On Base Station Antenna Beamwidth for Sectorized WCDMA Systems

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Abstract— **The radiation pattern of a base station antenna in WCDMA networks is an important system design parameter since it has a strong influence on the interference distribution in the network. In this paper we study the problem of finding the azimuth beamwidth which optimizes system performance. We find the optimal beamwidth under a wide range of operating conditions for networks with 3 or 6 sectors per site. In particular, we investigate how the optimal beamwidth is affected by network irregularities and various environmental and system design parameters. The optimization problem is shown to be robust in the sense that a fairly large interval of beamwidths gives near-optimal performance.**

I. Introduction

In sectorized wideband code division multiple access (WCDMA) systems different user equipments (UEs) share the same frequency at all times. Separation of different UEs is achieved in the code and spatial domains. The spatial domain separation is accomplished by utilizing the propagation loss and directive antennas on the radio base stations (RBSs). Consequently, the spatial filtering property of the RBS antenna is a system design parameter which has a fundamental impact on the interference environment in WCDMA systems.

The most important parameters describing the spatial filtering properties of an antenna are the beamwidth and sidelobe level. The gain is of course also an essential parameter of the antenna but it is not considered herein as a spatial filtering parameter, since it is primarily a power scaling of the antenna pattern.

In this paper we investigate the impact of the RBS antenna beamwidth on WCDMA system performance. System performance is optimized with respect to beamwidth under a wide range of operating conditions for systems with 3 or 6 sectors per site. In theoretical studies regular networks are often assumed, i.e. the network is assumed to consist of identical sites placed on a regular grid. In this paper, we study how irregularities in the network affects the optimal beamwidth. We also investigate how the optimal beamwidth is affected by other system design and environmental parameters. We assume throughout this paper that the performance is interference limited, i.e. the coverage is adequate and the system is highly loaded. Furthermore, we consider downlink (DL) only since we assume that this is the limiting transmission direction under such circumstances.

The impact and optimization of beamwidth with respect to WCDMA or CDMA2000 performance have been studied previously in [1–6] using various models and performance metrics. However, no extensive analysis of how the optimal beamwidth depends on network irregularities and different system parameters has been performed. An analysis of how sensitive system performance is with respect to the choice beamwidth as other parameters are changed appears also to be lacking in the literature. In this paper we present results that complement previous contributions by treating these issues in more detail.

II. System Model

In a sectorized WCDMA system the UEs will receive different types of interference: intra-cell interference, I_{intra}, from the own cell, inter-cell interference, I_{inter}, from the other cells, and noise in the receivers, N_0. Ideally, UEs within the same cell will not interfere with each other owing to the orthogonal channelization coding. However, delay spread in the channel will destroy the perfect orthogonality. This leads to that the power transmitted to one UE will partially be received as interference by the other UEs. We model this non-orthogonality by a factor α such that if the power P is transmitted to one UE, on average a fraction αP will appear as interference to the other UEs.

In addition to the dedicated channels (DCH), power is also transmitted in control channels (CCH). We model that the same fraction, α, of this power appears as interference to UEs in the same cell. We separate the power in the synchronization channel (SCH) from the other common channels since this channel is completely non-orthogonal to the DCH.

The inter-cell interference is not reduced by any factor since there is no code orthogonality between cells. Hence, we model the downlink signal-to-interference-plus-noise-ratio (SINR) for a link between cell j and UE i according to

$$\text{SINR}_{i,j} = \frac{P_{\text{Rx}}}{I_{\text{intra}} + I_{\text{inter}} + N_0} = \frac{G_i\, g_{i,j}\, P_{i,j}}{g_{i,j}(\alpha_{i,j}(P_{\text{DCH},j} + P_{\text{CCH}}) + P_{\text{SCH}}) + \sum_{c \neq j} g_{i,c} P_c + N_0} \tag{1}$$

where P_{Rx} is the received desired signal power, G_i is the processing gain needed to support the service required by UE i, and $g_{i,j}$ is the path gain (= antenna gain/path loss) between cell j and UE i. Furthermore, $P_{i,j}$ is the transmitted DCH power from cell j to UE i, and $P_{\text{DCH},j}$ denotes the DCH power in cell j. Finally, P_{CCH} is the CCH power excluding the SCH power, P_{SCH} is the SCH power, and P_c is the total power transmitted from cell c.

We model that the links between UEs and cells are established based on best path gain. In addition to the primary connection between a UE and the cell with best path gain, we also connect handover (HO) links between the UE and cells which have a path gain that is within a specified HO margin. There is also a limit to the number of links a UE can have in its active set. Assuming maximum ratio combining, a UE connected to L handover links obtains the total SINR according to

$$\mathrm{SINR}_i = \sum_{j=1}^{L} \mathrm{SINR}_{i,j}. \tag{2}$$

The goal is to assign the powers, $P_{i,j}$, so that each UE obtains the SINR needed to meet its service quality requirement, specified by a target SINR. Since the transmitted power to any UE also acts as interference to all other UEs it is crucial not to transmit more power than necessary. This problem is solved by using power control. The aim of power control is to balance the SINR requirements of all UEs so that each UE attains its target SINR. To this end, we use the following constrained, iterative power control

$$P_{i,j}(n{+}1) = \min\left\{ P_{i,j}(n)\left[0.9\frac{\mathrm{SINR}_{\mathrm{target},i}}{\mathrm{SINR}_i(n)} + 0.1 \right], P_{\max} \right\}, \tag{3}$$

where $P_{i,j}(n)$ and $\mathrm{SINR}_i(n)$ is the power and SINR, respectively, at time step n in the iteration. Furthermore, $P_{\max}$ denotes the maximum allowed value of $P_{i,j}$, and $\mathrm{SINR}_{\mathrm{target},i}$ is the target SINR for UE i. UEs which hit $P_{\max}$ without reaching their target SINR are defined to be in outage. The iteration is initialized with low values of $P_{i,j}$ and continued until the SINRs of all the UEs not in outage are sufficiently close to their target SINRs.

The powers obtained from (3) are then summed on a cell-by-cell basis and by adding the power in the common channels we obtain the total required DL power in each cell. This power is used as performance measure when we optimize the RBS antenna beamwidth. It is a relevant optimization criterion since any savings in power can be used to increase the capacity of the system.

The antenna pattern is modeled by a Gauss shaped main beam with a sidelobe floor according to

$$A(\phi) = A_0 \max\left[\, e^{-1.2\log 10\,(\phi/\mathrm{HPBW})^2},\ \mathrm{SLL}\,\right], \tag{4}$$

where A_0 is the antenna gain, HPBW is the half-power beamwidth, and SLL is the sidelobe level. Fig. 1 illustrates an example of this model. This model is suitable for optimization since it renders a simple parametrization of the beam pattern in terms of HPBW and SLL. The idealized model of the sidelobe region is desired since we do not want to draw general conclusions from the specific sidelobe structure of a particular antenna. The gain is kept constant as the HPBW is changed. This is not physical, but a change in gain (the same for all antennas in the network) has no impact on the required DL power if the system is interference limited. This can be seen easily from (1). We assume that the elevation pattern is isotropic except when we study the impact of electrical downtilt on the optimal azimuth HPBW. In this case we use the model in (4) also for the elevation pattern.

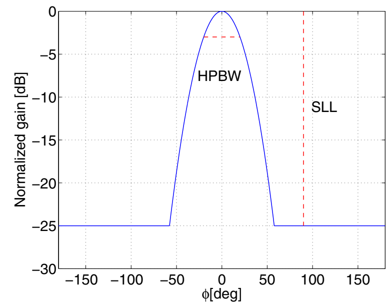

Fig. 1. Beampattern model when HPBW = 40° and SLL = -25 dB.

We model path loss according to the Hata model [7] and shadow fading by a lognormal distribution around the mean path loss. Correlation in the shadow fading between a UE and the different base stations is modeled by assigning one fading component to each link, $F_{i,j}$, and one related to the UE, F_i, according to [8]

$$F = \sqrt{\rho}\, F_i + \sqrt{1-\rho}\, F_{i,j}, \tag{5}$$

where ρ is the correlation between the components. We ignore any spatial correlation of the lognormal fading since we have found in simulations that this has no significant impact on the optimal HPBW and it is computationally demanding to generate correlated fading samples. Fast fading is accounted for implicitly when specifying a target SINR and using an average non-orthogonality factor.

III. Performance Optimization

A. Simulation Setup

We evaluate system performance by means of Monte Carlo simulations. In each Monte Carlo trial, a specified number of UEs are placed at random positions in such a way that all positions in the network are of equal probability. The UE positions are fixed within a trial, i.e. mobility is not modeled in the simulator. New realizations of the lognormal fading are also produced in each trial. We use the total number of UEs divided by the number of cells in the network as a measure of the average number of UEs per cell. We assume that all UEs require the same service of 12.2 kbps, which implies that all UEs will have the same processing gain and target SINR. Furthermore, the link dependent non-orthogonality factor $\alpha_{i,j}$ is for simplicity replaced by an expected average factor, α.

A nominal network configuration is created by placing the sites on a regular hexagonal grid. We study 3-sectorized and 6-sectorized networks separately, i.e. a network consists either of only 3-sector sites or either of only 6-sector sites. In the nominal network, all sites have identical antennas and are oriented according to an Ericsson cell plan if the network consists of 3-sector sites and according to a Bell cell plan if the network consists of 6-sector sites, see Fig. 2.

Although such regular networks are often used in theoretical studies they never appear in real life due to various deployment

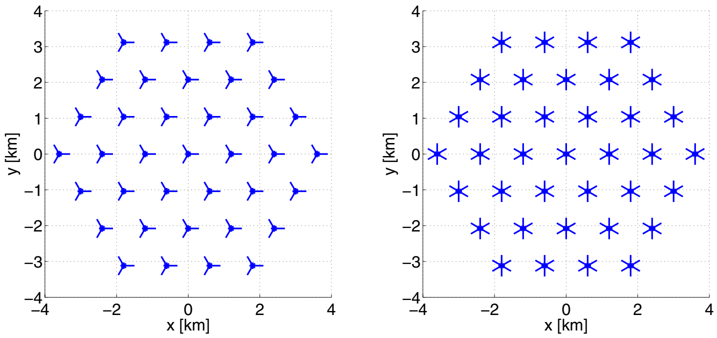

Fig. 2. Nominal network configurations for 3-sector (left) and 6-sector (right) networks. The lines indicate the pointing directions of the RBS antennas.

constraints. To simulate irregular networks we apply random perturbations to the regular network. The irregularities are simulated by making random changes in the site positions and orientations and the pointing directions of the individual antennas.

In order to quantify how the optimal HPBW is affected by network irregularities we use the size of the random perturbations as a measure of irregularity. The site positions are changed by moving each site a random distance in a random direction. The distance is drawn from a uniform distribution on $[0, R_{\max}]$, and the direction from a uniform distribution on $[0, 360°]$. The site orientations are changed by rotating the entire site by a random angle ψ_s and the individual antenna pointing directions are then rotated by additional random angles ψ_a. Both ψ_s and ψ_a are drawn from a uniform distribution on $[0, \psi_{\max}]$. We use $R_{\max}$ and $\psi_{\max}$ as measures of network irregularities.

The criterion function used in the optimization is then computed by averaging the required DL power in the center site over all Monte Carlo trials. We use only the center site in order to reduce edge effects when simulating a finite network. Due to computational requirements we are limited to include three tiers of surrounding sites, which amounts to a total of 37 sites in the network.

B. Simulation Results

First, we compute the DL power as a function of HPBW for a default setting of the model parameters according to Table I. The results for this simulation are shown in Figure 3. The optimal beamwidths, indicated by dots in the figure, are in this case 63° and 35° for 3- and 6-sectorized systems, respectively. We also note that the curve is flat around the optimum, which shows that the DL power is not very sensitive to the choice of beamwidth. In fact, we can choose any beamwidth in the intervals $[48°, 80°]$ and $[24°, 52°]$ for the 3- and 6-sector case, respectively, without requiring more than an additional 10% of the minimum power. These intervals are indicated by dashed lines in the plots. We can view the lengths of these intervals as measures of how robust the performance is with respect to the choice of HPBW.

However, it may be hazardous to draw general conclusions from one specific example. The optimal solution may depend

Site-to-site distance	1200 m
Base station height	20 m
Processing gain	25 dB
Target SINR	7.6 dB
CCH power, P_{CCH}	3.8 W / 1.9 W for 3/6 sector
SCH power, P_{SCH}	0.2 W / 0.1 W for 3/6 sector
Noise power, N_0	-97 dBm
Average non-orthogonality factor, α	0.3
Path loss	$134 + 35\log_{10} R$ dB, R in km
Lognormal fading standard deviation	8 dB
Fading correlation between different cells, ρ	0.5
Antenna gain	18 dBi / 21 dBi for 3/6 sector
Elevation HPBW (when applicable)	7°
Elevation SLL (when applicable)	-15 dB
Azimuth SLL	-20 dB/ -25 dB for 3/6 sector
Handover margin	3 dB
Max #links in active set	3
Max DCH power, $P_{\max}$	1 W
Average number of UEs per cell	30/20 for 3/6 sector
Number of sites in network	37

TABLE I
DEFAULT PARAMETER SETTINGS USED IN THE SIMULATIONS.

on many different parameters. In order to obtain some results of more general applicability we study how the optimal HPBW is affected by changes in the default setup. We also investigate if the length of the HPBW interval for $<$10% more power than optimal is affected by parameter changes. A joint optimization over all parameters in our simulation model is not feasible due to computational requirements. Therefore, we study the behavior when one parameter is changed at a time, keeping the others fixed at their default values.

We will study how the optimal HPBW is affected by changes in the following parameters:

- Antenna sidelobe level
- Site orientation, defined as counterclockwise rotation from an Ericsson cell plan (= 0° for Ericsson plan and 30° for Bell plan)
- Standard deviation of the lognormal fading
- Non-orthogonality factor
- Average number of UEs per cell

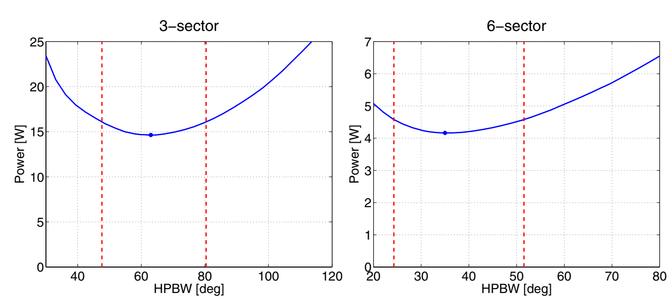

Fig. 3. Average DL power vs HPBW for the default simulation setup.

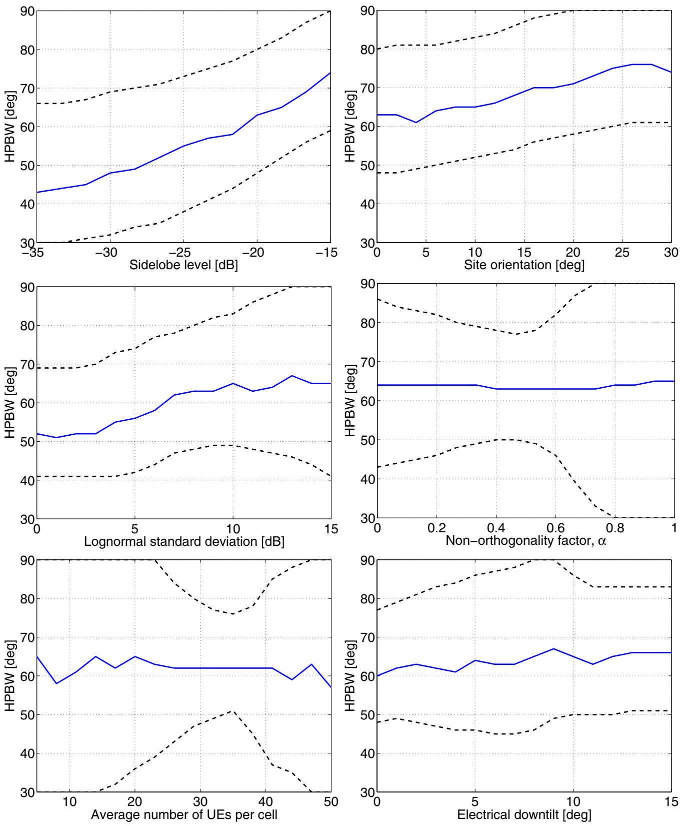

Fig. 4. Optimal HPBW (solid) and HPBW corresponding to <10% additional power from optimum (dashed) vs model parameters for the 3-sector regular network using parameter settings according to Table I.

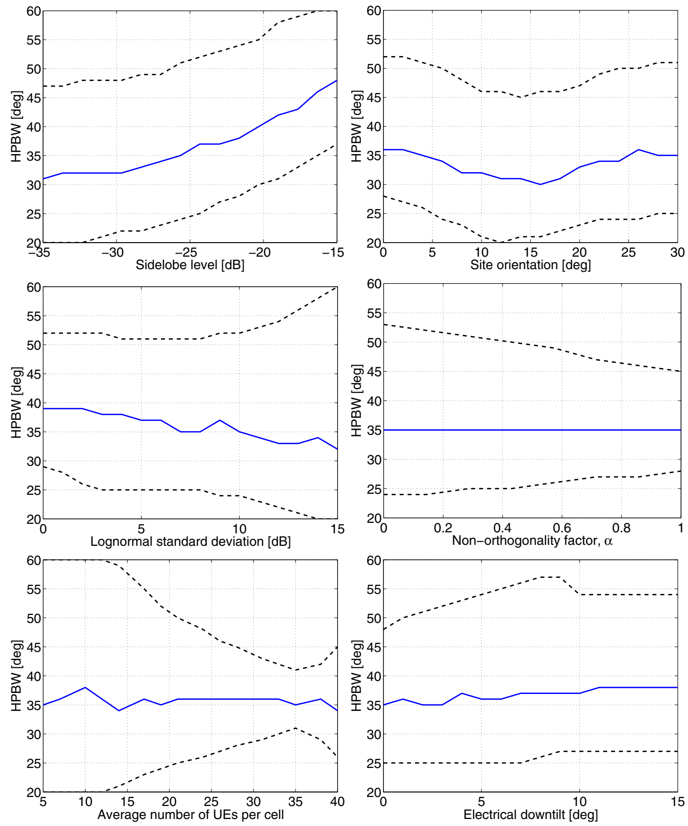

Fig. 5. Optimal HPBW (solid) and HPBW corresponding to <10% additional power from optimum (dashed) vs model parameters for the 6-sector regular network using parameter settings according to Table I.

- Electrical downtilt (downwards from the normal of the antenna)

The impact of these parameter changes on the optimal HPBW is studied for regular networks only. The impact of irregularities is then studied separately using the default values for the parameters listed above.

1) Regular Networks: Figure 4 and 5 show how the optimal HPBW depends on changes in the parameters listed previously for 3- and 6-sectorized regular networks, respectively. The solid curves show the power-optimal HPBWs and the dashed curves show the end points in the 10% interval described previously.

For 3-sector networks the optimal HPBW increases with the sidelobe level, site orientation, and the fading standard deviation. Changes in the non-orthogonality factor, the number of UEs, and tilt have no significant impact on the optimal HPBW.

For 6-sector networks the behavior of optimal HPBW is similar to the 3-sector case with respect to all parameters except site orientation and fading standard deviation. The optimal HPBW is the same for 0° and 30° site orientation but shows a minimum at around 15°. Unlike the 3-sector case the optimal HPBW decreases with increasing fading standard deviation in the 6-sector case.

The different behavior of the optimal HPBW with respect to site orientation and fading standard deviation for 3- and 6-sector networks is coupled to the different cell plans, recall Fig. 2. A site in an Ericsson cell plan can have relatively narrow beams since the cross-over region (angular region where the straddling loss is high) between the beams in adjacent sectors is covered by the main beam from the neighbor sites. A site in a Bell cell plan needs to have wider beams since the antennas point toward the symmetry points between the sites. For a 6-sector network, 30° site orientation corresponds to a Bell cell plan. When the site orientation is 0° the antennas on different sites point toward each other, whereas 15° site orientation is more similar to an Ericsson cell plan (an exact Ericsson plan is not possible for 6-sector networks). This can explain the different behavior of the 3- and 6-sector networks with regard to site orientation.

The different behavior of the 3- and 6-sector networks with regard to the fading standard deviation can be explained by looking at the region with lowest path gain. A UE in a low-gain cross-over region between two narrow beams in a 3-sector Ericsson cell plan is dependent on high path gain to a cell in the neighbor site. However, this support will disappear if there is a fading dip between the UE and the cell in the neighbor site. If the beams in the own site are wider this effect is reduced since the cross-over region is reduced. The “weak point” in a 6-sector Bell plan is on the middle of a straight line between adjacent sites. However, at this position there are 6 viable candidate cells to serve the UE. In this case the beams can be

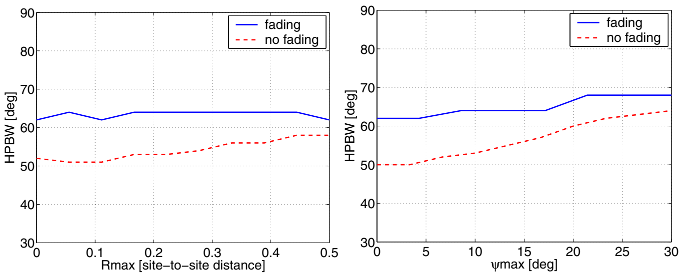

Fig. 6. Optimal HPBW vs network irregularity parameters for 3-sector.

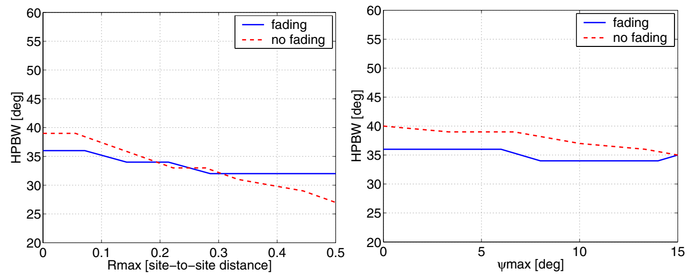

Fig. 7. Optimal HPBW vs network irregularity parameters for 6-sector.

made more narrow since the path gain to at least one cell will fade up with high probability. This is in contrast to the 3-sector case in which a UE at the weakest position is dependent on high path gain to one single cell.

Regarding the 10% interval, we can see that it increases when the fading standard deviation increases and decreases when the non-orthogonality factor increases. When the lognormal fading is strong it neutralizes the spatial filtering property of the antennas since it randomizes the path gain between the base station and UEs. Therefore, the sensitivity to the choice of HPBW is reduced. The 10% interval decreases when the number of UEs and non-orthogonality factor increases. This can be explained by the choice of HPBW being more important when the interference level in the system is high. In the 3-sector case, the interval becomes broader when the number of UEs and non-orthogonality factor increase above a certain point. The reason for this change of behavior is that at this point there is a rapid increase in the number of UEs that are in outage. Since UEs in outage have reached a power limit the dependence on HPBW will level out.

2) Irregular networks: Random changes in site positions, site orientations, and antenna pointing directions will have an effect similar to shadow fading since they all produce random changes in path gains between base stations and UEs. If the fading standard deviation is high, the effects of network irregularities may therefore be hard to discern (and vice versa). Therefore, we will show how the optimal HPBW depends on network irregularities both with and without fading.

Figure 6 and 7 show how the optimal HPBW depends on the size of network irregularities for 3- and 6-sector networks. The solid curves show the optimal HPBW when there is 8 dB lognormal fading and the dashed curves when there is no fading present. As expected, the dependence on the size of the irregularities is weak when there is fading. When there is no fading it can be seen that irregularities have similar impact on the optimal HPBW as the lognormal fading has alone, cf. Fig. 4 and 5.

IV. Conclusions

We have investigated the problem of optimizing the azimuth HPBW of the base station antennas in WCDMA networks with 3 or 6 sectors per site. The optimization problem has been posed as minimizing the average downlink power in an interference limited environment. For a default simulation setup the criterion was found to have a flat optimum at around 35° and 63° for 6- and 3-sectorized systems, respectively. There is an approximately 30° wide interval of HPBWs which require less than 10% more power than the optimal solution. This robustness property can be utilized to take other aspects into consideration when a base station antenna shall be designed, e.g. cost and other issues not modeled in our simulator.

Furthermore, we have investigated how the optimal HPBW and the 10% interval is affected by changes in other system design and environmental parameters. We found that the parameters having the strongest impact on the optimal HPBW are the antenna sidelobe level, site orientation, shadow fading standard deviation, and network irregularities. Briefly speaking, narrow beams are preferred in regular Ericsson cell plans with weak shadow fading and using antennas with low sidelobes. Parameters with weak impact on optimal HPBW are interference orthogonality, traffic load, and electrical downtilt. We also found that performance is more sensitive to the choice of HPBW when fading standard deviation and interference orthogonality are low and when traffic load is high.

The results presented in this paper are based on downlink capacity in interference limited scenarios using a static system simulator. There may be several aspects not covered by this model that could have an impact on the choice of beamwidth, e.g. coverage, uplink performance, dynamic effects, and site installation issues.

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