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Performance Analysis of Vertical and Higher Order Sectorization in Urban Environment at 28 GHz

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Abstract—The main aim of this paper is to compare the performance of cellular network using higher order sectorization in horizontal domain, vertical sectorization, and super cell configuration. The urban macrocellular environment from Helsinki city is targeted, and 28 GHz frequency is used as frequency of operation. Conventional three sector site deployment scenario is also included for reference. The comparative analysis is conducted from different dimensions, and the performance metrics considered in this study includes the SINR, inner sector traffic share, server dominance with 3 dB overlapping window, and the spectral efficiency of the system. This research work is carried out by doing 3D ray tracing simulations utilizing “sAGA”, a MATLAB based 3D ray tracing tool. It is found more complicated to find the optimal antenna configuration for vertical sectorization and super cell configuration in comparison with higher order sectorization. It is also established from the acquired results that higher order sectorization is more simpler and better approach for enhancing the cell capacity compared with vertical sectorization and super cell configuration. Higher order sectorization provides a spectral efficiency gain of around 96.7%, whereas the relative spectral efficiency gain of vertical sectorization and super cell configuration is limited to 62.8% and 10.6%, respectively, with respect to three sector site deployment.

Index Terms—Higher order sectorization; Vertical sectorization; 3D ray tracing; macro cellular; Super cell, System performance.

I. INTRODUCTION

The increased mobile traffic demand can be met by several ways, utilizing more bandwidth and densification of sectors are two of them. From the cellular network management and roll-out point of view, the site acquisition and site maintenance has significant cost. From the economical point of view, it is cost efficient to add sectors to an existing site compared with adding a new site in the network. Due to limited available spectrum, operators are not always able to add another carrier at the existing sector. In this case, the higher order horizontal sectorization can provide additional capacity to the network. However, the sector densification gain is not linear with the increasing number of sectors at the site [1]. Splitting a horizontal sector into multiple co-channel sectors in the vertical domain is referred as vertical sectorization [2]. The antenna beam of the inner sector is tilted more down than the antenna beam of the outer sector. The isolation between the vertical sectors is enough high that it enables to use the same radio resources independently in the

Fig. 1. Graphical illustration of vertical sectorization.

inner and outer sector. Fig. 1 shows the graphical illustration of vertical sectorization. In Fig. 1, α and β are the downtilt angles of outer and inner sector, respectively, and θ is the angular separation between the two vertical sectors. One major drawback of vertical sectorization is that the antenna beams of vertical sectors are partially overlapped, and hence cause interference to each other [3]. The overlap between the inner and outer cell is inevitable. In super cell scheme, multiple cells from the same sites start to act as single cell, and hence it helps in mitigating the inter-cell interference coming from own site. In vertical sectorization, the coverage area of the inner sector is generally small, therefore the inner sectors of the vertical sectorized site can be configured with super cell configuration [4]. Antenna downtilting is a promising and a commonly used technique for optimizing the coverage and quality of the network.

Frequency spectrum is the scarce resource, and at lower frequencies the available bandwidth is already occupied. Mobile network operators are eyeing on millimeter wave (mmWave) frequencies for their network expansion and for their future deployment. The 28 GHz frequency band has got the attention of the operators due to the availability of the large chunk of spectrum. On the other hand the rain attenuation and atmospheric absorption is also fairly low at 28 GHz frequency compared with other higher mmWave frequencies and that also makes 28 GHz band attractive for the mobile operators [5]. Higher propagation path losses are associated with mmWave frequencies, however that can be compensated with more directive antennas with higher antenna gain.

Fig. 2. Area under consideration with, (a) User distribution, (b) Three sector network layout, and (c) Six horizontal sector network layout.

II. SIMULATION MODEL, TOOLS, CASES AND PARAMETERS

This section provides details about the simulation tool used for the study of this paper, explains the simulation methodology adopted, briefly explains about the considered simulation cases, and informs about the assumptions and models used.

A. Simulation Platform and Environment

Three dimensional ray tracing is a promising and a sophisticated technique for accurate channel modeling, and can be used for coverage prediction. Authors have developed a 3D ray tracing tool in MATLAB. In this paper, 3D ray tracing is used for evaluating the performance of higher order sectorization and vertical sectorization using a realistic building environment from Kruuninhaka region of Helsinki. The region under consideration has an urban environment, and have different varieties of building structures ranging from two stories buildings to eight stories buildings. Considered area mainly consists of shopping malls, office buildings, residential buildings and public area. Therefore, a large number of users are located in an indoor environment compared with an outdoor environment. There are 850 test location points randomly distributed as shown in Fig. 2(a). The distribution of test location points in an outdoor and in an indoor environment at different floors is presented in Table. I.

TABLE I
DISTRIBUTION OF USERS.

	Number	Percentage
Total RX points	850	100
Outdoor	128	15.06
Indoor	722	84.94
Ground floor	269	31.65
Second floor	259	30.47
Fifth floor	160	18.82
Seventh floor	34	4

A simple open space hall without any wall partition is assumed for an indoor plan. It is learned from [6] that at 28 GHz the penetration loss is around 26.5 dB for a concrete wall of 40 cm thickness. Therefore, for indoor users outdoor to indoor penetration loss of 26.5 dB is used. The targeted

area is covered with ten outdoor macro sites with 30 m antenna height. An extended 3GPP antenna model proposed in [7] is used to model the antenna radiation pattern in horizontal and vertical domain. There are three antenna types used and their modeling parameters i.e. HPBW in horizontal domain (θ_H), HPBW in vertical domain (θ_V), Front to Back ratio in horizontal domain (FBR_H), Side Lobe Level in vertical domain (SLL_V), and antenna maximum gain (A_M) are provided in Table. II.

TABLE II
3GPP ANTENNA MODEL PARAMETERS

	θ_H [°]	θ_V [°]	FBR_H [dB]	SLL_V [dB]	A_M [dBi]
Antenna Type 1	65	6.2	30	-18	18.23
Antenna Type 2	32	6.2	30	-18	21.30
Antenna Type 3	65	6	30	-18	18.37

B. Simulation Cases

The following cases are considered in this paper:

1) *Reference 3-sector case (3x1 ref)*: It is the conventional and the most commonly used case in current cellular networks. In this case, there are three horizontal sectors of each site. The azimuths of the sectors are selected after careful consideration of the targeted area, and a minimum of 100° separation is ensured between the horizontal sectors as shown in Fig. 2(b). Antenna type 1 given in Table. II is used for this case.

2) *Horization sectorization (6x1 HS)*: It is the case of higher order sectorization in horizontal domain. There are six horizontal sectors covering 360°. Antenna type 2 with narrow beamwidth in azimuth plane is used in this case to avoid sector overlapping. A minimum of 50° separation is ensured between the horizontal sectors as shows in Fig. 2(c).

3) *Vertical sectorization (3x2 VS)*: It is the case of vertical sectorization, where each site has three sectors in an azimuth plane, and each sector has two vertical sectors i.e. inner sector and outer sector as shown in Fig. 1. Antenna type 3 is used for both inner sector and outer sector. All the sites are assumed to have same separation between the vertical sectors in an elevation (vertical) plane.

Fig. 3. Mean SINR, (a) 3-sector (3x1 ref) and 6-sector horizontal sectorization (6x1 HS) (b) Vertical sectorization (3x2 VS) , and (c) Super cell (3+1 SC).

TABLE III
GENERAL SIMULATION PARAMETERS

Parameters	Unit	Value
Frequency	GHz	28
System bandwidth	MHz	20
TX power	dBm	43
Number of Sites	No.	10
Antenna height	m	30
Building penetration loss	dB	26.5
UE noise figure	dB	8

4) *Super cell (3+1 SC)*: It is the special case of vertical sectorization, where the inner sectors of the site collectively form a super cell. It follows the same configuration as used in the case of vertical sectorization. Other general simulation parameters are provided in Table. III.

III. SIMULATION RESULTS AND DISCUSSION

In this paper a basic configuration of three sector site is used as a reference case for performance comparison. First an optimal configuration that provides the best signal quality is found for the reference case by trying different antenna downtilts. Fig. 3(a) shows the mean received signal level and the mean SINR of three sector reference case (3x1 ref) and higher order horizontal sectorization case (6x1 HS). Fig. 3(a) has double y-axis. The y-axis on the left side shows the mean received signal level in dBm, the y-axis on the right shows the mean SINR value in dB, whereas the x-axis shows the downtilt angle in degrees. In Fig. 3(a), it can be seen that higher order sectorization provides 2.4-2.75 dB better received power compared with three sector case due to higher antenna gain and dense sectors. The RX level improved with downtilting and then after reaching the maximum it starts to degrade with additional downtilting. It can be seen that by tilting the antenna down by 9° the SINR of the reference case is improved by 2.75 dB. The maximum SINR of 3.71 dB and 3.55 dB is achieved with 3x1 ref case and 6x1 HS case, respectively with 9° downtilt angle. It is also important to notice here that the SINR is not degraded much in case of higher order sectorization as narrow i.e. 32° HPBW antenna

is used for six sector sites.

In case of 3x1 ref case and 6x1 HS case, there is only one variable for optimization i.e. antenna downtilting. However, in case of vertical sectorization there are two variables, 1) downtilt angle of the outer sector, and 2) the angular separation between the inner and outer sector in elevation plane. Fig. 3 shows the mean SINR for vertical sectorization (3+3 VS) and super cell (3+1 SC) configuration. Fig. 3 has three dimensional graphs, the x-axis shows the downtilt angle of the outer sector in degrees, the y-axis shows the angular separation between the inner and outer sector in degrees, the the z-axis shows the mean SINR in dB. First thing to mention here is that the super cell configuration does not noticeably improve the system SINR compared with vertical sectorization, as it can only help the sector edge users which are located at the border of inner sectors. Due to severe overlapping between the inner sector and the outer sector, the maximum SINR of 2.24 dB and 2.37 dB achieved with 3+3 VS and 3+1 SC configuration, respectively, is still lower than the 3.55 dB of SINR attained with 6x1 HS. It can be seen in Fig. 3(a) and Fig. 3(b) that the overlapping between the inner and outer sector reduces by increasing the angular separation, and therefore the SINR is improved by increasing the angular separation between the sectors.

Fig. 4(a) and Fig. 4(b) shows the percentage of the users served by the inner sectors in vertical sectorization and super cell case, respectively. We have already seen earlier that the SINR improves with large separation (θ) between the vertical sectors and with aggressive downtilt angles (α). However, it is interesting to see that with large θ and aggressive α the percentage of the users served by the inner sector is quite small. Fig. 4(a) shows that only 18.3% of the users are served by inner sectors of the site, while 82.7% of the traffic (users) is handled by the outer sectors of the site for the antenna settings which provides the best SINR in case of vertical sectorization. It means traffic is not optimally balance between the sectors. Similarly, Fig. 4(b) shows that 20% of the users are served by inner sectors of the site for super cell configuration. It should be fine in case of super cell configuration as there are total four

Fig. 4. Inner sector user share, (a) Vertical sectorization (3x2 VS) , and (b) Super cell (3+1 SC).

Fig. 5. Percentage of users with single server within 3 dB window (a) Vertical sectorization (3x2 VS) , and (b) Super cell (3+1 SC).

sectors per site i.e. three outer sectors and one inner sector and if inner sector is carrying 20% of the traffic then its mean that the traffic is optimally balance between the sectors. Thus super cell configuration can be helpful in fulfilling the requirement of small hot spot area. This discussion also highlights the issue of in-efficient utilization of resources in 3x2 VS configuration.

Fig. 5 shows the percentage of the users with single server within 3 dB window. It can be seen that single server dominance area is improved by increasing the antenna downtilt and by increasing the separation between the vertical sectors. Vertical sectorization gives 58%–71% of single server dominance area within 3 dB range, whereas super cell configuration also provides almost similar 58.5%–72% of single server area. The SINR results presented in Fig. 3 are in line with the cell dominance results presented in Fig. 5 and shows that SINR is a direct function of cell dominance area.

Fig. 6 shows the percentage of users with single server within 3 dB window, and also shows the mean system spectral efficiency of three sector reference (3x1 ref) case and six sector horizontal sectorization (6x1 HS) case. Three sector configuration provides 64.4%–82.4% of single server dominance area , whereas horizontal higher order sectorization gives 64.8.5%–79% of single server area within 3 dB range. By comparing the results of cell dominance area presented in

Fig. 5 and Fig. 6 it can be said that higher order horizontal sectorization keeps a healthy ratio of users with clear single server dominance compared with other 3x2 VS and 3+1 SC configuration. Another performance metric shown in the Fig. 6 is the spectral efficiency of the system, and it is given in bps/Hz . Spectral efficiency of the system actually defines the maximum data handling capacity of the network. Surprisingly, by doing horizontal sector densification the mean spectral efficiency of the system has relatively improved by almost 96.7% with respect to a reference case, as 52.32 bps/Hz and 102.95 bps/Hz of peak mean spectral efficiency is achieved with 3x1 ref configuration and 6x1 HS case, respectively. In case of 6x1 HS the improvement in system efficiency is a result of two factors, first due to sector densification and secondly a healthy SINR was maintained by virtue of narrow antenna radiation pattern. Therefore, the increase in capacity of the network is witnessed by adopting horizontal higher order sectorization.

Fig. 7(a) and Fig. 7(b) shows the mean spectral efficiency of the system for 3x2 VS and 3+1 SC configuration, respectively. There is significant difference between the spectral efficiency of the system of both cases due to different number of cells. The maximum achieved spectral efficiency of the system by 3x1 VS and 3+1 SC configuration is 85.2 bps/Hz and

Fig. 6. Percentage of users with single server within 3 dB window and mean system spectral efficiency of three sector reference (3x1 ref) case and six sector horizontal sectorization (6x1 HS) case .

Fig. 7. Mean spectral efficiency of the system, (a) Vertical sectorization (3x2 VS) , and (b) Super cell (3+1 SC).

57.887 bps/Hz, respectively. The maximum relative spectral efficiency gain with respect to reference case by 3x1 VS and 3+1 SC configuration is limited to 62.8% and 10.6%, respectively. It is important to remember that 3x1 VS provides 62.8% relative capacity gain by adding three more sectors at the site, whereas 3+1 SC provides 10.6% gain by adding one more extra sector at the site. These results show the incompetency and in-efficiency of vertical sectorization and

super cell configuration. It is critical to mention here that in case of vertical sectorization 62.8% of relative gain is achieved with 8° outer tilt and 11° angular separation, and it has been shown in Fig. 5 that at given antenna configuration only 18.3% of the area is covered by the inner sector. Therefore, such configuration is not suitable for area with homogeneous traffic distribution.

IV. CONCLUSION

In this paper we analyzed the performance of horizontal higher order sectorization, vertical sectorization and super cell configuration in real world scenario at 28 GHz frequency. The impact of antenna downtilting and angular separation between the vertical sectors is deeply studied. The target was to compare the peak performance of considered configurations and to find the maximum traffic (data) handling capacity of the network. The maximum SINR of 3.71 dB and 3.55 dB is achieved with three sector and horizontal six sector site, respectively. Whereas, as a result of more overlapping between the innersector and the outer sector, the maximum SINR of 2.24 dB and 2.37 dB achieved with vertical sectorization and super cell configuration, respectively. Acquired result shows that while maintaining the maximum achievable SINR, only 18.3% and 20% of the coverage area is served the by the inner sectors of vertical sectorization and super cell configuration, respectively. Higher order horizontal sectorization provides relative capacity gain of 96.7%, whereas relative capacity gain is limited to only 62.8% and 10.6% in case of vertical sectorization and super cell configuration, respectively.

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