

# Downtilted Base Station Antennas – A Simulation Model Proposal and Impact on HSPA and LTE Performance

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**Abstract**— This paper proposes a low-complexity model for vertical antenna radiation patterns, e.g. for inclusion in system-level simulations. They can be seen as extensions to the horizontal radiation pattern model used in 3GPP simulation scenarios. The model is verified against and compared to predicted and measured data from real networks. The impact on system-level performance is also investigated. It is seen that using the proposed model, simulated geometry distributions and soft handover statistics closely matching those of real networks may be achieved. The analysis also concludes that many real networks have better cell isolation than what is modeled by the 3GPP antenna model. As a consequence, the horizontal radiation pattern model significantly under-estimates the system level performance in such networks. Furthermore, the proposed model is used to assess the LTE and HSPA system-level performance for realistic scenarios.

**Keywords**- Antennas, radiation patterns, models, base stations, land mobile radio cellular systems, system level performance, LTE, HSPA, WCDMA.

## I. INTRODUCTION

The increasing demand for wireless services implies a need for efficient cellular radio networks. This means more efficient and capable radio links and systems, but also more efficient network deployments and tuning. When evaluating the benefits of different features in system simulations, it is important that the simulated cellular network deployment represents a realistic network deployment. This is subjective, since there are large variations between different deployments of the same system, as well as different requirements on the deployment from different systems.

For example, in some systems like GSM, frequency planning can be adopted so that adjacent cells are allocated different frequencies in order to avoid co-channel interference. This means that such cells may have a quite large overlap without causing significant interference between communications links. Other systems like WCDMA use the same frequency band in all cells, which means that large cell overlaps cause significant inter-cell interference from adjacent cells. However, WCDMA supports macro diversity or soft(er) handover, which means that some cell overlap is beneficial. In LTE, where the same frequency band is used by all cells and no macro diversity is adopted, an even smaller cell overlap is desirable. When co-siting different radio access technologies using the same antennas, there is a trade-off between all these aspects.

When evaluating capacity and spectrum efficiency, it is important that the simulated cellular network deployment represents a well planned network deployment where efforts have been spent on limiting the cell overlap. In order to allow comparisons between different system simulation campaigns, a set of simulation scenarios needs to be agreed upon. Important parameters include propagation parameters, inter-site distances, antenna properties, channel models, etc. Such parameters typically vary between radio access technologies and the considered frequency bands. Some scenarios are defined in 3GPP for Evolved UMTS Terrestrial Radio Access (E-UTRA) evaluations [1], essentially based on scenarios inherited from prior UMTS evaluations.

Base station antennas usually have directivity in the vertical plane. In many cellular networks, this is utilized to improve cell-isolation by antenna down-tilting. This effect is however not always included in simulation-based system-level evaluations. Instead, only a horizontal radiation pattern is used as antenna gain model [1][2], with the vertical pattern only implicitly modeled via the maximum antenna gain. However, numerous publications have reported on the impact of modeling the vertical pattern on capacity, coverage, interference, etc.

Antenna downtilting has been identified as an efficient means to reduce the inter-cell interference in both uplink and downlink and consequently increase the capacity [2]-[9]. However, too aggressive downtilting may result in insufficient coverage and mobility support. Furthermore, also the antenna beamwidths and the sectoring properties of the antennas are important as has been reported in [7][10][11].

In this paper, a simple model of a vertical antenna pattern is proposed. An early version of this model was tested for WCDMA in a single-cell scenario (with wrap-around), indicating the potential for large performance gains in real networks with properly tilted antennas [7]. Moreover, simulations based on measured horizontal and vertical antenna patterns from the Kathrein antenna 742215 [12] (common macro deployment antenna) with adequate tilting also shows significant gains [9].

The objective with this paper is to propose an antenna model suitable for systems simulations, and tune the proposed antenna model to measured antenna patterns, simulated realistic deployments, as well as observed network statistics. Thereby, the antenna model can be used in conjunction with hexagonal deployment models to represent realistic well planned deployment conditions in system simulations and performance evaluations. Section II provides the proposed

TABLE I. ANTENNA MODEL PARAMETERS ADOPTED FROM KATHREIN 742215 AT 2140 MHZ.

$G_m$	$HPBW_h$	$FBR_h$	$HPBW_v$	$SLL_v$
18 dBi	65°	30 dB	6.2°	-18 dB

antenna model, and this model is tuned to realistic network data in Section IV. In addition, we investigate the impact of the antenna model on LTE and WCDMA performance in Section V. The simulated scenarios in these two sections are further described in Section III. Finally, Section VI gives some concluding remarks.

## II. ANTENNA MODELING

The objective with the proposed model is to extend the model in [1][2] with a vertical antenna pattern. Furthermore, it is desirable that the model parameters are physical, and can be related to data sheet parameters of real antennas. Kathrein 742215 [12] is a commonly deployed antenna, and it has e.g. been used in the system performance evaluation in [9]. This antenna will serve as a realistic reference and provide data sheet parameters to the proposed antenna model.

The horizontal (azimuth) gain model in [1][2] is parameterized with a max gain  $G_m$  dBi, horizontal half-power beamwidth  $HPBW_h$  degrees, and a front back ratio  $FBR_h$  dB, which are combined in the gain expression according to

$$G_h(\varphi) = -\min(12 * (\varphi / HPBW_h)^2, FBR_h) + G_m \quad (1)$$

where  $\varphi$ ,  $-180^\circ \leq \varphi \leq 180^\circ$ , is the horizontal angle relative the main beam pointing direction. The selected parameters values in [1] are  $G_m = 14$  dBi (including a 4 dB feeder loss),  $HPBW_h = 70^\circ$ , and  $FBR_h = 20$  dB.

One of the intentions with the proposed vertical gain component is that it should be simple, in order to make system simulations tractable. Therefore, the same structure as for the horizontal component is re-used for the vertical component, parameterized using the vertical half-power beamwidth  $HPBW_v$  degrees, a side lobe level  $SLL_v$  dB relative the max gain of the main beam, and an electrical downtilt angle  $\theta_{eilt}$  in degrees

$$G_v(\theta) = \max(-12 * ((\theta - \theta_{eilt}) / HPBW_v)^2, SLL_v) \quad (2)$$

where  $\theta$ ,  $90^\circ \leq \theta \leq 270^\circ$ , is the negative elevation angle relative the horizontal plane (i.e.  $\theta = -90^\circ$  is upwards,  $\theta = 0^\circ$  is along the horizontal plane, and  $\theta = 90^\circ$  is downwards). Parameter values are obtained from the Kathrein 742215 data sheet for 2140 MHz and are summarized in Table I.

Fig. 1 shows horizontal and vertical antenna patterns of the Kathrein antenna together with the horizontal antenna pattern described in [1][2] as well as the proposed antenna model. Clearly, the proposed antenna model captures the main characteristics of the Kathrein antenna.

The modeled or measured data only describe the antenna along horizontal and vertical cuts, respectively. In order to describe the antenna gain in a general direction  $(\varphi, \theta)$ , an interpolation procedure is needed. Different interpolation

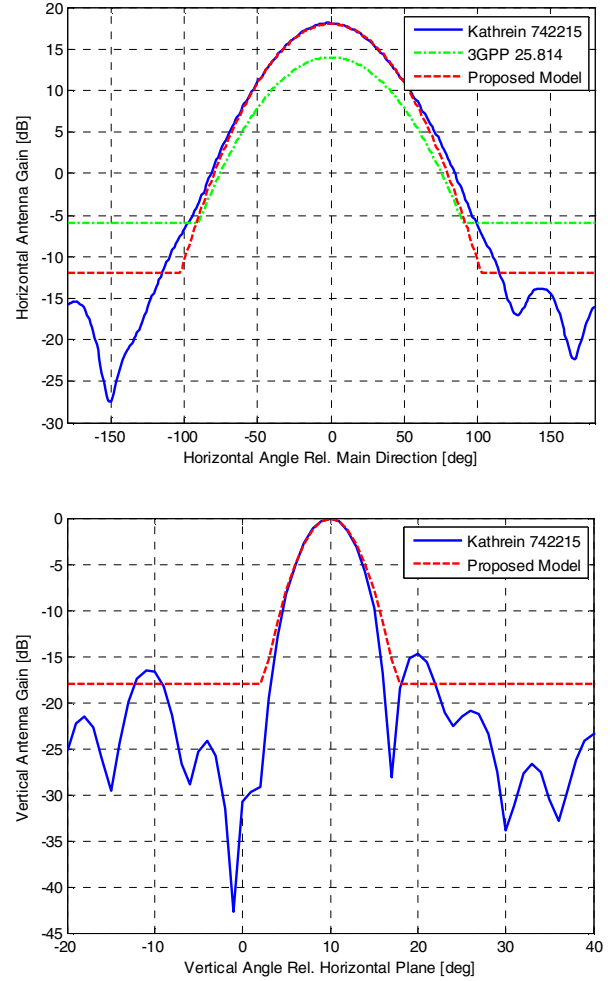


Figure 1. Top: Horizontal antenna patterns of Kathrein 742215, the model in [1][2] as well as the proposed model. Bottom: Vertical antenna pattern (normalized) of Kathrein 742215 with 5 deg. electrical tilt and 5 deg. mechanical tilt, and the proposed model with 10 deg. downtilt.

approaches has been presented in the literature, either with the ambition to represent full-sphere measurements as accurately as possible, or to represent the full-sphere gain with only a small set of parameters. The ambition here is to use a simple interpolation scheme suitable for systems simulations, e.g. as discussed in [13][14]. The conclusion is that a careful weighting of the horizontal and vertical models improve the accuracy, but for simplicity, the two gain components are added with unity weights:

$$G(\varphi, \theta) = G_h(\varphi) + G_v(\theta) \quad (3)$$

Moreover, the entire interpolated radiation pattern may be rotated by the mechanical downtilt angle  $\theta_{milt}$ . This will for example up tilt the antenna backlobe.

## III. MACRO-CELL SIMULATION CASE

The macro-cell simulation case in [1] is based on a hexagonal 19-site deployment with 3-sector sites and wrap-around propagation. The latter means that the cell layout is folded like a torus in order to avoid boundary effects.

TABLE II. MODELS AND ASSUMPTIONS

Parameter	Value
Traffic Model	Full buffer (10 users per sector)
User location	Uniform distribution
Site-to-site distance	500m
BS antenna height	30 m
Carrier frequency	2.0GHz
Carrier bandwidth	LTE 10MHz , HSPA 5MHz
Distance-dependent pathloss	$L = 1 + 37.6 \cdot \log_{10}(R) + P$ , R in km, $I = 128.1$ for 2GHz, $P = 20$ dB penetration loss
Lognormal shadowing	8dB std dev, 50m correlation distance, 0.5 correlation between sites
Channel model	3GPP SCM, Urban Macro High Spread (15 deg), extended to 10MHz
Terminal speed	3km/h
BS / Terminal power	LTE 46dBm / 23dBm, HSPA 43dBm / -
Antenna configurations	BS: 2 transmit and receive Terminal: 1 transmit, 2 receive
Scheduler	LTE: DL: Proportional fair in time and frequency, UL: Quality-based FDM
MIMO	Codebook-based pre-coded adaptive rank MIMO
Power control	Open loop with fractional pathloss compensation ( $\alpha=0.8$ ), SNR target 10dB at cell edge
Receiver type	MMSE with SIC in DL

Table II provides central modeling parameters and assumptions. In addition to the antenna pattern provided in [1], the proposed antenna model is considered with different downtilt angles, 8-10 degrees.

#### IV. REPRESENTING REALISTIC DEPLOYMENTS

Network data is approached in two different ways – either as statistics of soft handover data, or as planner models providing downlink radio and interference conditions. Both types of data are compared to data from system simulations based on the hexagonal case described in Section III, but for one carrier WCDMA and a Pedestrian A channel model.

Fig. 2 illustrates the soft handover statistics from 25 different networks. The statistics is presented in terms of the *average soft handover factor*, which is the average number of additional radio links, i.e. in addition to the one obvious radio link. Note that the overlap between cells is much different in the different networks, ranging from very well-planned networks, to networks with extensive overlap and consequently extensive inter-cell interference.

In the comparable system simulations, active set updates are based on realistically parameterized intra-frequency measurements. Active set additions are based on a 3 dB triggering threshold relative serving cell and time-to-trigger 320 ms, while removals are based on a 5 dB triggering threshold relative serving cell and time-to-trigger 640 ms. Furthermore, L1 and L3 filtering are also realistic. It can be concluded that the overall behavior in terms of the soft handover factor is lower in more than half of the observed

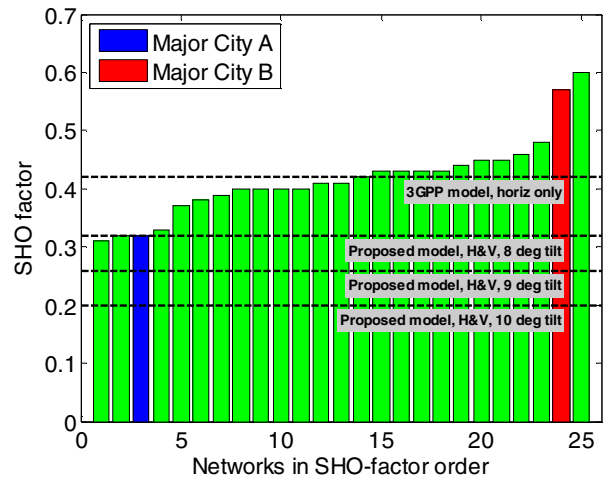


Figure 2. Soft handover factor statistics for 25 different networks.

networks compared to a network with an antenna model according to [1][2].

In order to model networks where tuning efforts are spent, it is important to consider a vertical antenna gain component. The four best planned networks with respect to average soft handover factor match well with the 8 degree electrical tilt simulation scenario according to Figure 2. Note that this is the overall network figures and most of the networks consist of thousands of cells. It can be expected that cell overlap optimization has been done for only some parts of each network, such as in high load densely planned areas. As an example, within the network in major city B, with the highest average soft handover factor of the two, there are several hundreds of cells with a soft handover factor below 0.2. As another example, 70% of the cells in city A have better soft handover factor than what is modeled by the 3GPP model with only a horizontal radiation pattern. Hence, for capacity evaluation of densely planned areas the simulation environment with 10 degree tilt may be more appropriate.

The soft handover statistics describe the impact from the antenna pattern on the cell overlap, but it does not capture the impact on the inter-cell interference. Therefore, two network deployments in major cities A and B with soft handover factors according to Fig. 2 have been modeled with care in a cell planning tool [15]. The modeling includes the exact site locations, antenna orientations, antenna patterns per individual antenna, and tuned path gain propagation based on terrain and elevation information. The downlink geometry, defined as the received power from the serving cell divided by the received power from other cells plus thermal noise, is well correlated to downlink performance. It is gathered from static simulations of the two network models with all cells operating at max power. The distributions are either based on all cells, or on the cells with the 10% best average downlink geometry. The latter represents the regions of the network with the best cell isolation. System simulations based on the deployment and propagation in III give comparable downlink geometry distributions, and Figure 3. illustrates the comparison.

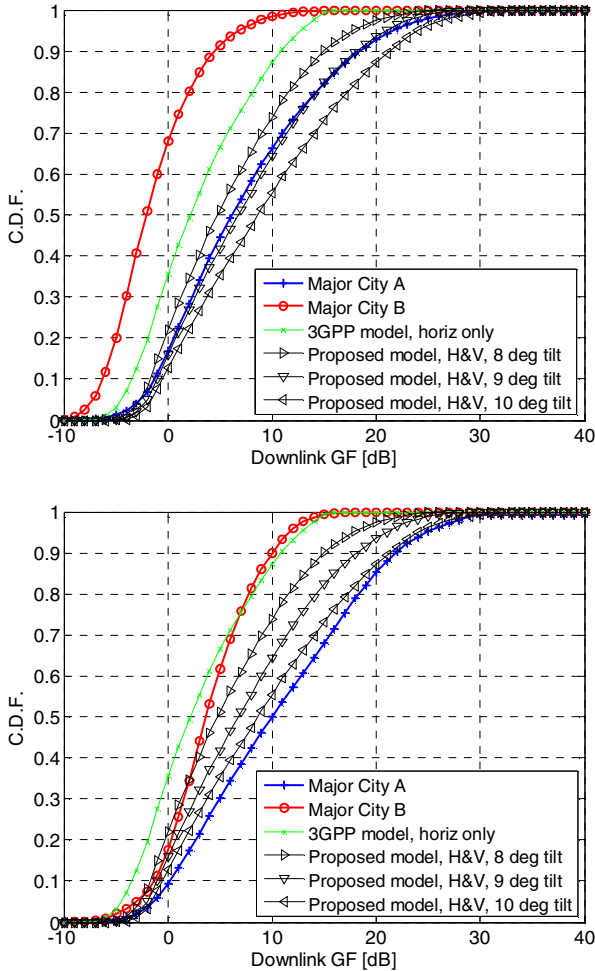


Figure 3. Downlink geometry distributions based on deployment in two different cities, and hexagonal deployment and the proposed antenna model with different electrical tilt. Top: the geometry distributions considering the entire service areas of the realistic deployments. Bottom: the geometry distributions considering the service areas of the cells with the 10 % best average geometry in the realistic deployments.

Again, the conclusion is that there are real networks with much better cell isolation than is captured by the antenna model in [1][2]. The proposed antenna model better describes a realistic network that is reasonably well planned and tuned compared to a model where the vertical gain component has been omitted.

In summary, the simulated hexagonal case described in Section III with a electrical downtilt of 8 degrees gives a reasonable model of a well planned but realistic whole network. Furthermore, in areas where tuning efforts have resulted in good cell isolation, a downtilt of up to 10 degrees can be considered representative.

## V. SYSTEM PERFORMANCE EVALUATIONS

The impact of the antenna models on system performance of 3GPP LTE and HSPA (based on 3GPP release 8) has been evaluated. The performance is evaluated both using the antenna model in [1][2] based only on a horizontal gain model

TABLE III  
SPECTRUM EFFICIENCY [BPS/HZ/SECTOR]

System	SE horizontal model	SE proposed model, 8 deg	SE proposed model, 10 deg
HSPA DL	1.5-1.9	1.7-2.2	2.0-3.2
LTE DL	1.7-1.9	2.4-2.6	3.4-3.7
LTE UL	1.0	1.5	2.0

and the proposed antenna model with 8 and 10 degrees vertical tilt. Other models and assumptions are aligned with the recommendations in [16]. Table II contains a brief summary. The evaluation methodology is based on time-dynamic, multi-cell system simulations.

Fig. 4-6 show user throughput distributions, normalized with system bandwidth, for HSPA downlink, LTE downlink, and LTE uplink respectively. Significant increases in user throughput are achieved with the proposed model in all cases. With 10 degree downtilt, a gain of about a factor two is achieved for most percentiles. Note that this also includes the cell-edge users (low percentiles). The observed performance improvements are due to a reduction of the intercell interference.

Spectrum efficiencies are summarized in Table III. In a fully loaded network with full buffer traffic, the spectrum efficiency equals the mean normalized user throughput multiplied with the number of user per sector (10). In general, achievable spectrum efficiencies depend strongly on models and assumptions. To capture this, in addition to the antenna model, also overhead and channel model assumptions are varied. This results in the spectrum efficiency ranges given in Table III. It is seen that also in this measure increases of about a factor two are achieved with the proposed model and 10 degrees downtilt. With 8 degrees downtilt the increase is about a factor 1.2-1.4.

## VI. CONCLUSIONS

Antenna tilting has a large impact on system performance and should hence be considered when performing such evaluations. The proposed antenna radiation pattern model provides a low-complexity means for this, suitable for system-level simulations.

When evaluating capacity and spectrum efficiency in a densely planned scenario, the simulation environment should model well-planned regions of a network. Real network measurements and predictions have been compared with the commonly used 3GPP simulation case with 500m site-to-site distance, and both the proposed antenna model and the horizontal-only gain model. Analysis of network statistics and simulation campaigns concludes that many real networks have better cell isolation than what is modeled by the 3GPP antenna model. However, the proposed antenna model with an appropriate downtilt can be seen as a representative model for realistic well-planned network deployments. As a consequence, the horizontal-only antenna gain model significantly underestimates the system level performance in such networks. Furthermore, the proposed model is used to assess the LTE and

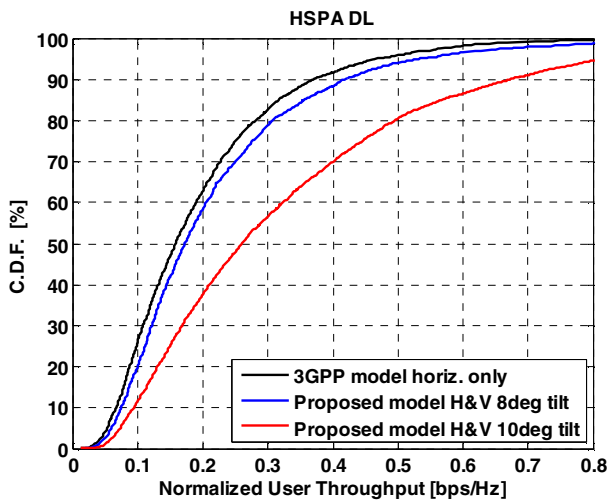


Figure 4. HSPA downlink normalized user throughput distribution.

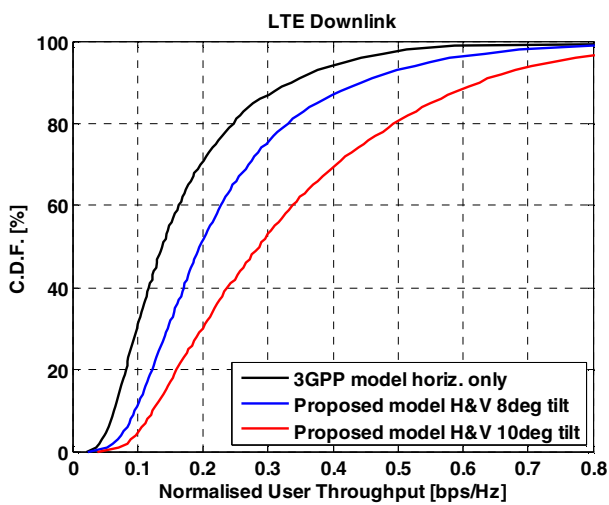


Figure 5. LTE downlink normalized user throughput distribution.

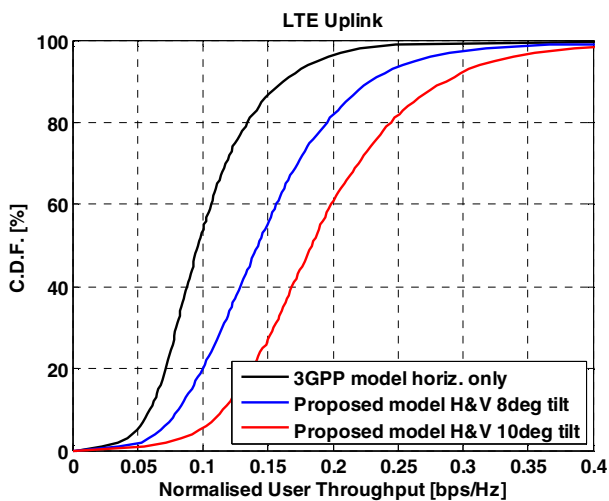


Figure 6. LTE uplink normalized user throughput distribution.

HSPA system-level performance for realistic scenarios. The difference in predicted system level performance between using the horizontal gain model and using the proposed model is about a factor of two.

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