

Super-Cell From Inner Sectors of Active Antenna System (AAS) - Vertical Sectorization

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Abstract—Active Antenna System (AAS) is an advanced antenna technology that features the ability of advanced beamforming techniques to provide a great flexibility in cellular network deployment which enables improvements in network capacity and coverage. 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, however, varying traffic concentrations can be flexibly handled by dynamic cell densification, e.g. by splitting a sector into smaller "sub-sectors". Vertical sectorization is a well-known approach where a conventional sector is split vertically in to two, inner and outer sectors, resulting in 3x2 sectors per site for AAS-based tri-sectorized site. In this paper work, an alternative vertical sectorization deployment configuration is presented where the inner sectors build a so called super-cell resulting from transmitting the same cell information in all inner sectors. Investigation results show that the super-cell configuration can mitigate unwanted back and side lobe effects in close proximity of the site and, therefore, provides a significant gain for users in this coverage area.

Index Terms—Active Antenna Systems, Vertical Sectorization, Super-cell, Mobility

I. INTRODUCTION

Cellular communication technology has undergone a dramatic evolution through different generation (G), i.e. 2G, 3G, and 4G, in the last two decades featuring various advanced service capability. Also cell site architecture was evolving in a way to allow more flexible and cost-efficient cell deployment by means of remote radio heads (RRH) [1]. The next stage in the evolution of the site architecture is the active antenna system (AAS) where separate transceivers and amplifiers are distributed across the antenna elements providing, in addition, flexible beam shaping capability. In 3GPP RAN work group (WG) 4 [2], a study item has been approved on the RF and Electromagnetic Compatibility (EMC) requirements for AAS based on a macro-cell deployment scenarios targeting an improved system capacity and simplified site-deployment.

One of the requirements of AAS in [2] [3] is flexibility in cell lay out deployment by cell-splitting using beamforming techniques such as sectorization in horizontal and vertical planes to achieve a better capacity/performance gain compared to a BS installed with a traditional antenna. Vertical Sectorization (VS) is a scheme where a conventional cellular sector is split into two, inner and outer sectors, by using two dedicated

beams each having its own electrical tilt per vertical sector and formed from a group of multiple active array elements of the AAS arranged vertically as shown in Figure 1(a). The total system bandwidth can be used independently in the inner and outer sectors, and this will double the amount of the total radio resources per a conventional sector. System level simulations have been performed for the Long Term Evolution (LTE) systems in [4] and results have shown that vertical sectorization can provide a significant capacity gain. Figure 1(b) depicts a 3x2 sectors per site where a vertical sectorization is applied on a standard tri-sectorized deployment.

RATs like LTE and UMTS are spectral efficient and are operated with a frequency reuse of one. As a result, in a sectorized cell deployment, intra-site co-channel interference is more critical issue, in particular, the sector area in close vicinity to the antenna heavily suffers from interference due to the effect from back and side lobes of antenna radiation leaking to neighboring sectors. The interference level gets worse with vertical sectorization due to the addition of additional adjacent vertical sectors. The 3GPP Adjacent Channel Interference Ratio (ACIR) criteria is investigated in [5] to evaluate the impact of VS and to verify the AAS-based BS capabilities with the existing BS requirements for LTE systems. Furthermore, in the real world propagation environment, the serving cell power signal detected in the inner most area of the inner sectors, called critical area here, depends mainly on the nature of the side and back lobes of the antenna radiation beam pattern. This area where due to back and side lobe effects all six sectors might become dominant is characterized by highly defragmented best server map and bad SINR. This effect is investigated in this paper using a ray tracing approach for a 3D model of urban scenario using a real antenna radiation pattern provided from antenna manufacturer, KATHREIN, and shown in Figure 1(c) for specific tilt settings. Furthermore, the fact that outer sector radiation pattern becomes randomly dominant in the critical area creates more coverage granularities and coverage boundaries inside the inner sectors. This would have impact on user mobility related network operation like handover (HO), radio link failure (RLF) and ping-pong.

This paper work presents an alternative VS deployment by introducing a super-cell resulting from combining the inner sectors to act as a quasi omni-directional antenna sector by

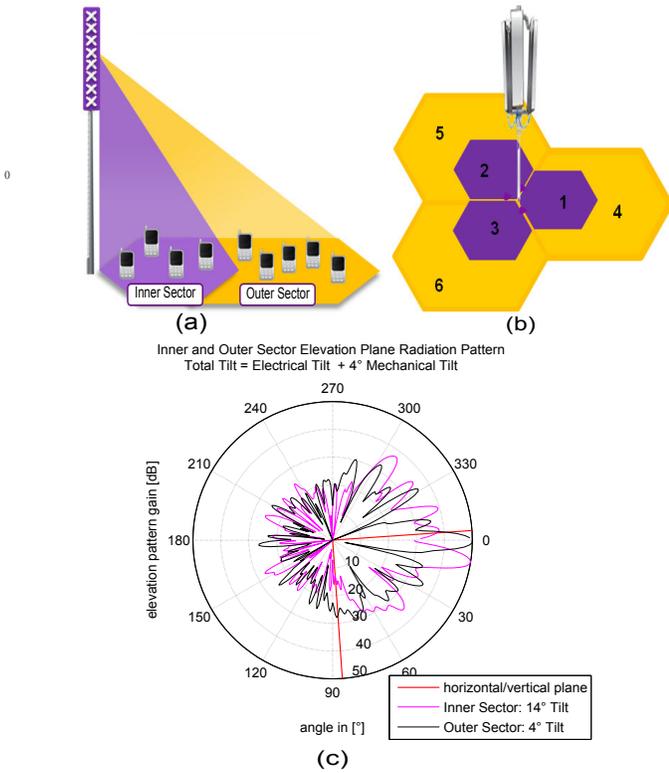


Fig. 1. Vertical Sectorization

using simulcast concept [6] while the standard sectorized configuration is still assumed for the outer sectors. Simulative investigations using a realistic 3D ray tracing propagation model have shown that the super-cell deployment in VS significantly improves the performance of users in critical areas inside the inner sectors by mitigating the interference problem and reducing the mobility aspect issues mentioned above.

The rest of the paper is organized as follows: Section II presents the super-cell deployment concept with respect to VS for AAS in detail. The scenario and system model utilized for the investigation is described in Section III. The results of the performance evaluation are discussed in Section IV and finally Section V concludes the work.

II. SUPER-CELL DEPLOYMENT IN AAS-VS

Super-cell technology is a scheme of deployment that makes multiple cells to act as one by assigning identical cell IDs to each cells and hence eliminates inter-cell boundaries and co-channel interference among the cells. This involves simulcast transmission of identical signals to different cell antenna from the same baseband unit (BBU) [6]. In [7], super-cell configuration is discussed in a coordinated clustered multi-cell cellular systems where a number of coordinating BSs serving a defined super-cell area are linked by fibers and their signals are jointly processed by a central unit in-order to reduce the inter-cell interference.

Assuming a standard sectorized site deployment with 3

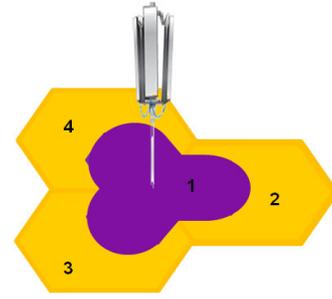


Fig. 2. Super-cell in AAS-based Vertical Sectorization (VS)

conventional sector per site and corresponding sector index k , the power received by a user u from a sector located at a site j , $c_{j,k,\gamma}$, is described by $P_{c_{j,k,\gamma}}^u$ where $c_{j,k,\gamma}$ represents a sector with a unique cell ID and the parameter γ is introduced to identify a sub-sector at sector k in case of vertical sectorization. Thus, γ takes values of 1 and 2 to represent inner and outer sector respectively when vertical sectorization scenario is considered. The serving sector of u is represented by c_{j^u,k^u}^u and it is the k_γ^u sub-sector located at a site j^u and the corresponding received power is given by $P_{c_{j^u,k^u}^u}^u$. Assuming a 3x2 AAS-based VS deployment, and an inner sector user u served by one of the inner sectors, k_1^u , the total interference power received at u , I_{Tot}^u , from inter-site $I_{inter(\gamma)}^u$ and intra-site $I_{intra(\gamma)}^u$ inner and outer sectors can be described as:

$$\begin{aligned} I_{Tot}^u &= I_{inter(1)}^u + I_{inter(2)}^u + I_{intra(1)}^u + I_{intra(2)}^u, \\ &= \sum_{j \neq j^u} \sum_k P_{c_{j,k_1}}^u + \sum_{j \neq j^u} \sum_k P_{c_{j,k_2}}^u \\ &\quad + \sum_{\substack{k \\ k \neq k_1^u}} P_{c_{j^u,k_1}}^u + \sum_k P_{c_{j^u,k_2}}^u \end{aligned} \quad (1)$$

And the Signal to Interference and Noise (N) Ratio (SINR) becomes:

$$SINR^u = \frac{P_{c_{j^u,k_1}^u}^u}{I_{Tot}^u + N} \quad (2)$$

In this paper, a super-cell configuration is implemented for the inner sectors to eliminate the intra-site inner sectors' interference contribution and to mitigate the bad effects of the antenna radiation pattern. Accordingly, the inner sectors will be virtually combined and assigned identical cell ID giving rise to one inner-sector called super-cell eliminating the inter-sector boundaries between the inner sectors as shown in Figure 2. In this configuration, the digital base band signal from one BBU is split up and transmitted to the AAS of each sector where the corresponding RF modulated signal is emitted by the beam pattern determining the inner sectors. As a result, a user will no longer see three distinct inner sectors from site j rather identical signals from each sectors' AAS regarded as a super-cell signal. Hence, the the desired signal power received by an inner-sector user u from its serving supper-cell located at a site j^u can be seen as the superposition of the signals

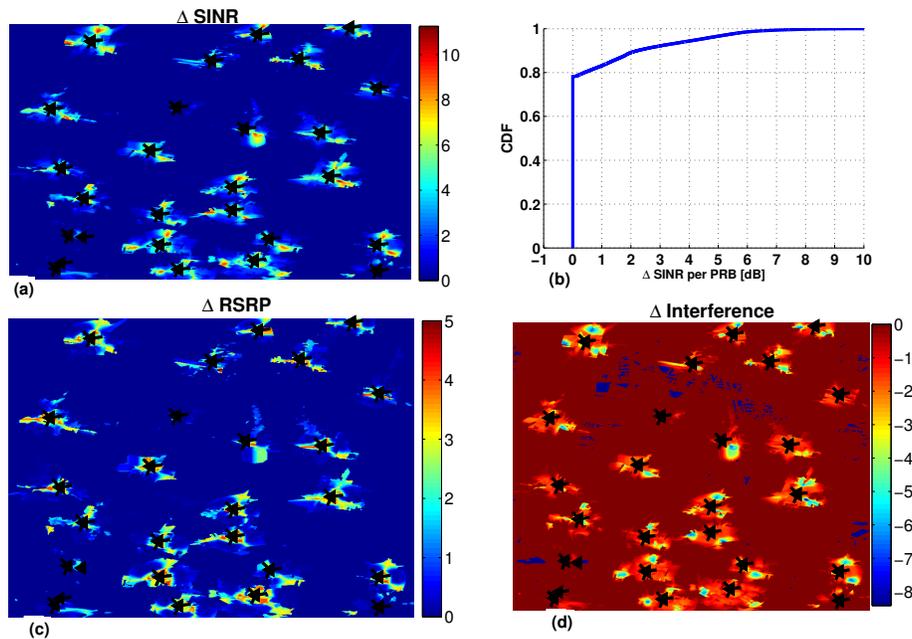


Fig. 3. Observed change in SINR, RSRP and Interference after a super-cell configuration is employed in AAS-based 3x2 VS [colorbar scale in dB].

transmitted by AAS of the sub-sectors of the super-cell:

$$\sum_k P_{c_{j^u, k_1}}^u \quad (3)$$

Furthermore, since inner-sector combining lowers the number of neighboring vertical sectors in the VS configuration, it significantly reduces the level of the inter-sector interference inside the inner sectors in particular the intra-site inter-inner sector interference is eliminated. Thus, equation 1 is reduced to:

$$I_{Tot}^u = \sum_{\substack{j \\ j \neq j^u}} \sum_k P_{c_{j, k_1}}^u + \sum_{\substack{j \\ j \neq j^u}} \sum_k P_{c_{j, k_2}}^u + \sum_k P_{c_{j^u, k_2}}^u \quad (4)$$

Consequently, the SINR experience is significantly improved:

$$SINR^u = \frac{\sum_k P_{c_{j^u, k_1}}^u}{I_{Tot}^u + N} \quad (5)$$

Besides, the stronger desired signal resulted from the super-position leads to a better and smoother super-cell coverage by nearly eliminating the defragmented coverage boundaries and granularities problem from the inner sectors caused by the radiation pattern effect observed in the case of the 3x2 VS deployment. This improves mobility related issues for a moving user thereby yielding a better service experience. Moreover, the super-cell implementation reduces the number of BBUs needed to have the same sector coverage with the conventional three sector deployment, hence, it offers economical benefit to an operator by saving extra cost of infrastructure. However, the super-cell operation has a trade-off that while using the same BBU, it allocates the base band resources available per a conventional sector to the super-cell

resulting in total resource reduction in the super-cell coverage area. For example, in a 10 MHz LTE system bandwidth, 50 Physical Resource Blocks (PRBs) are assumed per sector, thus, after combining the three inner sectors and make them to act as one, only these 50 PRBs are assigned to the super-cell thereby reducing the total radio resources to 1/3 in the inner sectors' coverage area. On the other hand, in contrast to the 3x2 VS which creates coverage imbalance due to small inner and larger outer sectors' size, the super-cell configuration results in a better balanced sectors' coverage leading to a more fairly distributed traffic sharing among the inner and outer sectors in the system.

III. SCENARIO AND SYSTEM MODEL DESCRIPTION

For the investigation, a 3D model of the city of Munich, Germany, and corresponding urban clutter behavior is considered in a network planning tool that employs a ray tracing technique to predict a propagation map. The scenario assumes 27 sectorized sites where the site plan and system parameters configuration settings are done based on realistic site deployment. The network is divided in to a grid of pixels with a resolution of 5 m where a pixel represents a potential location of user u and the received power from a transmitter is predicted at each pixel point. The tool utilizes real two 2D plane antenna radiation patterns, azimuth and elevation, provided by antenna manufacturer and a horizontal projection interpolation (HPI) technique is employed to estimate the corresponding 3D radiation pattern needed during propagation map prediction [8]. An LTE down-link operating at 2.6 GHz carrier frequency and 10 MHz of system bandwidth with a total of 50 PRBs is assumed. Dominant path Prediction Model (DPM) setting is used for the ray-tracer to generate an outdoor

propagation map [9]. The indoor propagation is predicted from the outdoor propagation map by applying 20 dB penetration loss to strongest of all received signals at the pixels around a building and an additional attenuation loss of 1 dB/pixel. The vertical sectorization is realized by configuring the tilt of the inner and outer sectors' beam to 14° and 4° respectively, and a transmit power of 20 W is assumed for each inner and outer sectors. Due to the limitation to the extent of electrical tilt setting of the antenna used, additional mechanical tilt of 4° is applied to extend the range of total tilt setting where maximum electrical tilting considered here is 10° . For the mobility aspect investigation, a total of 1000 moving users are considered where 500 of them are pedestrian moving with a velocity of 3 km/h walking indoor and outdoor, and the rest 500 are fast moving vehicular users having a velocity of 30 km/h and are always on a street.

IV. RESULTS AND PERFORMANCE EVALUATION

In this section, the performance evaluation in real world LTE scenario is presented. The investigation shows the advantages and the tradeoffs of the super-cell deployment compared to the 3x2 VS and standard sectorized (without VS) deployment cases.

A. Interference Mitigation and SINR Performance

It is apparent that the inter-sector co-channel interference level increases with the number of sectors operating with the same carrier frequency. In the 3x2 vertical sectorization, the area closer to the base station is suffering from up to 5 strong interfering intra-site sectors as well as rather degraded and frequently changing best server zones. Since the super-cell deployment combines the three inner sectors to one, it reduces the number of interfering intra-site sectors leading to an improved interference situation compared to the 3x2 VS scenario as discussed before. Previous AAS vertical sectorization studies [10] show that the inner and outer sectors' main beam should have a reasonably high tilt separation gap in order to mitigate the resulting sector overlap, i.e. large down-tilts are needed for the inner-sectors. In this paper, the inner sectors are configured to 14° while outer sectors' tilts are fixed to 4° . Moreover, as explained in [11], electrical downtilting of the boresight of an antenna causes the side and back lobes to be downtilted as well with the same amount of tilting. This effect further worsens the interference situation in the inner sectors area in the case of the 3x2 vertical sectorization as the side and back lobes of the three aggressively down-tilted inner sectors considerably contribute to high interference in close proximity of the base station. In the super-cell case, however, this effect is mitigated as those lobes from the inner sectors will no longer interfere each other, rather contribute to the desired signal. Thus, the different signals from the corresponding inner sector's antenna arrays are seen as a replica signal similar like the various paths from multi-path propagation as they are transmitting the identical cell information and carry the same cell ID. This significantly improves the strength of signal level at the users as long as the different replicas are received within

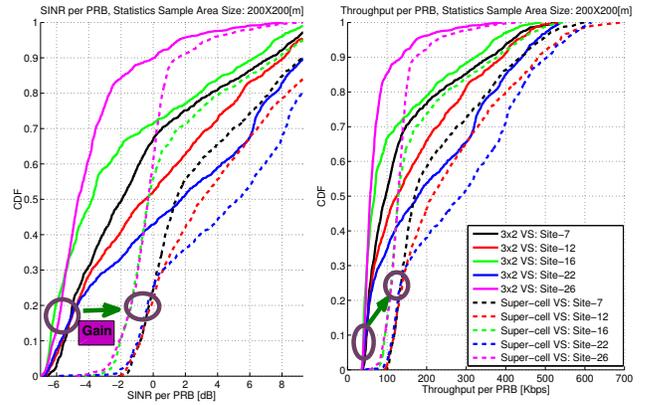


Fig. 4. SINR per PRB and Throughput per PRB performance Comparison for a 3x2 and Super-cell VS for selected sites.

a time delay of not longer than the cyclic prefix (CP) of the OFDM symbol, and this can be guaranteed in close proximity of the base station.

Figure 3 shows the performance improvement in terms of the reference signal received power (RSRP), SINR and interference level at each pixel point in the considered network scenario after employing a super-cell configuration for the inner sectors in vertical sectorization implementation compared with the 3x2 VS scenario. As can be seen from the intensity of the colors, the super-cell configuration have a visible impact on the network areas close to the sites, i.e. 20% of the pixels from the whole network area, Figure 3 (b), which are to be served by the inner sectors. Accordingly, the SINR for those areas is significantly improved due to better RSRP and lower interference level condition resulted from combining the inner sectors. The SINR and throughput evaluation is further demonstrated in Figure 4 where statistics are analyzed per a PRB level and samples are taken from a fixed area of 200 m by 200 m in size around some selected sites. The size of the statistics area is assumed in such way that it reasonably contains the pixels from the inner sectors which are impacted with the super-cell configuration. Thus, it can be seen that with the super-cell deployment, a gain of more than 4 dB is achieved in the system SINR which in turn offers an average throughput per PRB gain of around 60% for the inner sectors' users compared to the 3x2 VS scenario, Figure 4.

B. Sector Coverage Boundaries and Load Share

Figure 5 demonstrates comparison of sectors' coverage and load sharing among sectors for the three types of deployment, (a) standard three sector, (b) 3x2 VS and super-cell VS and (c) super-cell VS. The analysis is taken from two randomly chosen sites out of the 27 sites of the Munich network scenario. As can be seen from the best server plot, the 3x2 vertical sectorization improves network coverage by up-tilting the tilt of the outer sectors while maintaining the inner area coverage via down-tilting the tilt of the inner-sectors, Figure 5 (b), compared to the standard three sector deployment, Figure 5 (a), while

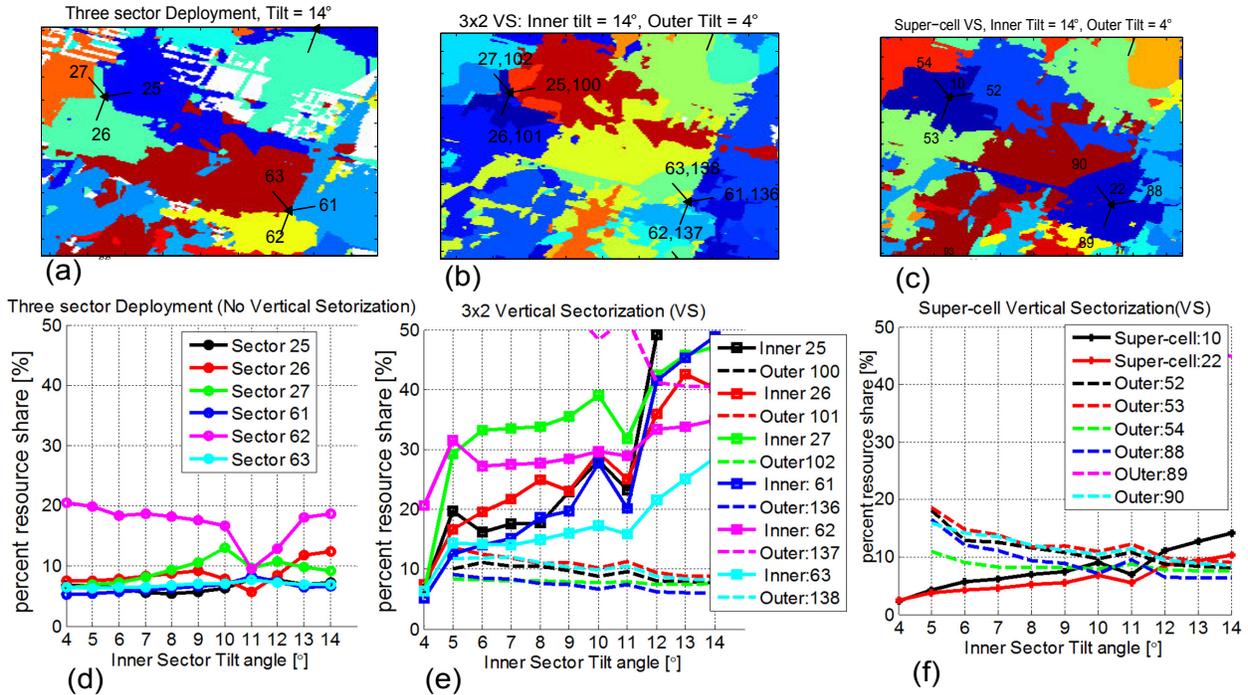


Fig. 5. Coverage and Percent resource share comparison for different deployment case scenarios.

creating fragmented coverage from outer sectors resulting in more coverage boundaries inside the inner sectors. However, this problem is significantly reduced in the super-cell VS deployment case where combining the inner sectors yielding a smoother inner sector coverage as exhibited in Figure 5 (c).

Principally, the 3x2 VS configuration is providing higher capacity gain due to higher cell densification in-terms of providing more radio resources for the inner sectors' users, since the inner sectors become relatively small due to the conical shape of the sectors as can be seen in Figure 5 (d), (e) and (f) where percentage of resource share of a user, defined here as the inverse of the number users being served, in a sector is presented assuming a resource fair scheduler. In case of homogeneous user traffic situation in the network, this would create unbalanced traffic load distribution among sectors. On the other hand, the super-cell configuration has a bigger coverage area comparable to one of the outer sectors resulting in a better balanced traffic sharing among sectors. This can clearly be seen in Figure 5 (f) where the inner and outer sector users have comparable resource share than in Figure 5 (e). In case of a simplified hexagon cell lay out as depicted in Figure 1(a), the coverage balance with the super-cell VS deployment can be shown in the following equations, where the inner super-cell coverage area (A_{super}) is exactly the same as the remaining part of one of the outer-sectors' (A_{outer}), if edge length of the inner sector hexagon is half of the outer edge, $d/2$. In the equation follows, A_i represents the area of sector i hexagon and d is the side length of the outer sector hexagon.

$$A_4 = \frac{\sqrt{3}}{2} \times (d)^2, \quad (6)$$

$$A_1 = \frac{\sqrt{3}}{2} \times (d/2)^2 = \frac{1}{4} \times \frac{\sqrt{3}}{2} \times (d)^2 \implies A_4 = 4 \times A_1, \quad (7)$$

$$A_{super} = A_1 + A_2 + A_3 = 3 \times A_1 \quad (8)$$

$$A_{outer} = A_4 - A_1 = 3 \times A_1 = A_{super},$$

C. Impacts on Mobility Aspect Operations

As discussed before, the sector densification via 3x2 VS leads to rather fragmented best server in the critical area as all six sectors are getting quite randomly dominant and thereby creating more coverage boundaries. Such situation has an impact in particular to moving users as they need to frequently hand-off between sectors while crossing the borders. This increases the handover operations causing increased signaling traffic and consequently more radio link failures (RLFs) resulting in unreliable link experience for users.

Figure 6 (a) compares the number of handover counts occurred between different sectors for the different deployment scenarios. Due to the fact that the super-cell configuration eliminates the intra-site inter-sector boundaries between the inner sectors, the intra-site inner-to-inner sector handover is 100% reduced as depicted in the Figure 6 (a) and (b). In the 3x2 VS deployment, the most frequent HO that occurs in the critical area close to the base station is the intra-site inner-to-outer and outer-to-inner sectors' HO caused by the presence of fragmented outer-sector coverage in the inner sector area. With the super-cell deployment, these HOs are significantly minimized. Figure 6 (b) shows the change in the number of HO count after a super-cell is configured compared with the case of the 3x2 VS deployment. Accordingly, 17% and 11% reduction is gained in the number of inner-to-outer and outer-

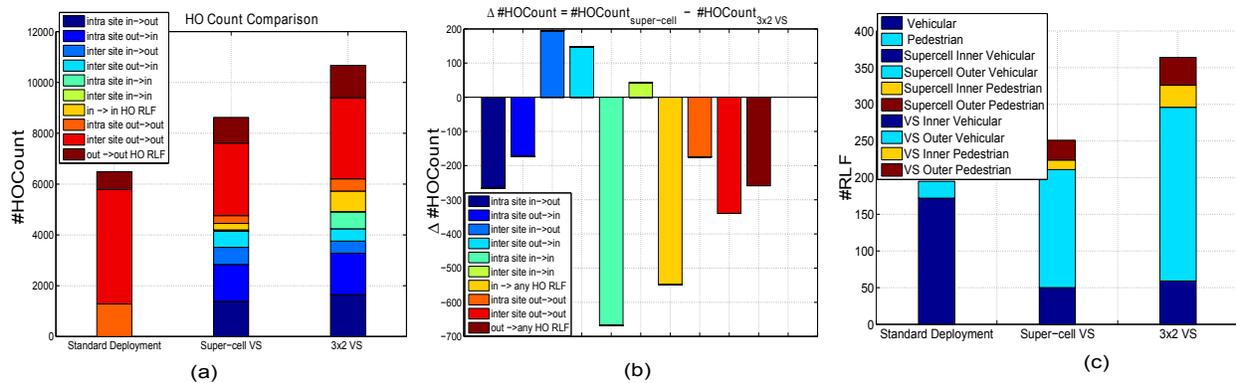


Fig. 6. Coverage and Percent resource share comparison for different deployment case scenarios.

to-inner sector intra-site HO counts respectively. Moreover, the fact that the critical area users suffer from high interference from side and back lobes leads to an increased number of HO RLF in the case of 3x2 VS deployment where a handover is triggered but not executed in time and in the meanwhile the moving user fails to connect any longer due to bad connection caused by deep interference situation. As can be seen in Figure 6 (b), the super-cell configuration incredibly reduces the HO RLF in the fragmented critical area by 70% for users served by the inner sectors and by 21% for users doing handover from the outer sector coverage region via significantly reducing the interference situation as illustrated in Figure 3 (d). On the other hand, the superposition of the signals from the sub-sectors of a super-cell creates an improved and extended inner sectors' coverage. This introduces coverage boundaries between inter-site inner sectors increasing probability of a handover between inter-site inner-inner and outer-inner sectors unlike to the 3x2 VS deployment case as indicated in Figure 6 (b).

In addition to the HOs, aggressive interference situation in the critical area results in more RLFs. Figure 6 (c) shows the number of RLFs comparison for the three deployment scenarios for pedestrian and vehicular users separately. RLF ratio is defined here as the ratio of the total number of RLF to total number of HO. Accordingly, RLF ratio of 3.6% is observed in the case of 3x2 VS whereas this figure gets reduced to 2.4% in the case of super-cell deployment and the absolute number of RLFs in the super-cell is dramatically reduced by 66% due to aforementioned reason.

V. CONCLUSION

In this paper, a super-cell configuration is presented as an alternative way of vertical sectorization in AAS-based deployment. Results have shown that the super-cell compared to the traditional 3x2 VS deployment offers a significant performance improvement for inner-sectors' users, in particular to those in a close proximity of the base station, by mitigating the intra-site inter-sector interference as well as the spotted and defragmented best server map resulting from side and back lobes effects of six overlaying beams each representing a separate cell. Both effects are dramatically reduced with the super-cell configuration by emitting the same RF signal

over the inner heavily tilted beams and making those intra-site inter-sector lobes to combine them into a single cell. Simulcast of inner sectors yields a stronger serving signal power thereby leading to a smoother and improved inner-sector coverage. Besides, the reduction of the coverage granularities and coverage boundaries in those areas considerably reduces the number of frequent HO operations and RLFs yielding a better situation for a seamless service experience for users. Another interesting economical benefit to operators by saving infrastructure costs results from the fact that the super-cell deployment is implemented with a reduced number of base band units compared to the 3x2 AAS-enabled VS deployment.

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