Analysis of Vertical Sectorization for HSPA on a System Level: Capacity and Coverage

Youqi Fu*†§, Jian Wang†, Zhuyan Zhao†, Liyun Dai‡, Hongwen Yang*
*School of Telecommunication Engineering, Beijing University of Posts and Telecommunications, Beijing, China.
†Nokia Siemens Networks, Beijing, China.
‡School of Software and Communication Engineering, Jiangxi University of Finance and Economics, Nanchang, China.
§youqi_fu@bupt.edu.cn

***Abstract*—In this paper, capacity and coverage performances by deploying vertical sectorization in HSPA networks are evaluated. A novel resource-scheduling scheme for vertical sectorization is proposed to improve the SINR of cell-edge users. Performances of both conventional vertical sectorization and proposed mechanism are investigated through analysis and simulations. A three dimensional propagation model is used in the system level simulator. Our results indicate in a regular HSPA network conventional vertical sectorization is able to provide up to 59.2% capacity gain at the cost of significantly increased network outage levels. On the other hand, the proposed scheme can remarkably improve network outage performance while providing maximal 21% network throughput enhancement.**

***Index Terms*—active antenna system; beam selection; HSPA; Vertical Sectorization**

I. Introduction

It is reasonable to imagine that future mobile networks will be comprised of a variety of elements. Nevertheless, this will raise challenges to operators since the myriad of cells and layers requires smart optimization and network management solutions. Active antenna technologies are one of the feasible approaches to meet this requirement with its supports to different radio access technologies, Remote Electrical Tilt (RET) and beam-forming etc. One of the recent developments in active antenna technologies is the concept of vertical sectorization as illustrated in Figure 1. In vertical sectorization, multiple antenna elements form two separate beams with their distinct parameters, i.e. Down tilting, Half-Power Beam Width (HPBW), to serve vertically split inner and outer cells. In the paper, the co-sector inner and outer cells are defined as a vertical cell pair.

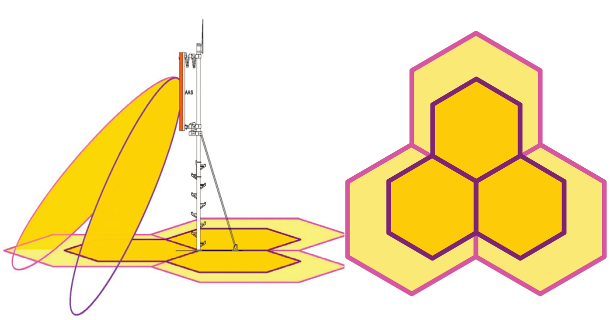

Fig. 1. Vertical Sectorization and 3×2 Sector Layout.

Performance of vertical sectorization in Long Term Evolution (LTE) networks is investigated in [1]. The study results show when eNodeB is configured with conventional Single Input Single Output (SISO) antenna system the vertical sectorization is able to provide up to 47% capacity gain in a regular network with 500m Inter Site Distance (ISD). Furthermore, the network operational energy savings with vertical sectorization deployment is studied in [2].

On the other hand, another Key Performance Index (KPI) for a cellular network is the capability to maintain users' Quality of Service (QoS) requirements. In most cases, this KPI would reflect the user experience in a network, thus operators are strongly concerned with the QoS outage performance of networks. Nevertheless, outcomes from previous studies suggest that vertical sectorization will raise challenge to the QoS outage performance due to following reasons: 1, downlink SINR of cell edge users are notably degraded by splitting transmission power between adjacent vertical beams and interference introduced by additional cells. 2, a new "cell edge" is formed in the areas where two vertical beams overlap. However, it is noteworthy that former researches fail to examine possible impacts of vertical sectorization upon network outage.

Universal Mobile Telecommunications System (UMTS) [3] with its upgrade High Speed Packet Access (HSPA) is one of the most widely used 3G technologies around the world. HSPA refers to the deployment of both High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (H-SUPA). In HSPA networks, the practical data rates are beyond 2Mbps in downlink and 1Mbps in uplink, the transmission latency is under 100ms [4].

One major contribution of this paper is to provide a system level evaluation of capacity and outage performance of HSPA networks with vertical sectorization. Based on these findings then we propose a novel method to schedule radio resources between adjacent inner and outer cells, aiming to balance the network capacity gain and outage rate. Simulations are carried out in macro-cell deployment model case 1 defined in 3GPP specifications [5] [6].

The rest of this paper is organized as follows: Section II describes the performance evaluation methodology; Section III proposes a novel scheduling scheme for vertical sectorization; Section IV shows simulation results and gives some discussions and Section V concludes the paper.

II. Performance Evaluation Methodology

A. Modeling of Antenna Radiation Pattern

As the vertical radiation pattern and down tilting of the antenna are not specified in details in 3GPP HSPA specifications [5], the formulas we apply for horizontal and vertical radiation patterns of HSPA NodeB antennas are from 3GPP LTE specifications [6].

The horizontal antenna pattern is defined as:

$$A_H(\phi) = -\min\left[12\left(\frac{\phi}{\phi_{3dB}}\right)^2, A_m\right], A_m = 25dB \quad (1)$$

The vertical antenna pattern is defined as:

$$A_V(\theta) = -\min\left[12\left(\frac{\theta - \theta_{etilt}}{\theta_{3dB}}\right)^2, SLA_v\right], SLA_v = 20dB \quad (2)$$

where ϕ and θ are the angles from bore sight direction along horizontal and vertical planes respectively, ϕ_{3dB} and θ_{3dB} refer to HPBW of horizontal and vertical beams, θ_{etilt} is the electrical antenna down tilting, A_m is the front-to-back attenuation and SLA_v is side lobe attenuation.

The 3D antenna pattern consists of two cross-sections azimuth and elevation patterns, which is also defined in [6] as shown below:

$$A(\phi, \theta) = -\min\{-[A_H(\phi) + A_V(\theta)], A_m\} \quad (3)$$

The antenna gain is defined as:

$$G(\phi, \theta) = A(\phi, \theta) + G_{ant} \quad (4)$$

where G_{ant} is the bore sight antenna gain defined in Table I.

B. Modeling for 3×2 Vertical Sectorization

In the paper, the HSPA networks without sectorization are referred as 3×1 networks. This is because in the regular network, a NodeB has 3 sectors and each sector only has one cell. On the other hand, the HSPA networks with vertical sectorization are referred as 3×2 networks since each sector is divided into inner and outer cells. The transmission power of a sector in 3×1 network is 43dBm. For a fair comparison between 3x1 networks and 3×2 networks, we assume total transmission power of a sector of 3×2 networks remains the same as 3×1 networks, and power is equally split between vertical cell pairs.

$$P_{total} = P_{inner} + P_{outer} \quad (5)$$

where P_{total} is the total transmission power configured for NodeB in 3×1 networks and P_{inner}, P_{outer} are the transmission power used for inner and outer cell of 3×2 networks, respectively.

As shown in Figure 2, the same system bandwidth of 5 MHz is allocated to the cells in both 3×2 networks and the 3×1 networks. Therefore the radio resource is doubled for vertical sectorization networks at the cost of halved transmission power per cell as shown in Figure 2.

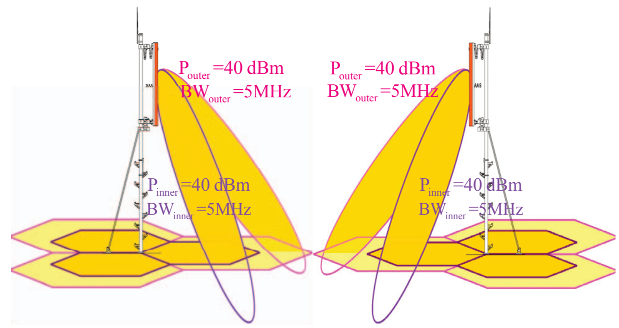

Fig. 2. Transmission Power and System Bandwidth in 3×2 vertical sectorization.

C. Assumptions for Capacity Evaluations

In this paper, we use the same simulation assumptions defined in [1]. Then, obtained throughput gains in HSPA networks can be compared to the former studies. Based on this, the network outage performance of vertical sectorization can be investigated under generally the same configurations to prove our predictions made early in this paper. Evaluations are performed by mapping link-level simulation results into a static system level HSPA simulator. In addition, a three dimensional propagation model is used to reflect the effect of vertically split beams. Parameters and assumptions for capacity studies are selected according to 3GPP specification for UMTS macro-cell network performance evaluations [5] as shown in Table I. The combination of antenna configurations such as HPBW, down tilt degree are set to the values optimized in [1] as well.

Performance of vertical sectorization and the proposed scheduling scheme is investigated in a 3GPP case 1 network where ISD is 500 m. UEs are uniformly distributed in the whole simulated area and traffic mode is full-buffer. The Round-Robin scheduler is used where NodeB equally shares available radio resources among the users in a cell. Network capacity refers to the total downlink throughput of monitored 19 sites.

D. Assumptions for Coverage Evaluations

As it mentioned in the previous part of the paper, deployment of vertical sectorization will reduce the received power of users in downlink due to the power split between the vertical cell pairs. The downlink SINR of users will be further degraded due to inner-outer cell interference.

One main purpose of this paper is, through simulations, to investigate how network outage performance will be impacted by deploying vertical sectorization. We set downlink minimum

TABLE I
SIMULATION ASSUMPTIONS FOR HSDPA

Parameter	**Simulation Cases 3GPP Case 1**
Network layout	3×2 sectorized 91 sites (monitored elements: 19 sites)
System frequency	2000 MHz
System bandwidth	5 MH
Number of UEs	25 / vertical sector pair
TTI	2 ms
Frequency reuse factor	1
Inter-site distance	500 m
NodeB height	32 m
UE height	1.5 m
Shadowing STD	8 dB
Shadowing Correlation	0 (sites), 1 (sectors)
Shadowing Correlation Distance	50 m
Propagation loss model	$L = 128.1 + 37.6 \log_{10}(R)$, R in kilometers
TX power	43 dBm (40 dBm/vertical sector)
Horizontal HPBW	$\phi_{3dB} = 65°$
Vertical HPBW	$\theta_{3dB} = 3.0°, 4.4°, 6.8°$
TX antenna gain	14 dBi
TX cable loss	2 dB
RX antenna gain	0 dB
RX body loss	0 dB
Thermal floor	-174 dBm/Hz
RX noise figure	9 dB
Traffic distribution	Uniform
Traffic model	Full-buffer/Best-effort
Scheduling	Round-Robin

data rates for all users as 256 kbps and 512 kbps which are commonly used values in HSPA simulations and assume if throughput of a user is not able to fulfill preset threshold, the user is in outage. A range of numbers of user is used to reflect the change of network outage level under different traffic loads. In addition, an alternative scheduler is used to minimize outage rate for both 3×1 reference and 3×2 vertical sectorization networks. Through the outage-optimized scheduler, a cell will arrange its served users with corresponding SINR in descending order. Then resources will be firstly allocated to the user with best SINR. After this user's minimum data rate is met, same procedure goes to the next user in the order and rest of users. After all users meet their required throughput, if there is any resource left, they will be equally shared by all users. Under this mechanism, users with high received SINR will get less resources than Round-Robin case since users with lower SINR require more resource to fulfill the minimum data rate. The overall throughput of the network is expected to be lower than that of capacity case.

These changed parameters are listed in Table II and others remain the same as in Table I.

TABLE II
SIMULATION ASSUMPTIONS FOR QOS OUTAGE

Parameter	**Simulation Cases 3GPP Case 1**
Number of UEs (served by monitored 19 sites)	220 - 480
Minimum data rate	256 kbps, 512kbps
Scheduling	Outage Optimized

III. PROPOSED SCHEDULING SCHEME FOR VERTICAL SECTORIZATION

As analyzed in previous section, without proper interference cancelation mechanism, the utilization of vertical sectorization would worsen the network coverage performance. For a vertical cell pair, the inner and outer cells independently schedule radio resource for the users in their respective dominance areas. Figure 3 illustrates an example of a possible scheduling scenario of a vertical sector pair. In the example, resource (i.e. time slot and spreading code) are allocated to User 6 by the inner cell and to User 2 by outer cell as well. The signals become mutual interference to these two users. We can imagine such scheduling confliction will happen all the time in conventional vertical sectorization. Furthermore, in a vertical cell pair, the path loss of a user to inner and outer cell are basically identical because two beams are radiated from the same active antenna. Then, the received signal and interference is largely determined by the vertical antenna patterns (vertical antenna gains) of the vertical cell pair. In the area where two vertical antenna pattern overlap, the inner-outer cell interference becomes the dominance factors for network performance.

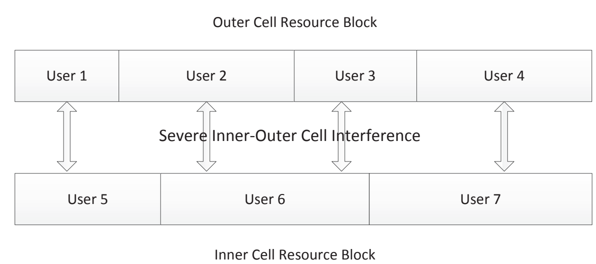

Fig. 3. Inter-Cell Interference Brought by Vertical Sectorization.

However, the same active antenna serving a vertical cell pair gives us the opportunity to avoid the inner-outer cell interference through co-operative scheduling. The proposed scheduling scheme is shown in Figure 4. Instead of scheduling resources independently by the inner and outer cells of a vertical pair, the radio resources are scheduled orthogonally to users located in the same sector. Therefore at certain time slots and spreading code only one cell in a vertical cell pair is transmitting. In this case, users connect with the beams providing the best received SINR. This is similar to the beam selection procedure in the switched beam system [7], and details of beam selection mechanism are describe in [8]. As this topic is beyond the scope of this paper we assume users are served by their respective cell determined in conventional vertical sectorization in our simulations. After the beam selection completes, resource is allocated in the similar manner of that in the 3×1 network for both Round-Robin and outage-optimized scheduler. The only difference here is received SINR of users served by a vertical cell pair may be obtained from different vertical beams.

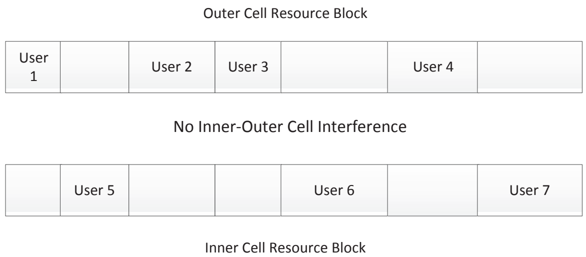

Fig. 4. Proposed Scheduling Scheme for Vertical Sectorization.

Advantages of the proposed scheme are: 1, the inner-outer cell interference is eliminated as orthogonal radio resource is assigned to the users in the same sector; 2, transmission power for each cell remains the same as that in 3×1 network because in traffic channel only one cell is transmitting at certain time slots in a paired inner and outer cells. Therefore total transmission power in 3×2 vertical sectorization using propose scheduling scheme would remain the same as that in reference network; 3, the fact that cells are not transmitting traffic channel signal at all time slots will reduce the probability of resource block collision to cells in other vertical sector pairs in the network, thus further decrease the overall inter-cell interference level; 4, the proposed scheme is not only limited to HSPA networks, but can also be conveniently adapted for LTE and LTE-A networks.

IV. Analysis and Discussions on Simulation Results

SINR curves from capacity simulations for 3×1 sector layout, 3×2 vertical sectorization and proposed scheme are shown in Figure 5. In the figure, the vertical sectorization is denoted as VS and config1 - config4 is the antenna configurations defined in Table III. In the figure, the SINR of 3×2 vertical sectorization is degraded compared with 3×1 sector because the inner-outer cell interference of a vertical pair. On the other hand, the user SINR are considerably improved for all three sets of antenna configurations when proposed scheduling scheme is applied.

TABLE III
Enumerations of Antenna Configurations

Enumeration	Antenna Configurations
Config. 1	Vertical HPBW = 6.8°, Electrical Downtilt = 12°
Config. 2	Vertical HPBW = 6.8°, 6.8°, Electrical Downtilt = 18°, 10°
Config. 3	Vertical HPBW = 4.4°, 4.4°, Electrical Electrical Downtilt = 18°, 10°
Config. 4	Vertical HPBW = 3.0°, 3.0°, Electrical Downtilt = 14°, 8°

Figure 6 demonstrates the capacity gains of both conventional vertical sectorization and proposed scheme compared to regular 3×1 reference networks. The antenna configuration:

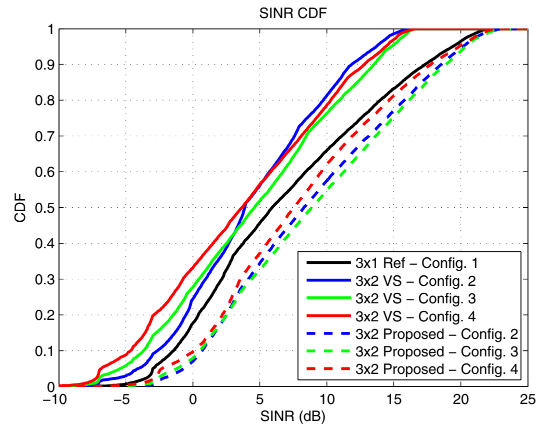

Fig. 5. User SINR Distribution in 3GPP Case 1.

config1, which is defined in Table III, is used for the 3×1 network in all simulation cases. From the simulation results, in the best case where vertical antenna HPBW is set to 4.4° (the same as optimal case in [1]), vertical sectorization can provide 59.2% capacity enhancement compared to 3×1 networks. The results indicate that double resource in vertical sectorization can achieve remarkable capacity gain despite of decreased user SINR. The results in Figure 6 also show that the proposed scheduling method can provide up to 18% capacity gain compared to 3×1 networks.

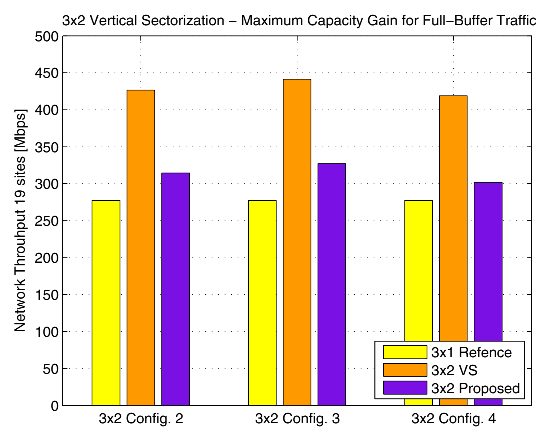

Fig. 6. Capacity Gain for 3×1 and 3×2 Sector Layouts in 3GPP Case 1.

The simulation results of the network outage are shown in Figure 7 and Figure 8. In the scenarios where the minimal request user data rate is 256 kbps and 512 kbps, the outage rate is increased when conventional vertical sectorization is used. These findings further validate our predictions towards vertical sectorization asserted in this paper. On the other hand, the proposed scheduling scheme proves its capability to improve the network outage performance since we can see from the figures that outage rate is maintained at the lowest level, even lower than outage rate of 3×1 reference network.

It is noteworthy to point out, although in the capacity

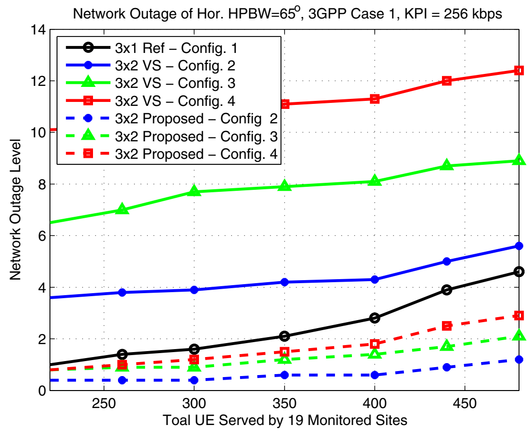

Fig. 7. Network Outage Levels, KPI=256 kbps.

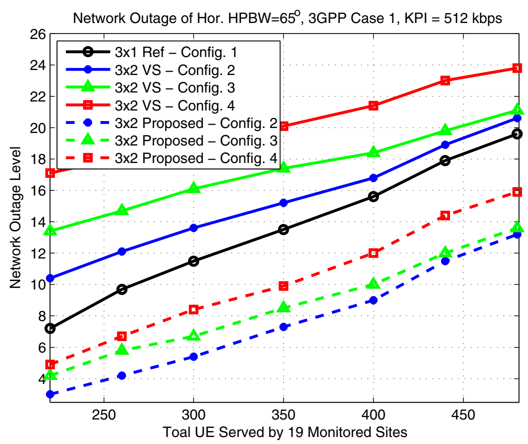

Fig. 8. Network Outage Levels, KPI=512 kbps.

simulation cases the antenna configuration set in which the HPBW equals 4.4° provides the highest gain, the same settings in different scenarios for outage evaluation will result in higher outage levels compared to the 6.8° HPBW settings. This phenomenon, along with degraded coverage performance in vertical sectorization and lowered outage levels in the proposed scheme, can be explained from the outcomes in Figure 5. The network outage level is largely determined by the 5%-tile of SINR CDF. Vertical sectorization with narrow HPBW results in a lower value at this criterion, whereas the proposed method is 3.5 - 4.5dB better.

Furthermore, the total network throughput is improved by both conventional vertical sectorization and proposed scheduling method with outage-optimized scheduler and small user number in the network. For instance, in the case that optimal vertical HPBW setting is 6.8° and the minimum data rate is 256 kbps, the total network capacity gain of conventional vertical sectorization and proposed scheduling scheme is 42.85% and 20.61% respectively. Therefore, the proposed scheme can still provide adequate level of capacity gain, along with the enhancement in network outage performance.

V. Conclusions

In this paper, the capacity and coverage performance of vertical sectorization is investigated for a HSPA network. According to the simulation results, 3×2 vertical sectorization will provide a significant capacity gain in HSPA networks. However, the drawback of the approach is the degradation on network outage performance due to the interference and power-splitting between inner and outer cell.

A novel scheduling scheme for vertical sectorization is proposed. It aims to decrease the network outage level while maintaining a comparatively moderate level of capacity gain. Simulation results show the proposed scheme is able to decrease the network outage to a remarkably low level, and provide certain amount of capacity gain at the same time.

One major drawback of proposed scheduling scheme is that the radio resources of a vertical cell pair are orthogonally utilized. How to improve the radio resource re-use factor is the next step of our study.

Acknowledgements

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