Mathematical Model for Vertical Sectorization (VS) in AAS Based LTE Deployment

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***Abstract*—Active Antenna System (AAS) features are promising to enable a dynamic cell deployment layout change based on the nature of the traffic distribution and capacity demand. One of the dynamic deployment options is vertical sectorization (VS) where cell densification is done by activating a new inner sector with its own cell ID in the existing conventional sector layout. In order to investigate the performance of VS and assess the impacts of the parameters determining the VS performance, an appropriate model is required. This paper proposes and presents a mathematical model for vertical sectorization. Moreover, the model shows vital relationships among the system performance and various system parameters. In addition, the performance of the presented model is demonstrated using a 3GPP defined scenario based simulations.**

***Index Terms*—Active Antenna Systems, Vertical Sectorization**

I. Introduction

Active Antenna System (AAS) is an advanced antenna technology that features the ability of advanced beam-forming techniques to provide a great flexibility in cellular network deployment. Conventionally, network dimensioning is done based on busy hour traffic leading to cost-intensive over-dimensioning for most of the time via deploying additional macro and small cells. In AAS deployment, however, varying traffic concentrations can be flexibly handled by dynamic cell densification, e.g. by splitting a sector into smaller "sub-sectors" with unique cell-IDs. Vertical sectorization is a well-known approach where a conventional sector is split vertically in to two, inner and outer sectors and this is realized by activating an inner sector on the existing conventional sector layout [1] [2] [3].

In the case of conventional sector deployment, the amount of system bandwidth assigned per sector is limited, all users are sharing the available radio resources at the sector depending on the the employed resource sharing scheme. When a sector is highly loaded, i.e. high number of users per sector, assigning the available resources results in a degraded resource share per user in the congested sector. Traditionally, such problems are handled by deploying additional small cells in order to increase system capacity. This approach, however, brings high network complexity and also economically expensive to operators as it incurs additional Capital Expenditures (CAPEX) and Operational Expenditures (OPEX).

In AAS based deployment, the load at the congested conventional sector can be handled by sector densification by enabling additional intra-site sector via vertical sectorization. While activating the inner sector, in VS, the same amount of system bandwidth that has been used for the total conventional sector is now can be independently used at each inner and outer sectors. This will double the total available radio resources per the conventional sector thereby resulting in an improved resource share for the users that could boosts system capacity. One of the trade-offs of VS is that the introduction of a co-sited new additional sector increases the level of inter-sector interference in the system.

System level simulations have been performed for the Long Term Evolution (LTE) and HSPA systems in [1] [2] [3] and results have shown that vertical sectorization can provide a significant capacity gain. Various vertical sectorization investigations have been also carried out to enhance the performance of VS via a better beam-forming [4] and suitable resource scheduling scheme [3] for HSPA based networks. The existing investigations' results on vertical sectorization are carried out by using simulative approach and assumptions looking at system level outputs. However, in order to figure out the relationship between the performance of VS with the system parameters that determines it, there needs to have a general system model that will quantify and tells the degree of their impacts. To the knowledge of the authors, such model is not currently available in literatures.

In this paper, a mathematical model for vertical sectorization is presented and discussed in detail. Moreover, the model shows vital relationships among performance and system parameters that determines the VS performance. In addition, the performance of the model is demonstrated using a 3GPP defined scenario where the model is validated and VS performance is illustrated for various system parameter settings.

The paper is organized as follows. The system model is discussed in detail in Section II. In Section III, parameters that determines the VS performance and their dependency are presented. Section IV shows the scenario description used for model illustration. The performance analysis and further discussions are presented in Section V and finally the work is concluded in Section VI.

II. Mathematical Model for VS

In this section the proposed mathematical model for vertical sectorization is described in detail.

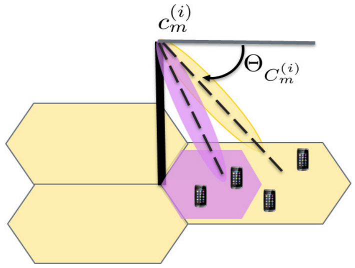

Fig. 1. Vertical Sectorization (VS): Activating an inner sector

Assume a cellular network with a conventional sector deployment layout with a total number of K sectors in the network. In this paper notation C is used to refer to a sector and any sector with conventional sector index i is denoted by $C_m^{(i)}$ where m is used to indicate if vertical sectorization is applied or not at the i^{th} conventional sector. In this case, for the conventional sector layout deployment, the value of m will be zero, i.e. $m = 0$, but if vertical sectorization is activated, m takes a non-zero value of $m = 1$ and $m = 2$ to specify the outer and the inner sectors respectively. A potential user equipment (UE) location in the network is defined by u. The power received from any of the sectors in the network by a UE at location u is given by $p(u, C_m^{(i)})$ and it can be described as:

$$p(u, C_m^{(i)}) = \frac{P_{tx}^{C_m^{(i)}} \cdot G(u, C_m^{(i)})}{L_t(u, C_m^{(i)})} \tag{1}$$

where $P_{tx}^{C_m^{(i)}}$ is the total power transmitted by sector $C_m^{(i)}$. The terms $G(u, C_m^{(i)})$ and $L_t(u, C_m^{(i)})$ are total antenna gain and total propagation loss of the respective transmitting antenna with respect to the location point u respectively. The total antenna gain depends on the radiation pattern of the antenna. Thus, it is given by multiplying the maximum linear antenna gain G, with its radiation pattern B_p, i.e., $G(u, C_m^{(i)}) = G \cdot B_p(u, \Phi_{C_m^{(i)}}, \Theta_{C_m^{(i)}})$ where $\Phi_{C_m^{(i)}}$ and $\Theta_{C_m^{(i)}}$ are the azimuth orientation and elevation tilt setting of sector $C_m^{(i)}$. In all the definitions above, the parameters are defined in linear scale.

The total power available at the base station for transmission per each sector ($C_0^{(i)}$) is given by P_T, and the fraction of P_T that is actually transmitted by a sector in the conventional sector deployment is given by β such that $P_{tx}^{C_0^{(i)}} = \beta \cdot P_T$.

A UE at u connects to the sector with strongest received signal power. A connection function $s(u)$ is defined which gives the serving sector of for a UE at u. The corresponding SINR performance of a UE located at u denoted by $x(u)$ and in the case of the conventional deployment $x(u)$ is given by:

$$x(u) = \frac{p(u, s(u))}{\sum\limits_{\substack{i, \\ c_0^{(i)} \neq s(u)}} p(u, c_0^{(i)}) + N}, \tag{2}$$

A. Assumptions

In real network, vertical sectorization is needed to introduce an additional intra-site sector in a highly loaded conventional sector layout by activating a new inner sector beam with its own cell ID and higher tilt setting as depicted in Figure 1. Thus, the decision to activate the inner sector and the resulting vertical sectorization is assumed to take place only at the intended conventional sector ($C_0^{(i)}$) while maintaining the deployment layout of the other $(K-1)$ sectors unchanged. Therefore, the model description in this paper is looking at a single conventional sector with index $i = z$ denoted by $C_m^{(z)}$ and the investigation considers all potential user location points $u \in \mathbb{U}$ covered by this sector, $C_o^{(z)}$.

$$\mathbb{U} = \left\{ u \middle| s(u) = c_0^{(z)} \right\} \tag{3}$$

Moreover, due to the fact that activating an inner sector at $C_0^{(z)}$ is not expected to introduce unintended cell lay out change in the neighboring sectors of an already optimized network, the outer sector border is assumed to remain unchanged after vertical sectorization. As a result, all the sector coverage of $C_0^{(z)}$ will be taken over by the outer and inner sectors.

$$\mathbb{U} = \left\{ u \middle| s(u) = c_0^{(z)} \right\} = \left\{ u \middle| s(u) = c_1^{(z)} \bigcup \ u \middle| s(u) = c_2^{(z)} \right\} \tag{4}$$

B. Vertical Sectorization: Deactivated

When vertical sectorization is not activated, the deployment is already at its optimized network settings like tilt and other parameters. The SINR performance ($x(u)$) for a UE at $u \in \mathbb{U}$ is given by

$$x(u) = \frac{p(u, c_0^{(z)})}{\sum\limits_{\substack{i, \\ c_0^{(i)} \neq c_0^{(z)}}} p(u, c_0^{(i)}) + N}, \tag{5}$$

C. Vertical Sectorization: Activated

While activating an inner sector, during vertical sectorization, the inner and outer vertical sectors have to share the total available power, P_T. In this model, power allocation factors γ_m is defined to indicate the amount of power allocated to outer and inner sectors with respect to the total power transmitted by the conventional sector, $c_0^{(z)}$, i.e., $P_{tx}^{C_0^{(z)}}$, before activation of the inner sector.

$$\begin{aligned} P_{tx}^{C_1^{(z)}} &= \gamma_1 \cdot P_{tx}^{C_0^{(z)}}, \\ P_{tx}^{C_2^{(z)}} &= \gamma_2 \cdot P_{tx}^{C_0^{(z)}} \end{aligned} \tag{6}$$

where $P_{tx}^{C_1^{(z)}} + P_{tx}^{C_2^{(z)}} \leq P_T$.

The signal power received by a UE at $u \in \mathbb{U}$ from the inner and the outer sector is given by $p(u, c_2^{(z)})$ and $p(u, c_1^{(z)})$, respectively, and are related by a factor $k(u)$ as shown in Equation 7. Since, a stationary user is assumed, the total propagation loss, $L_t(u, C_m^{(z)})$, at u with respect to inner and outer sectors can be assumed to remain the same. As a consequence, the value of $k(u)$ will be determined by the antenna gain value of each sector sector antenna with respect to u and the power allocation factor γ_m.

$$k(u) = \frac{p(u, c_2^{(z)})}{p(u, c_1^{(z)})} = \frac{\gamma_2 \cdot G(u, C_2^{(z)})}{\gamma_1 \cdot G(u, C_1^{(z)})} = \gamma \cdot \frac{G(u, C_2^{(z)})}{G(u, C_1^{(z)})} \quad (7)$$

where $\gamma = \frac{\gamma_2}{\gamma_1}$.

Therefore, with inner sector activated, the UE at u will be connected to one of those sectors with the strongest received signal power level.

$$s(u) = \begin{cases} c_1^{(z)}, & k(u) \le 1 \\ c_2^{(z)}, & k(u) > 1 \end{cases} \quad (8)$$

The SINR performance of a UE at u after inner sector is activated is denoted by $x'(u)$ and given by

$$x'(u) = \begin{cases} \frac{p(u,c_1^{(z)})}{\sum\limits_{\substack{i, \\ c_0^{(i)} \ne c_1^{(z)}}} p(u,c_0^{(i)}) + N + p(u,c_2^{(z)})}, & k(u) \le 1 \\ \\ \frac{p(u,c_2^{(z)})}{\sum\limits_{\substack{z, \\ c_0^{(i)} \ne c_1^{(z)}}} p(u,c_0^{(i)}) + N + p(u,c_1^{(z)})}, & k(u) > 1 \end{cases} \quad (9)$$

As can be seen from Equation 9 the inner and outer sectors appear as an additional interference to one another. For the ease of later simplification, Equation 9 can be rewritten as,

$$x'(u) = \begin{cases} \frac{\frac{p(u,c_1^{(z)})}{\sum\limits_{\substack{i, \\ c_0^{(i)} \ne c_1^{(z)}}} p(u,c_0^{(i)}) + N}}{1 + \frac{p(u,c_2^{(i)})}{\sum\limits_{\substack{i, \\ c_0^{(i)} \ne c_1^{(z)}}} p(u,c_0^{(i)}) + N}}, & k(u) \le 1 \\ \\ \frac{\frac{p(u,c_2^{(z)})}{\sum\limits_{\substack{i, \\ c_0^{(i)} \ne c_1^{(z)}}} p(u,c_0^{(i)}) + N}}{1 + \frac{p(u,c_1^{(i)})}{\sum\limits_{\substack{i, \\ c_0^{(i)} \ne c_1^{(z)}}} p(u,c_0^{(i)}) + N}}, & k(u) > 1 \end{cases} \quad (10)$$

If the antenna parameter configurations like tilt and half power beam width settings are not changed for the outer sector after activating the inner sector, then, the antenna gain with respect to the outer sector remains the same after vertical sctorization, i.e., $G(u, C_0^{(z)}) = G(u, C_1^{(z)})$. Thus, also from Equation 1 and 7, the following relationship can be derived.

$$\begin{aligned} &p(u, c_1^{(z)}) = \gamma_1 \cdot p(u, c_0^{(z)}), \\ &p(u, c_2^{(z)}) = k(u) \cdot p(u, c_1^{(z)}) = k(u) \cdot \gamma_1 \cdot p(u, c_0^{(z)}) \end{aligned} \quad (11)$$

From Equations 5, 7, 10, and 11, the SINR performance before and after vertical sectorization can be related using $k(u)$ and γ_m as shown in Equation 12.

$$x'(u) = \begin{cases} \frac{\gamma_1 \cdot x(u)}{1 + k(u) \cdot \gamma_1 \cdot x(u)}, & k(u) \le 1 \\ \\ \frac{k(u) \cdot \gamma_1 \cdot x(u)}{1 + \gamma_1 \cdot x(u)}, & k(u) > 1 \end{cases} \quad (12)$$

In order to meet the condition mentioned in Equation 4, our model has put a constraint that, only 50% of the total sector power budget, P_T, is utilized in the conventional sector deployment, therefore, $\beta = 50\%$. Hence, when activating the inner sector, during vertical sectorization, the remaining 50% of P_T is allocated to the inner sector, i.e., $\gamma_1 = \gamma_2 = \gamma = 1$. In this case, the value of $k(u)$ in Equation 7 will be determined by only the antenna gain values with respect to inner and outer sectors. Therefore, $k(u)$ value can be controlled by adjusting the tilt configuration of the inner and outer sector beams.

III. Parameters Determining VS performance

In this section parameters that determine the performance of vertical sectorization is discussed.

The primary advantage of vertical sectorization is enhancing sector capacity via doubling the total radio resources per the conventional sector layout. Due to the fact that, the SINR performance of a UE is highly impacted by VS, as shown in Equation 13, the expected overall throughput performance gain is mainly attributed to the amount of achieved resource gain. For illustration purpose, the throughput (TP) performance of a UE at location u, $TP(u)$, before activation of vertical sectorizaton is approximated and described using Shannon's capacity formula in terms of its resource share and SINR performance as shown in Equation 13.

$$TP(u) \approx R(u) \cdot B_w \cdot \log_2(1 + x(u)), \quad (13)$$

where $R(u)$ is the amount of total resource allocated for the UE in terms of number of LTE Physical Resource Block (PRB) and B_w is the bandwidth of a single PRB, i.e. 180 kHz.

When vertical sectorization is activated, a UE at u connects to either inner or outer sector depending on the the received signal strength and consequently will have a different resource share, $R'(u)$, depending on the respective sector load and different SINR performance, $x'(u)$. As a result, the UE TP after vertical sectorization, $TP'(u)$, is given by:

$$TP'(u) \approx R'(u) \cdot B_w \cdot \log_2(1 + x'(u)), \quad (14)$$

The throughput performance gain η for a UE at u, $\eta(u)$, is then defined as:

$$\eta(u) = \frac{TP'(u) - TP(u)}{TP(u)} = \frac{R'(u)}{R(u)} \cdot \frac{\log_2(1 + x'(u))}{\log_2(1 + x(u))} - 1 \quad (15)$$

As can be seen from Equation 15, the UE TP performance gain is determined by the amount of resource share and the SINR performance of the UE before and after vertical sectorization.

A. SINR

After vertical sectorization, due to the introduction of a newly interfering inner sector, outer sector UEs' SINR is always degraded, however, there could be some SINR improvement for those UEs which are connected to the inner sector. This effect can be more explained with the relationship found in Equation 12, accordingly, the SINR for the inner sector UEs is proportional to the value of $k(u)$ whereas the

SINR of the outer sector UEs is inversely proportional to $k(u)$. Since the inner and outer sector total power is the same, $\gamma = 1$, $k(u)$ value is determined by the antenna gain difference relative to inner or outer sectors as described and illustrated in Equation 7. Hence, the SINR performance is mainly dependent on the antenna tilt setting difference between inner and outer sectors that controls the interference level between them.

B. Resource Share

The UE throughput gain, as described in Equation 15, is proportional to the resource gain achieved by the UE after activating the inner sector. In this paper, the resource gain is defined as the ratio of the number of PRBs assigned after and before vertical sectorization, i.e., $\frac{R'(u)}{R(u)}$. The overall expected gain from vertical sectorization is primarily determined by this resource gain factor as depicted in Equation 15.

Basically, the resource gain results from redistribution of the conventional sector load into the inner and outer sectors after inner sector is activated. Thus, the relative resource share for the UEs after vertical sectorization will be determined by the number of UEs competing for resource against each other in the respective sectors. Since, the outer sector border is assumed to be not changing, the sector load redistribution is mainly determined by the relative coverage size of the activated inner sector with respect to the outer sector. Apart from the inner sector size, the way UEs are distributed in the conventional sector layout is also crucial factor as it defines the number of UEs that go to the inner/outer sectors depending on their geographical location with respect to the inner/outer sector border.

The vertical sectorization model discussed in this paper is illustrated using 3GPP defined deployment scenario along with system performance comparison for different parameter settings.

IV. Scenario Description

3GPP defined regular hexagon 19 tri-sectored, i.e., 57 conventional sectors, deployment is considered with an inter site distance (ISD) of 1732 m for an a LTE-A network. All the sites are assumed to be deployed with AAS to enable vertical sectorization feature. Propagation models and simulation parameters are employed as defined by 3GPP [5]. In our investigation, a pixel based approach is used to define the user traffic distribution where the network is divided into a grid of pixels with pixel resolution of 10 m where a pixel is a potential location for a UE. A uniform user distribution and full buffer traffic is considered in the simulation. The scenario parameters definition and settings are revised in Table I.

V. Performance Analysis

A. Evaluation Metric Definitions

Investigation is conducted per a single conventional sector layout. System performance evaluation is done by taking user TP statistics before and after activation of an inner sector. In the case of total sector capacity study, the aggregated sector TP is utilized after VS which is found by combining the total sector TP of the inner and outer sectors.

TABLE I
SCENARIO PARAMETERS AND SETTINGS

System Model and Parameter Settings		
Description	Parameter	Value
Site	ISD	1732 m
	# Site	19 Tri-sectored
	Height [m]	Antenna =30, UE = 1.5
Antenna	Gain[dBi]	19.5
	Φ_{3dB}	62°
	Θ_{3dB}	5°
	Backward Attenuation	25 dB
Propagation	Pathloss	$128.1+37.6\cdot\log_{10}(r_{km})$
	Shadowing Std.	8 dB
	Penetration Loss	20 dB
User Traffic	UE Location	Pixel Based (10m X 10m)
	Distribution	Uniform
	Traffic	Full Buffer
System Setting	Frequency	2 GHz
	Bandwidth	10 MHz
	Operating Mode	Down-Link

B. Coverage and Load Distribution

After activating the inner sector, the inner/outer sector coverage is defined based on the relative power strength of the received signal from both sectors. In our model, the inner/outer sector border is defined where the same power level is detected from each sector, i.e., $k(u) = 1$. As discussed earlier, since $\gamma = 1$, $k(u)$ value is determined by only the antenna gain value with respect to the respective sectors, hence, the respective sector coverage size depends on how large is the difference in the antenna gain with respect to each sectors at location u which in turn depends on the difference in the tilt configuration setting of inner and outer sector. This is illustrated in Figure 2 where the antenna radiation pattern normalized to the maximum gain value is shown for the inner and outer sectors along with the resulting corresponding antenna gain difference in decible (dB) in the boresight direction of the antenna for various elevation angle value (θ) measured from horizontal plane as depicted in Figure 1. The antenna gain difference shown in dB scale in the figure is defined as $k_{dB}(u) = 10 \cdot \log_{10}^{k(u)}$. The corresponding best server map plot is also depicted in Figure 3, using 3GPP beam pattern model [5], for tilt setting of 5° and 11° for outer and inner sector respectively. As can be seen from Figure 2 and 3, vertical sectorization results in a relatively smaller inner sector coverage while large sector coverage remains with the outer sector. Moreover, the UEs close to the antenna are connected to one of the intra-site sectors due to nonexistence of a single dominant sector coverage at that region.

Since a uniform user traffic distribution is considered in our scenario, the resource gain after vertical sectorization, as a result, is determined by the redistribution of users into the inner and outer sectors which in turn depends on their coverage size. Assume a total of M_b total radio resources and N number of users per a conventional sector, after activation the inner sector, these users will be redistributed to inner and outer sectors, where n_2 and n_1 number of users are assumed in each sectors respectively, i.e., $N = n_1 + n_2$. Inner to outer sector load ratio, λ, is defined to know the fraction of sector load taken over from the conventional sector by the inner sector,

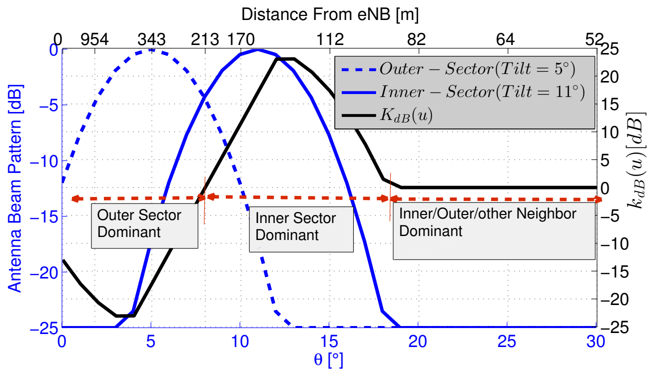

Fig. 2. Elevation Antenna Beam Pattern and $k_{dB}(u)$ in Boresight Direction

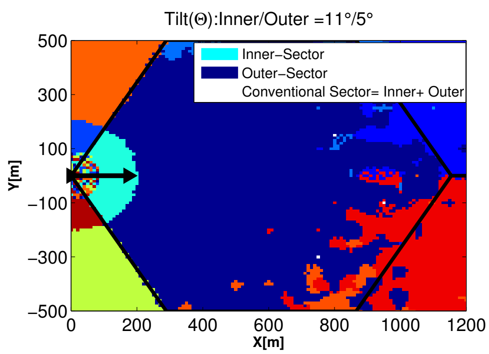

Fig. 3. Inner/Outer Sector Server Map From a Single Conventional Sector

hence, $\lambda = \frac{n_2}{n_1}$. Accordingly, n_1 and n_2 can be written as follows:

$$n_1 = \frac{N}{1+\lambda}, \quad n_2 = \frac{\lambda \cdot N}{1+\lambda} \tag{16}$$

A resource fair scheduler is assumed to assign resources where the available resource is shared equally among all UEs, for example, $R(u) = \frac{M_b}{N}, \forall u \in \mathbb{U}$. Since, M_b radio resources are available at inner and outer sectors each, the resource share per UE after and before sectorization can be related as follows:

$$R'(u) = R(u) \cdot \begin{cases} (1+\lambda), & k(u) \leq 1 \\ \frac{(1+\lambda)}{\lambda}, & k(u) > 1 \end{cases} \tag{17}$$

Based on the above defined relationship, the resource gain, $\frac{R'(u)}{R(u)}$ can be expressed in terms of λ and can be observed that, the resource gain for the outer sector UEs is proportional to the λ. This is because, the more traffic loads are taken over by the inner sector, the more unloaded the outer sector gets thereby leading to a better resource share for outer sector's UEs. The resource gain relationship with respect to λ is demonstrated in Figure 4 for various λ values.

C. SINR Performance

As explained in Section III, the SINR performance of the UEs in the inner/outer sector is impacted after activation of the inner sector. As shown in Equation 12, the SINR performance after vertical sectorization depends on the respective $k(u)$

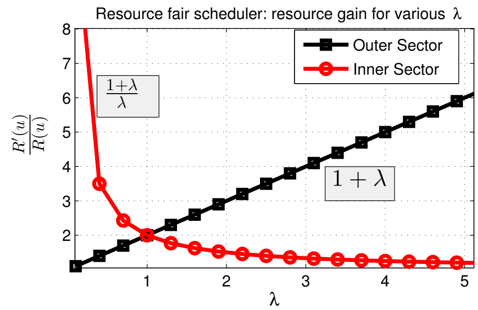

Fig. 4. $\frac{R'(u)}{R(u)}$ variation for various λ using Resource Fair scheduler

value which is defined as explained the earlier sub-section. In our model illustration scenario, the $k(u)$ values and the impact of vertical sectorization on SINR performance are depicted in Figure 5 for a single conventional sector layout for tilt setting of 11° and 5° for inner and outer sectors respectively. As can be observed from the Figure 5(b) and (c), the SINR performance is highly degraded in the outer sector region close to the inner/outer sector border area as this area is highly characterized by having a higher $k(u)$ values as we go closer to the inner sector, as shown in Figure 5(a). This is because the power received from inner sector gets more stronger and closer to that of the outer sector's. Hence, the SINR value gets worse as the relationship defined in Equation 12. Furthermore, it can be observed that, the SINR performance at far edge in of the outer sector is not significantly impacted by the inner sector. This is due to the fact that, the outer sector is relatively stronger and dominant over the inner sector and the interference level from the inner sector is less significant in this area, this effect is more illustrated by the corresponding $k(u)$ values in Figure 5(a) where it is shown in dB scale. Generally, SINR performance degradation of more than 7 dB is recorded from the highly impacted areas of the outer sector as indicated in Figure 5(d). Whereas, some SINR improvements are observed in the inner sector region due to the fact that the region get not better coverage by the inner sector than the outer sector, which is the same other the conventional sector before vertical sectorization.

D. Throughput Performance

The overall throughput performance gain of a UE located at $u \in \mathbb{U}$ is then determined by the mount of acquired resource gain and the SINR performance as shown in Equation 15. These performance determining factors are mainly related to the relative inner sector coverage with respect to the conventional sector layout and the level of interference between inner/outer sectors respectively. The interference level can be mitigated via properly adjusting the inner sector beam tilt away from the outer sector beam. Since, the outer sector beam tilt is considered to be fixed to its optimal setting, i.e., 5° in our scenario case, the tilt adjustment is done by choosing an appropriate tilt configuration for the inner sector. Thus, simulations for a range of different inner sector tilt

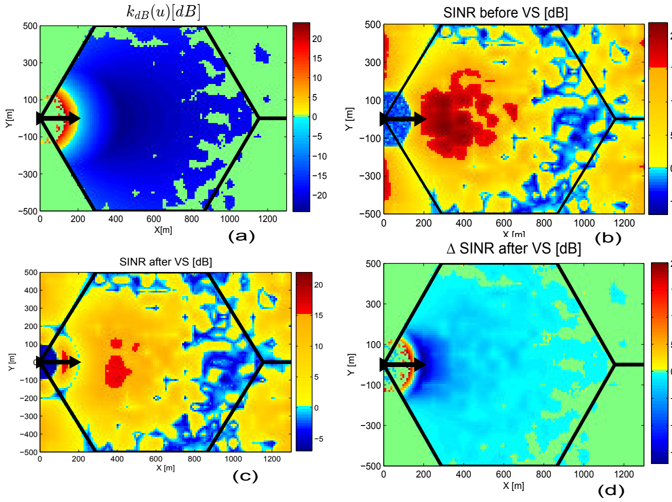

Fig. 5. (a) $k_{dB}(u)$, (b) SINR before VS, (c) SINR after VS and (d) Change in SINR after VS

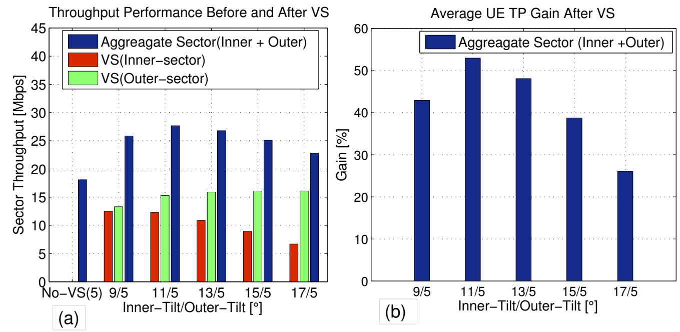

Fig. 6. Sector and Average UE Throughput Performance Comparison

configuration settings has been conducted for our defined simulation scenario.

In the case of a uniform traffic load distribution, since the Inner and outer sector coverage size is not balanced, it is expected that inner sector's UEs achieve a significant throughput performance which is attributed to the higher resource share acquired due to smaller inner sector load. Hence, it would be more interesting to evaluate system performance gain of vertical sectorization by looking at the overall capacity gain over the conventional sector layout and this is done by aggregating the total sector throughput performance achieved by the inner and outer sectors together. The sector TP and average user TP performances are presented in Figure 6 for different inner sector tilt settings.

As illustrated in the figure, keeping all other system parameters unchanged, varying only the inner sector tilt has a dramatic impact on the system performance for the reason explained earlier. In Figure 6(a), it can be observed that, the total aggregate sector TP keeps increasing up to a certain level while increasing the inner sector tilt as it is mitigating the interference level between these sectors. This is because, while increasing the inner sector tilt, the inner/outer sector power factor $k(u)$ becomes smaller which gives rise to a lesser interference level between them leading to a better corresponding SINR ($x'(u)$) for the outer sector UEs. This is well demonstrated in Figure 6(a) with an increase in the outer sector TP. In contrary, the inner sector TP shows degradation with the further increment of its tilt setting, this is attributed to the fact that, the inner sector coverage size gets much more diminished with a higher tilt and this reduces the number of good UEs that contribute to a higher total inner sector TP. Since there is a plenty of resource in the inner sector, the inner sector TP shows linear relationship with the number of available inner sector UEs. Consequently, the best inner sector tilt is seen at a point where the aggregate sector TP is maximized and this is observed at 11° inner sector tilt which gives a tilt difference of 6°. Moreover, the same best tilt setting also provides a maximum average user TP performance as depicted in Figure 6(b) showing more than 50% gain.

VI. Conclusion

In this paper, a mathematical model for vertical sectorization is presented in detail. The model considers a deployment case where outer sector tilt is kept unchanged in order not to introduce unintended deployment layout change in the neighboring sectors and the VS is realized by activating an inner sector at a congested conventional sector. The proposed model shows vital relationships between the parameters that determines the performance of VS like resource gain and SINR performance. Thus, the model can be employed in further investigation and development of scheme of cell densification via vertical sectorization in AAS based deployments. Furthermore, the paper demonstrates the impact of inner/outer sectors' tilt difference on the system performance and found out that it is not always the maximum tilt difference that brings maximum aggregate sector TP rather there should be a reasonable setting that balances the inner/outer sectors performance to maximize overall performance of the conventional sector. The proposed model is limited to the deployment case where outer sector's boundary remains unchanged in VS. The deployment option where outer sector's boundary changes and VS assigns unequal power to inner/outer sector is not included here and is put as an outlook for further investigation.

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