

IV. SIMULATION RESULTS

The simulation results are shown with low and high load scenarios. The low load scenario corresponds generally to a rural network scenario and high load to an urban network scenario. Antenna downtilt angle is shown respect to service probability and to downlink (DL) normalized load, which is the ratio of the average traffic channel (TCH) transmit power and the maximum power allocated power for traffic channel (Equation 3).

$$DL\_load = \frac{average\_TCH\_power}{max\_TCH\_power} \qquad (3)$$

An optimum downtilt angle is defined from downlink and uplink performances together. First, the range (downtilt angle) has been selected in such a manner that the service probability is at the maximum 0.02 lower than the highest service probability in that particular simulation scenario. Secondly, an optimum downtilt angle is defined from that particular range according to minimum transmit power loads both in downlink and uplink directions. Thereafter, these optimum downtilt angles are averaged.

In Figure 3, the results from the simulations with antenna of 6° vertical beamwidth, 25 m antenna height, and 1.5 km site spacing are presented. In the low load scenario, interference level in the network remains relatively low. After a certain downtilt angle, coverage limits the performance, and service probability decreases. In the high load scenario, the other-cell interference is deteriorating the network performance in non-tilted scenario. However, downtilt clearly improves the network performance, but after increasing the angle, the coverage limits the performance. In the high load scenario, DL load is gradually decreasing towards higher downtilt angles, and the system performance decreases due to the uplink coverage limitation. DL load curve behaves steadily in the low load scenario. The cell-breathing affects the service probability curves at the higher downtilt angles. This can be observed as a small cap in the service probability curves. However, the effect is not remarkable.

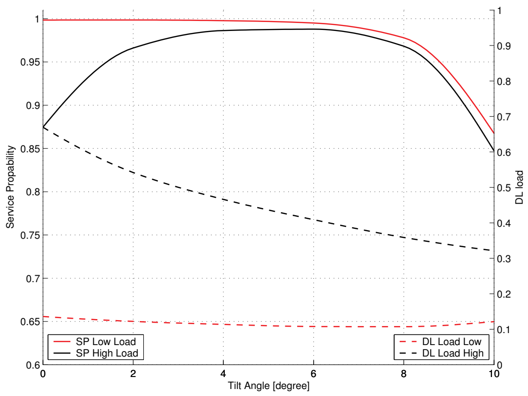

Figure 3: Service probability and downlink load as a function of tilt angle. Antenna vertical beamwidth 6°, antenna height 25m, and site spacing 1.5km.

Increasing the site spacing does not affect the performance in the low load scenario (Figure 4); the service probability is only slightly lower due to coverage restrictions, and moreover it starts to decrease a bit earlier than with smaller site spacing. In the higher load scenario, the network performance in non-tilted scenario is almost the same with lower DL load. However, after downtilting the antennas, the service probability is not rising as fast as in previous scenario, and only 0.92 service probability is reached. Also, the cell-breathing can be observed clearly at higher downtilt angles.

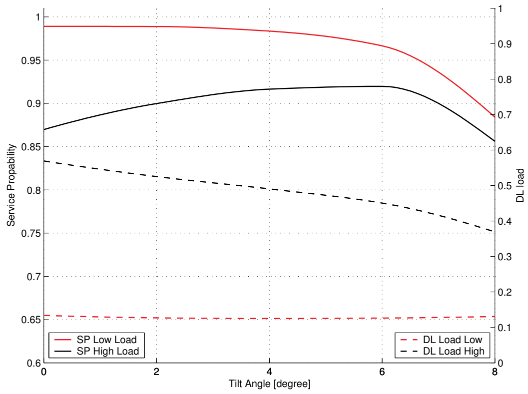

Figure 4: Service probability and downlink load as a function of tilt angle. Antenna vertical beamwidths 6°, antenna heights 25m, and site spacing 2.5km.

In Figure 5, the effect of higher antenna position is illustrated (site spacing is 1.5 km and antenna height 45 m). The low load scenario is similar to previous scenarios, and service probability curve decreases after too large downtilt angle. On the contrary, in the high load scenario, the effect of higher other-cell interference due to longer breakpoint distance can be seen very obviously. The service probability is near 0.6, but after downtilting, it increases extremely rapidly and reaches almost the maximum. Moreover, at the highest performance, the DL load remains lower than in the previous simulation scenarios. This indicates better network performance solutions for higher antenna positions with appropriate downtilt angle.

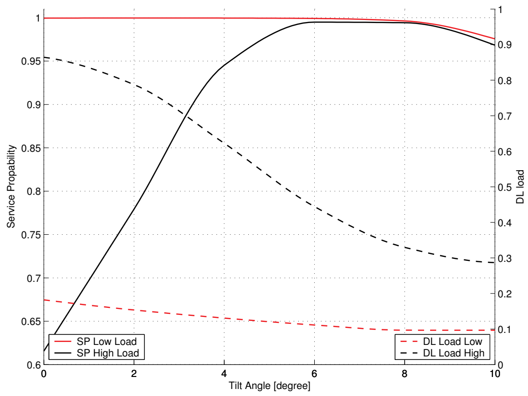

Figure 5: Service probability and downlink load as a function of tilt angle. Antenna vertical beamwidth 6°, antenna height 45m, and site spacing 1.5km.

In Figure 6, the low load scenario behaves expectedly, since the coverage restricts the performance at higher downtilt angles. In the high load scenario, larger site spacing restricts the coverage and full service probability is not achieved. Still, the network performance is better if compared to lower antenna topology.

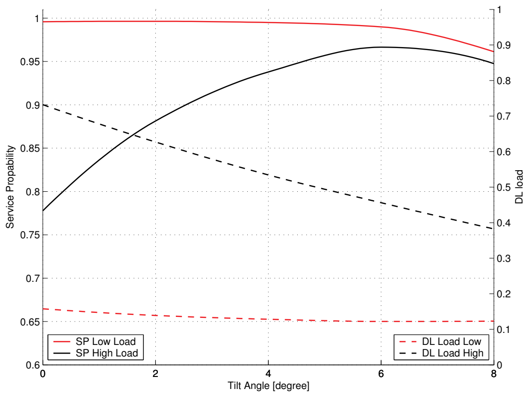

Figure 6: Service probability and downlink load as a function of tilt angle. Antenna vertical beamwidth 6°, antenna height 45m, and site spacing is 2.5km.

In Figure 7, the behavior of the uplink (UL) average transmit powers of the preceding high loaded simulation scenarios are shown. At lower downtilt angles, higher interference demands higher transmit powers. Moreover, there is always a local minimum in the uplink transmit power that cannot be observed in the downlink powers. After the local minimum, it is rising according to downtilt angle. The lowest uplink average transmit power level is achieved with 2-4° downtilt angles. After that range, the powers begin to increase exponentially. Moreover, this indicates that the network is changing from downlink limited (higher DL load at smaller downtilt angles in Figures 3-6) to uplink limited. The average transmit power level is rising also as a function of antenna height and site spacing.

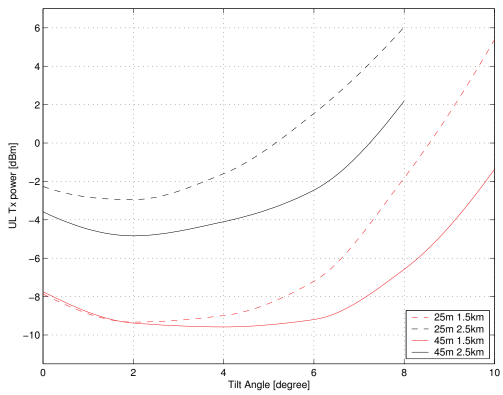

Figure 7: Uplink average transmit powers (high load scenario) as a function of downtilt angle. Antenna vertical beamwidth 6°.

Exactly the same simulations were carried out with 12° vertical antenna beamwidth. Altogether, the trend of the system performance is the same, but the changes (at this range from 0 to 10°) are not as dramatic. However, the low load scenarios are almost the same. In Figure 8, due to the wider vertical beamwidth, interference can be only slightly decreased after tilting is used. Moreover, if too large downtilt angle is used, the coverage restricts the system performance. The changes in the downlink load are also negligible compared to the simulations of narrower antenna beamwidth.

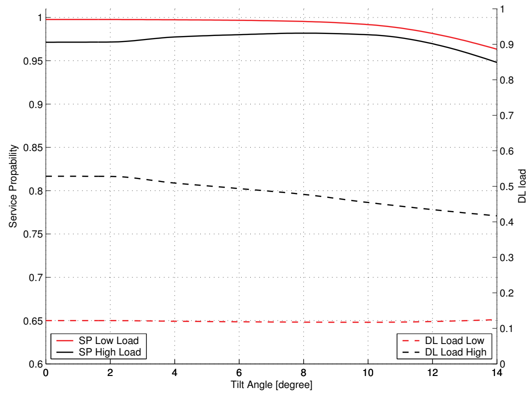

Figure 8: Service probability and downlink load as a function of downtilt angle. Antenna vertical beamwidth 12°, antenna height 25m, and site spacing 1.5km.

After increasing the site spacing, the network performance of the non-tilted scenario is decreasing due to the coverage limitation (Figure 9). Interference can be only slightly reduced towards the optimum downtilt angle, and hence the downlink load behaves also steadily. Altogether, the changes in the service probability and in downlink load are very small compared to the simulations of narrower antenna beamwidth. The optimum downtilt angles are obviously higher in the wider vertical beamwidth simulations.

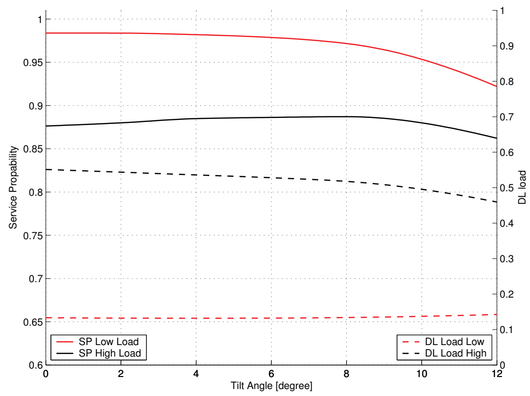

Figure 9: Service probability and downlink load as a function of downtilt angle. Antenna vertical beamwidth 12°, antenna height 25m, and site spacing 2.5km.

In Figure 10 (higher antenna positions), the other-cell interference is higher, and thus tilting affects more the system performance. The optimum downtilt angle increases, and the changes in the downlink load are also more significant. In Figure 11 (higher antenna positions and larger site spacing), the performance is similar to smaller site spacing case, expect that the coverage limitation emerges as in previous scenarios.

In the non-tilted scenario, the performance remains at the same level if site spacing is increased.

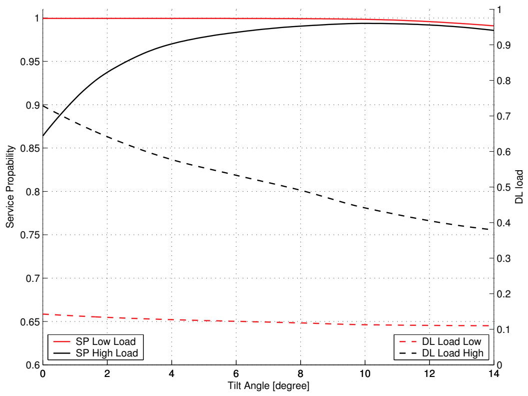

Figure 10: Service probability and downlink load as a function of downtilt angle. Antenna vertical beamwidth 12°, antenna height 45m, and site spacing 1.5km.

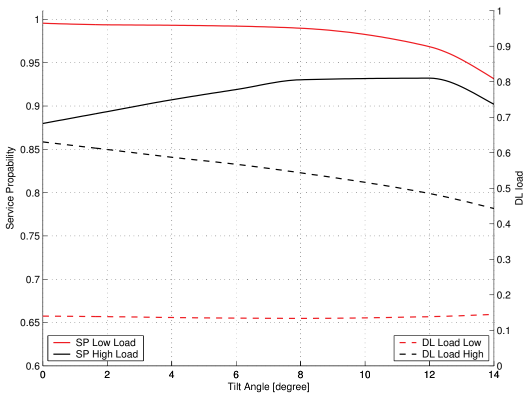

Figure 11: Service probability and downlink load as a function of downtilt angle. Antenna vertical beamwidth 12°, antenna height 45m, and site spacing 2.5km.

Uplink average transmit powers of wider antenna beamwidth simulations are shown in Figure 12. The curves of different scenarios act expectedly and correspondingly to narrower beamwidth simulations. The most significant difference is that transmit powers begin to increase not until 4-8° due to wider vertical antenna beamwidth.

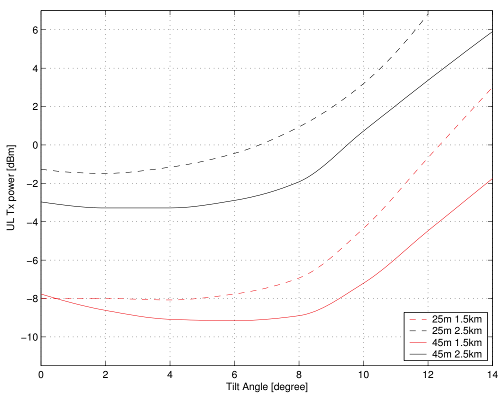

Figure 12: Uplink average transmit powers (high load scenario) as a function of downtilt angle. Antenna vertical beamwidth 12°.

In Figure 13, the effects of downtilt can be seen more comprehensively as a function of site spacing in the narrower vertical beamwidth scenario. The solid lines are optimum downtilt and dotted lines non-tilted scenarios. The improvement of the network performance, due to antenna downtilting, can be emphasized with smaller site spacings when the other-cell interference levels are higher. However, the network performance equalizes after the site spacing increases. Interestingly, a higher antenna position in the optimum downtilt scenario results a better system performance; opposite to the non-tilted scenario. The site spacing and antenna height do not affect as dramatically on the service probability. Thus, the use of antenna downtilt also stabilizes network behaviour.

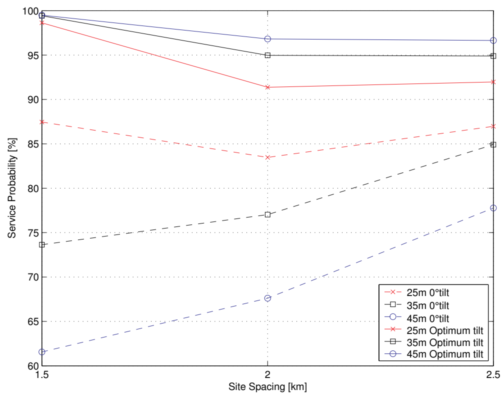

Figure 13: Service probabilities of high loaded networks as a function of site spacing. Antenna vertical beamwidth 6°.

The curves of Figure 14 with the wider antenna beamwidth show similar trend as the previous figure with the exception that downtilting does not improve the system performance so much. This is partly caused by the fact that the network is not so interference limited due to the smaller antenna gain. Moreover, the impact of downtilt is very small; especially with longer site spacing.

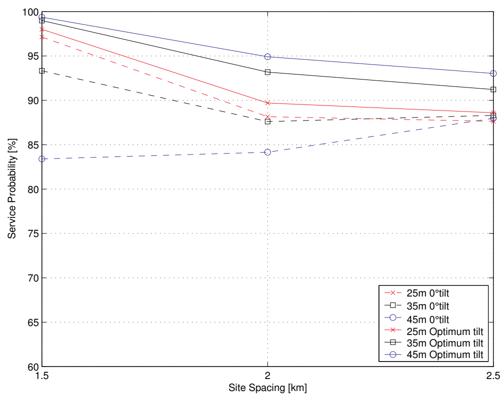

Figure 14: Service probabilities of high loaded networks as a function of site spacing. Antenna vertical beamwidth 12°.

In Figures 15 and 16, the behaviour of the soft handover (SHO) probabilities is presented respect to the antenna downtilt angle of different antenna heights and vertical beamwidths. Probability of SHO decreases rather linearly when downtilt angle is increased. This is a direct consequence to upper –3dB beam coming closer to the base station, and thus reducing coverage overlapping. The effects are expectedly smaller with the antennas of a wider vertical beamwidth. Intuitively, a higher antenna position creates larger coverage overlapping areas, and hence increases the soft handover probability. Moreover, larger site spacing decreases soft handover probability due to smaller coverage overlapping. With lower downtilt angles, these effects can be emphasized more, but while increasing the downtilt angle, differences in soft handover probabilities are disappearing.

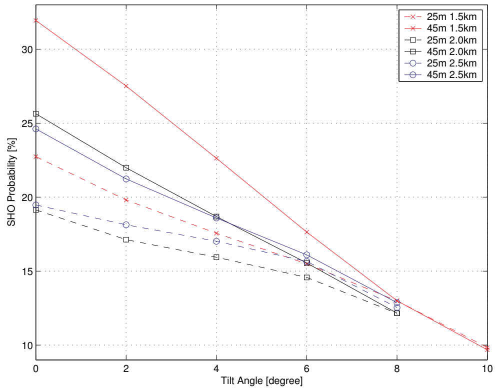

Figure 15: SHO probabilities as a function of downtilt angle. Antenna vertical beamwidth 6°.

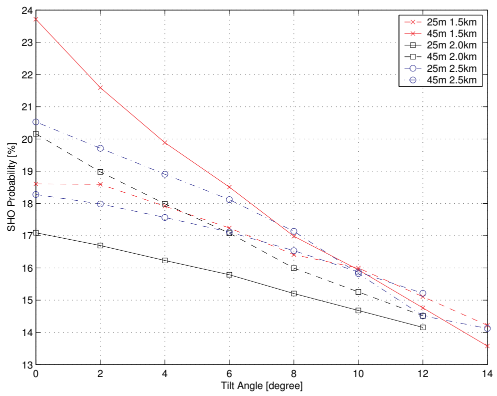

Figure 16: SHO probabilities as a function of downtilt angle. Antenna vertical beamwidth 12°.

Figures 17 and 18 show how soft handover probabilities change according to site spacing in the non-tilted and the optimum downtilt scenarios. Clearly, the changes in the soft handover areas are larger when antennas are not downtilted, and if higher antenna positions are used. However, the site spacing has a smaller impact on the soft handover areas. The soft handover probabilities in the non-tilted scenarios are larger with antennas of narrower vertical beamwidth, since the coverage overlapping is larger (higher antenna gain). Nevertheless, the soft handover probabilities in the optimum downtilt scenario are about the same (between 15-18%) regardless of the antenna vertical beamwidth.

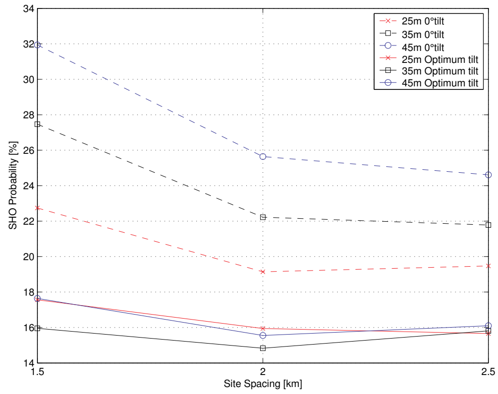

Figure 17: SHO probabilities as a function of site spacing of the optimum downtilt and non-tilted scenarios. Antenna vertical beamwidth 6°.

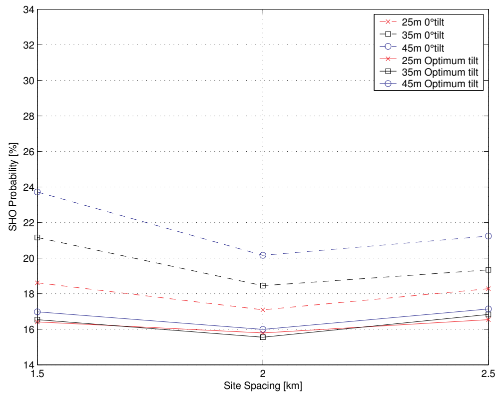

Figure 18: SHO probabilities as a function of site spacing of the optimum downtilt and non-tilted scenarios. Antenna vertical beamwidth 12°.

V. DISCUSSION AND CONCLUSIONS

In this paper, the impact of the base station electrical antenna downtilt in 3-sectored sites on UMTS network performance has been studied. An optimum downtilt angle has been found in all simulation scenarios. The antenna vertical beamwidth has clearly the greatest impact on the optimum electrical downtilt angle. The optimum downtilt angles with antennas of 6° vertical beamwidth were between 4-7°, where as the corresponding values with antenna of 12° were between 5-9°.

The base station antenna height and site spacing have also an impact on the optimum downtilt angle, but in a smaller scale. As a consequence of a higher antenna position, other-cell interference raises causing degradation in the network performance. The network performance can be maintained (or even improved) if antennas are downtilted, and thus the effect of tilting should be emphasized in case of higher antenna positions. Site spacing has also an expected effect on the downtilting scheme.

In Table 2, the optimum downtilt angles of all simulation scenarios are gathered. Clearly, a different antenna height changes the optimum downtilt angle almost in all scenarios. However, an increase of site spacing does not always decrease the optimum downtilt angle as could have been expected according to geometrical analysis. This could be caused by the fact that the method for defining the optimum downtilt angle takes into account both downlink and uplink performance. Since, the uplink limits the network performance already at lower downtilt angles, it is possible that the method underestimates the optimum downtilt angles with smaller site spacings.

TABLE 2: OPTIMUM DOWNTILT ANGLES OF ALL SIMULATION SCENARIOS

Site spacing	1.5 km		2.0 km		2.5 km	
Antenna vertical beamwidth/height	6°	12°	6°	12°	6°	12°
25m	4°	7°	4.5°	6°	5°	5°
35m	6°	8°	5.5°	7°	5°	6°
45m	7°	8°	6.5°	8°	6°	9°

The network behaves differently if antennas are downtilted. Especially, with higher antenna positions and smaller site spacings in the non-tilt scenarios, the downlink load is higher due to high other-cell interference, and moreover it has a tendency to decrease when the antennas are downtilted more. On the contrary, uplink transmit powers are increasing after a certain downtilt angle, and the network becomes strongly uplink limited.

The soft handover probability is decreasing almost linearly with respect to downtilt angle. Narrower antenna vertical beamwidth (higher antenna gain) results larger soft handover areas than wider antenna. However, in the optimum downtilt scenarios of different antenna vertical beamwidths, the soft handover probability is almost the same.

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