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Performance of HSPA Vertical Sectorization System under Semi-Deterministic Propagation Model

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Abstract

The performance of the Vertical Sectorization (VS) system has been evaluated previously using an empirical propagation model and a regular network layout. In this paper, our aim is to investigate the gain of the VS system under a more realistic scenario. A semi-deterministic path loss model run on a detailed 3D digital map is used for the evaluation. In addition, a real-world network layout and user density map is loaded into the simulator to represent a typical medium-size European urban city. The study shows that the empirical path loss model tends to overestimate the gain of the VS system, due to the fact that it is unable to take the complex relationship between the path loss and the antenna pattern into account. The size of the inner sector coverage is often a critical parameter for the VS deployment, and low gain is observed for VS when there is no or low number of users in the inner sector. As a result, for accurate network planning, a reliable 3D propagation model is required. ***Index Terms*—vertical sectorization, antenna, HSPA, path loss, propagation, 3GPP.**

I. Introduction

The Vertical Sectorization (VS) refers to splitting a horizontal sector in mobile cellular radio system into two co-channel sectors in the vertical plane. This is accomplished by using active antenna system, whose multiple antenna elements can be arranged to create two separate beams with different antenna parameters (i.e. downtilt, half-power beamwidth). The antenna beam of one of the sectors is tilted more down than the beam of the other one. In this way the antenna beams are partially overlapping. Since there is an overlap, there will be additional inter-cell interference, but the impact of that to the system throughput is more than compensated by the doubling of the number of sectors.

The performance of VS system has been earlier studied for the Long-Term Evolution (LTE) in [1] and for the High-Speed Packet Access (HSPA) in [2]. Both papers discussed the VS gain simulated using the empirical Third Generation Partnership Project (3GPP) propagation model in a regular base station grid defined as the 3GPP Case 1 with inter-site distance (ISD) of 500 meter. A simple three dimensional model was used for the antenna radiation pattern, but the bending of signal propagation paths due to obstacles, like buildings, was not taken into account. Their studies finds that the VS system is able to provide up to 47% capacity gain for the LTE and 59% for the HSPA network.

In this study we focus on the impact of propagation modeling to the simulated performance of VS in urban environment. In the typical installation the base station antennas are located on the roof-tops, but the users are located below roof-tops. Thus the signal cannot travel in a straight line, but is refracted and reflected by the buildings. This will often lead to a situation, where the vertical direction of the signal path at the base station is closer to horizon than the direct line would suggest. This fact is not taken into consideration in the statistical propagation models like the Okumura-Hata or 3GPP propagation models. In this study we compare VS performance simulated by the 3GPP propagation model against similar results obtained by a calibrated semi-deterministic path loss model run on a detailed 3-dimensional digital map. The simulation cases are based on a realistic network layout and user density map.

The rest of the paper is organized as follows. Section II introduces the used propagation models. Section III describes the simulator and its assumptions. It also introduces network layout and user density map. Section IV illustrates the simulated network performance for Signal to Interference plus Noise Ratio (SINR) and downlink throughput. Section V presents conclusions.

II. Propagation Models

In this paper, the performance of VS system is evaluated using two different path loss models. The first is the 3GPP propagation model [3], which is considered as the reference. Since empirical path loss models are usually derived independent of the antenna pattern, the effect of the pattern is often added linearly to the path loss. This is often done assuming that the signal travels between the user equipment (UE) and the base station (BS) in a straight line, or the *direct path*, and the obstructions only add attenuation on the signal as illustrated in Fig. 1. As a result, the 3GPP path loss can be written as:

$$L_{\text{3GPP}} = 128.1 + 37.6\log(d) + S - G(\varphi_{dr}, \theta_{dr}) \qquad (1)$$

where d is the distance in km between the BS and UE, and S is the spatially-correlated lognormal shadow fading. $G(\varphi_{dr}, \theta_{dr})$ is the antenna gain at the azimuth and elevation angle seen by the direct path $(\varphi_{dr}, \theta_{dr})$. This model assumes the base station antenna height is fixed at 15m above the average roof-top, and the carrier frequency is around 2GHz.

In addition to the 3GPP model, we evaluate the VS performance under a semi-deterministic 3D path loss model, namely the Urban Dominant Path Model (UDP) [4]. It predicts the path loss based on the assumption that the strongest signal path between the transmitter and the receiver is so dominant that all other paths can be neglected. The model works in two steps: first it determines all possible signal paths between the transmitter and the receiver taking into account the 3D map of the surrounding, antenna location and altitude. In the second step the loss along each of the paths is calculated using the equation:

$$L_l = 20\log\left(\frac{4\pi}{\lambda}\right) + 10p\log(d) + \sum_{i=1}^{N} f(\beta, i) - \Omega \qquad (2)$$

L_l is the path loss in dB of the l^{th} path with length d and wavelength λ. $f(\beta, i)$ is a function which determines the interaction loss in dB, i.e. the loss when changing the direction of propagation. The angle between the former direction and the new direction of propagation is β, and the loss increases linearly with the angle until a maximum interaction loss is reached [5]. N is the total number of the interaction along the propagation path. The factor p is the path loss exponent, which depends on the visibility situation between the current pixel and the transmitter and the breakpoint distance, similar to the two-ray path loss model. Ω is the waveguiding factor, which is not considered in this study. From 2 we can see that the UDP model does not take reflection phenomenon into account, and therefore it is valid only for low frequency range, where the contribution from reflection to the received signal is neglectable. Finally, the path with the least loss determines the path loss between the transmitter and the receiver:

$$L_{\text{UDP}} = \arg\min_{l} L_l - G(\varphi_{dp}, \theta_{dp}) \qquad (3)$$

The shadow fading is inherently included in the UDP model, due to the fact that it takes the 3D building map into account. Unlike the 3GPP model, the antenna gain in Eq. (3) is evaluated at the azimuth and elevation angle seen by the dominant path, $(\varphi_{dp}, \theta_{dp})$. Fig. 1 illustrates in the vertical plane the dominant path between the BS and UE, assuming that the dominant path is elevated above the roof-top and then diffracted down into the street. The UDP reflects better what is happening in reality than the 3GPP model, and the impact of the simplification made in the 3GPP model is going to be shown in Section IV. To improve the accuracy of UDP model, a drive-test was carried out in the study area, and the UDP parameters were calibrated to the drive-test measurement.

For indoor location, the path loss is computed similar to WINNER II recommendation [6], i.e. a outdoor-to-indoor penetration loss of 20dB and linear indoor attenuation of 0.6dB/m is applied in addition to the closest outdoor path loss.

III. System model

To evaluate the performance of the VS system, an existing real-world HSPA network is loaded into a static snap-shot network-level simulator. The scenario under study is a 5x5km area in a typical medium-size European city. The network layout consists of locations, antenna heights, and bearing angles for 160 sectors, corresponding to 55 BSs, at average

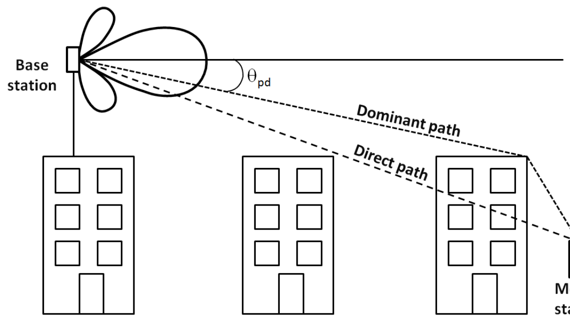

Fig. 1. Direct and dominant path between base station and mobile station.

1-neighbor ISD of 419m (see Fig. 2). The HSPA network is assumed to be single-carrier, operating at 2.1 GHz, with 5 MHz of bandwidth. Each site in the network is typically equipped with 3 horizontal sectors, and therefore it is referred to as the 3x1 reference (3x1REF) network. The transmit power is 43dBm per sector, out of which 10% is reserved for the pilot and another 10% for control signals. Users are dropped in the study area following a spatial traffic density map. The map is created according to the measured traffic load from the real-world network. Simulation statistics are collected from 10 sites (or 31 sectors, one site having 4 sectors) located in the center of the map, so that there is at least 1-tier of interference.

Based on the 3x1REF network, the VS system is formed by adding in the vertical plane an extra sector to each of the horizontal sectors. Therefore the VS system is sometimes referred to as 3x2 network. The same antenna pattern, measured from an active antenna production, is used for all sectors. While the antennas of the original sectors kept their downtilt, the second sectors are deployed with an offset of $+10^o$ to the tilt of the first sectors. Thus the original sectors become the outer sectors and the new sectors are the inner sectors of the VS system. In the VS system, the total transmitting power of 43dBm is splitted between the inner and outer sector, and again 10% of which is reserved for the pilot and another 10% for the control signals. This is to ensure that the total transmitting power per site is the same in all cases. Three VS setups are considered, namely the VS Balanced Transmit Power (VSBAL), VS Unbalanced Outer Sector (VSUNB-O) and VS Unbalanced Inner Sector (VSUNB-I). In the VSBAL case the inner and the outer sector transmits at the same power level, i.e. 40dBm. The VSUNB-O scenario allocates more power to the outer sector, resulting in a transmission power of 41dBm and 38dBm for the outer and inner sector, respectively. In contrast, the inner sectors are 41dBm in the VSUNB-I, leaving the outer sector transmitting at 38dBm.

The system performance is based on computation of the downlink SINR distribution in a sector of interest, i.e. for all UEs served by a specific sector, in the presence of a number of interference sources, i.e. neighboring sectors. Assuming that the network is fully loaded, such that all sectors are transmitting at their maximum power P_{tx} in all Physical Resource Blocks (PRBs), we can simply calculate the SINR

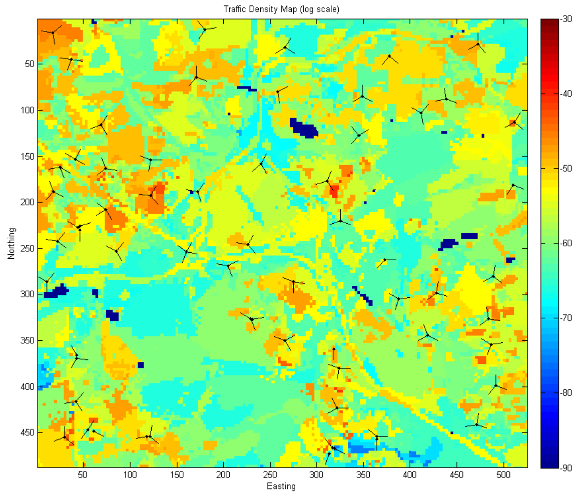

Fig. 2. The network layout and traffic density map (normalized logarithm-scale density).

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Network Layout	55 BSs (with 160 sectors)
Monitored Sites	10 BSs (with 31 sectors)
Carrier Frequency	2100MHz
System Bandwidth	5MHz
Antenna Model	Realistic active antenna
UE Height	1.5m
Path Loss Model	3GPP and UDP
Penetration Loss	20dB
Indoor Attenuation	0.6dB / m
Shadowing STD	8 dB
Shadowing Corr. Distance	50m
Shadowing Correlation	0 (sites), 1 (sectors)
Traffic Distribution	Realistic density map
Traffic Model	Full-buffer
Scheduling	Round-Robin

for the u^{th} UE in the system as following:

$$\text{SINR}_{s,u} = \frac{10^{(P_{tx}-L_{k,u})/10}}{\sum_{i=1;i\neq k}^{K} 10^{(P_{tx}-Li,u)/10} + N_0} \tag{4}$$

where Li, u indicates the path loss from the i^{th} sector to the u^{th} UE, computed by either Eq. (1) or (3). K is total number of sectors in the system and N_0 is the thermal noise power per PRB. We assume that sector selection is based on the strongest received signal strength, regardless of actual UE position and in this case the u^{th} UE is connected to the k^{th} sector. Both of the maximum transmitting power P_{tx} and the path loss Li, u are given in logarithm scale.

The user achievable throughput is calculated based on the SINR-to-throughput mapping curve provided in [7]. The network resources are distributed to each user in a round-robin fashion. All simulation parameters are summarized in Table I.

IV. Simulation Results

In this section, the performance gain of VS system is evaluated in terms of SINR and downlink throughput. Two different

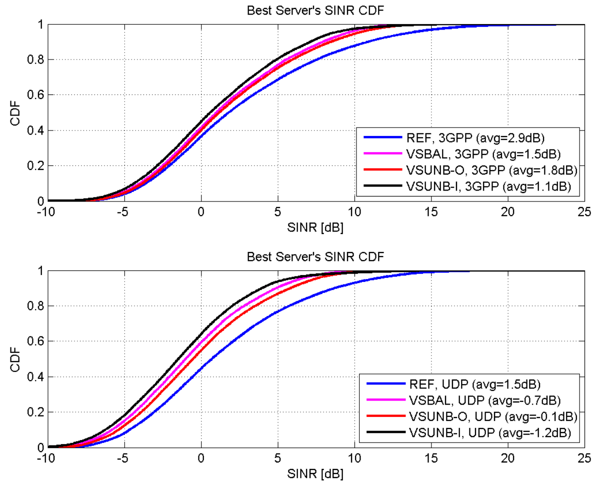

Fig. 3. SINR CDF of the 3x1REF and VS scenarios for (a) 3GPP model and (b) UDP Model.

TABLE II
SUMMARY OF SINR LOSS (DB) FOR VS SCENARIOS, RELATIVE TO 3X1REF CASE

Scenario	3GPP Model		UDP Model	
	5%-tile	Average	5%-tile	Average
VSUNB-O	-0.2	-1.1	-0.7	-1.6
VSBAL	-0.4	-1.4	-1.2	-2.2
VSUNB-I	-0.8	-1.8	-3.1	-2.7

SINR measures are of interest: The 5%-tile represents the cell-edge performance, and the average indicates the overall gain. The throughput is given per site, and the gain is computed in percentage relatively to the 3x1REF network throughput performance.

Fig. 3 illustrates the SINR cumulative distribution function (CDF) of the 3x1REF, VSBAL, VSUNB-I and VSUNB-O scenarios. Due to the deployment of the inner sectors, stronger interference is expected in the all of VS cases, and therefore their SINR is lower compared to the 3x1REF case. Both 3GPP and UDP model indicate that the VSUNB-O achieves the lowest SINR degradation, while the VSUNB-I is the case with the highest SINR degradation. Under the 3GPP model, the performance of three different VS scenarios are very similar, and they are relatively close to 3x1REF case: The 5%-tile and average SINR of the worst case, VSUNB-I, is lower than the 3x1REF by only 0.8 and 1.8dB, respectively (see Table II). On contrary, the UDP model shows much larger difference among VS scenarios, and the 5%-tile SINR loss for the worst case reaches 3.1dB. This is due to the fact that the transmitting power of the outer sector is reduced, and therefore the performance of the cell-edge users are strongly affected.

The SINR heatmap for the VSUNB-O case are shown in Fig. 4. In the figure, the hot color indicates high SINR region, while the cool color represents area with low or negative SINR. We can observe that the 3GPP model predicts much hotter color than the UDP, which indicates a better overall SINR condition. Due to the direct mapping of the antenna pattern in the 3GPP model, there often exists 2 or 3 rings of high SINR regions around the BS, representing the dominance areas of the

TABLE III
SUMMARY OF DOWNLINK THROUGHPUT (MBPS) AND RELATIVE GAIN (%) FOR DIFFERENT SCENARIOS

Site ID	3GPP Model							UDP Model						
	3x1REF	VSBAL		VSUNB-O		VSUNB-I		3x1REF	VSBAL		VSUNB-O		VSUNB-I	
	Tput	Tput	Gain	Tput	Gain	Tput	Gain	Tput	Tput	Gain	Tput	Gain	Tput	Gain
BS01	11.1	20.1	81.2	19.5	75.9	19.7	77.5	10.8	12.4	14.9	11.4	6.0	12.0	11.5
BS02	11.0	17.3	57.0	15.8	43.3	17.6	60.2	9.6	12.8	33.7	13.0	35.4	12.4	29.3
BS03	7.6	12.9	69.6	11.9	55.4	13.9	81.6	7.0	9.9	42.0	9.3	33.0	10.2	45.3
BS04	11.6	19.6	69.8	18.8	62.8	19.6	69.6	9.3	8.3	-10.9	8.1	-13.3	7.9	-15.1
BS05	12.4	21.9	76.4	21.1	70.3	21.9	76.8	7.3	7.8	5.8	7.3	-0.8	7.6	4.4
BS06	12.0	20.5	71.7	19.5	63.2	20.7	73.5	7.7	9.6	23.4	9.9	27.7	9.3	20.5
BS07	13.9	20.8	50.2	19.9	43.3	21.2	52.4	9.5	13.6	43.0	13.3	40.1	13.4	40.5
BS08 [*]	13.5	15.1	12.3	14.8	9.8	15.2	12.9	12.5	12.6	1.2	12.1	-2.7	12.4	-0.4
BS09	8.9	16.6	87.2	15.5	75.1	16.3	84.2	10.1	13.0	29.0	13.3	32.1	12.4	22.9
BS10	9.0	18.0	99.7	17.0	88.8	18.1	100.9	8.6	11.5	34.0	11.0	27.2	11.6	35.2
All sites	110.9	182.9	**64.9**	173.8	**56.8**	184.2	**66.2**	92.4	111.5	**20.7**	108.7	**17.6**	109.3	**18.2**

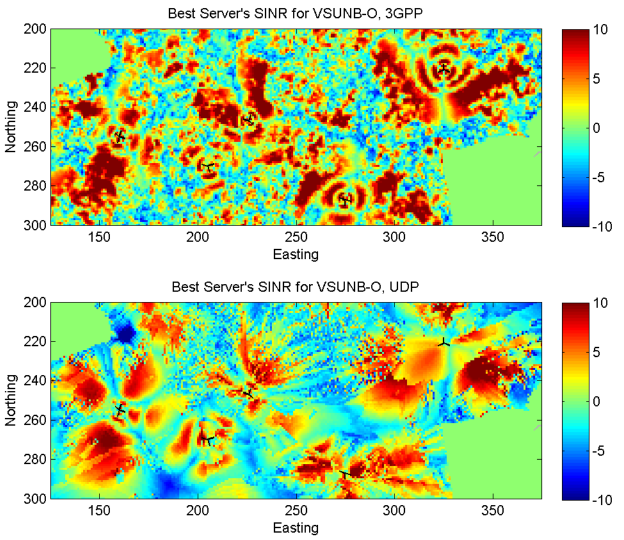

Fig. 4. SINR heatmap of the VSUNB-O scenario for (a) 3GPP model and (b) UDP Model.

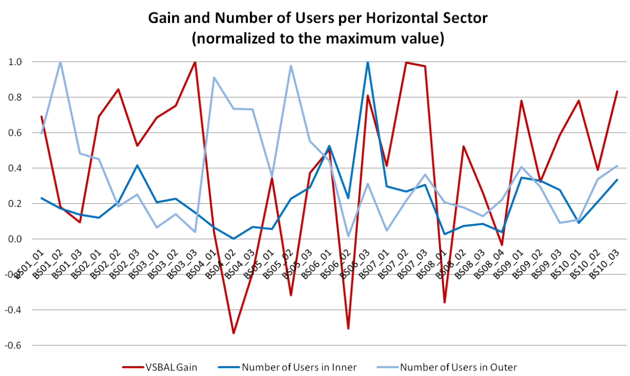

Fig. 5. The normalized gain and number of users per horizontal sector for VSBAL under the UDP Model.

inner and outer sectors. The inner sector's dominance area is much less visible in the UDP, and if visible, it is smaller than the the one shown in the 3GPP model. This implies two things: (1) No clear separation between the inner and the outer sector for the UDP model, and (2) the number of users served by the inner sector will also be lower for the UDP model compared to the 3GPP model. This is because the buildings around the BS cause signal to be diffracted, and therefore altering the effective antenna pattern in the UDP model, especially in the vertical plane.

Table III summaries the downlink throughput for the 3x1REF and VS cases, together with the throughput gain (in percentage) for VS cases, relative to the 3x1REF case. The throughput and relative gain is given for each of the monitored 10 sites, as well as for a total of all sites. The per-site throughput is calculated as the sum of the throughput from all of its sectors. The relative gain is of our interest here, as it shows how much gain VS deployment can bring on top of the current 3x1REF network. The site BS08 is marked with the star: It is a special 4-sector site, whereas the rest have only 3 sectors. The VS performance gain for this site is low for both of the 3GPP and UDP model, indicating that VS should not be deployed on site having more than 3 horizontal sectors. Despite of SINR losses, the VS system offers additional throughput gain to the 3x1REF network, because adding the inner sectors provides extra resources, i.e. doubling the number of PRB. The 3GPP model tends to overestimate the gain of VS system: The maximum per-site gain is up to 99.7% (at site BS10), and the overal gain is 64.9% for the VSBAL case. These numbers are 43.0% (at site BS07) and 20.7%, respectively, for the UDP model. The lower overall gain in the UDP model is due to the lack of inner / outer sector separation and the smaller number of users served in the inner sector as discussed in Fig. 4.

Even though having higher SINR gain, the VSUNB-O actually achieves lower throughput gain than the VSBAL case. This is because a significant throughput gain of VS system comes from the inner sector, which covers the area corresponding to the first null in the antenna pattern of the original sector and provides extra resources to the network. By setting more power to the outer sector, we effectively reduce the inner sector's dominance area and thus reduce the number of users served by the inner sector, which in turn lowering the performance gain of the VS system. Fig. 5 illustrates the normalized gain per horizontal sector for the VSBAL scenario in the UDP model, together with the normalized number of users served by either inner or outer sector. The gain per horizontal sector is computed by summing the donwlink throughput of the inner and the outer sector in the VSBAL, and then dividing it for the throughput of the corresponding horizontal sector in the 3x1REF case. It is clear that the gain is varying significantly from sector to sector, and those sectors with the negative gain is often associated with a low number of users served by the inner sector. The inner sector having low number of users is due to several reasons: (a) The inner sector dominance area is small because there is a high level of downtilting in the inner sector, or the inner sector was blocked by surrounding buildings, and therefore it cannot compete with the outer sector; and (b) there is a low traffic density in the area illuminated by the inner sector. In such situations, the inner sector should be turned off to avoid the inter-cell interference.

V. Conclusions

In this paper we investigated the performance of the Vertical Sectorization (VS) technique using two different propagation models, namely the 3GPP and UDP model. The 3GPP is an empirical-based model, where the effect of antenna pattern is included by linearly adding the antenna gain seen from the direct path between the BS and the user to the path loss. On the other hand, the UDP is a semi-deterministic path loss model, which takes the 3D building map into account, and therefore it is able to describe the complex relationship between the path loss and the antenna pattern more accurately. The simulated throughput gain in the VS system was clearly higher, when using the 3GPP model, than when using the UDP model. This finding supports the assumption that the buildings near the BS deflect the vertical direction of the signal paths and makes it more difficult to distinguish between the inner and outer sector. The size of the inner sector's dominance area is a critical parameter for VS deployment and in the simulation some inner sectors had no or very low number of users, and thus low VS gain is observed. For such a situation, the inner sector should be turned off to reduce inter-cell interference. In order to get a realistic picture of the performance of VS in an urban environment and in order to optimize the tilts of the inner and outer sector beams, it is essential to use planning tools based on 3-dimensional propagation modeling.

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List of Abbreviations

3GPP	Third Generation Partnership Project
BS	base station
CDF	cumulative distribution function
HSPA	High-Speed Packet Access
ISD	inter-site distance
LTE	Long-Term Evolution
PRB	Physical Resource Block
SINR	Signal to Interference plus Noise Ratio
UE	user equipment
UDP	Urban Dominant Path Model
VS	Vertical Sectorization
3x1REF	3x1 reference
VSBAL	VS Balanced Transmit Power
VSUNB-O	VS Unbalanced Outer Sector
VSUNB-I	VS Unbalanced Inner Sector