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Self Optimizing Network (SON) Framework for Automated Vertical Sectorization

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***Abstract*—Dynamic Vertical Sectorization (VS) is a flexible way of cell densification used to enhance system capacity in temporally and spatially varying overload situations. An automated control mechanism in the context of Self Optimizing Network (SON) is required to execute the sectorization only when there is a demand for extra capacity and the sectorization brings benefit in a dynamically varying traffic condition. The SON mechanism requires proper real-time modeling of the system performance with respect to VS activation/deactivation via monitoring the traffic situation and commonly used system parameters.**

***Index Terms*—AAS, Vertical Sectorization, SON**

I. Introduction

Cell densification, a typical means for capacity enhancement, can be achieved in a flexible and dynamic way through sectorization via deploying advanced antenna technologies like Active Antenna Systems (AAS) [1]. Vertical Sectorizatin (VS) is realized by splitting the beam covering a conventional sector layout in a vertical domain resulting in two sector beams representing an inner and outer sector [2], [3] reusing the same frequency band thereby doubling the total available radio resources to yield a better and improved resource share for the users. The particular advantage of AAS based VS is the flexibility to adapt the deployment to a temporarily and spatially varying traffic situation by activating/deactivating new sectors when and where extra capacity is needed [2].

One of the challenges in VS is the impact of the co-channel intra-site interference between the vertical sectors, and particularly the coverage region close to inner/outer sector border is characterized by critical interference condition [2], [4]. Thus, VS performance is highly determined by the geographical distribution of the users as well [2]. Unless favorable conditions are met, VS might be detrimental and should not be activated. Moreover, the expected gain with respect to radio resource share can be achieved only if a required level of user reconnection takes place after VS among the vertical sectors.

In order to properly adapt the deployment in a self-organized approach, an appropriate and timely decision needs to be carried out dynamically following the varying traffic and user distribution situation in the network. Therefore, a Self Organizing Network (SON) mechanism framework taking these aspects into account is essential and proposed in this paper in order to autonomously control the VS operation in an automated manner.

II. Generalized System Model For VS

Considering a LTE network of AAS equipped sites with index $\Omega = 1, 2, \ldots, N_{\mathrm{s}}$, where N_{s} is the total number of sites. The index of a sector antenna mounted at a site Ω is given by $i = 1, \ldots, N_\Omega$, where N_Ω is the total number of sector antennas on the site. With the AAS capability, several serving sectors can be created with further sectorization from a single sector antenna. Thus, a sector c is given by $c \triangleq (\Omega, i, m)$ where $m \in \{0, 1, 2\}$ identifies a particular sector beam created at antenna i. If vertical sector is activated, i.e. VS=ON, index m takes non zero values of $m = 1$ and $m = 2$ to refer to outer and inner sector respectively, otherwise $m = 0$ for the conventional sector layout when VS=OFF. Assuming the total available power at any i is P_T and the transmit power per sector is $P^{tx}_{(\Omega,i,m)}$, the power received by a user terminal u from any sector is represented by $P^u_{(\Omega,i,m)}$:

$$P^u_{(\Omega,i,m)} = P^{tx}_{(\Omega,i,m)} \cdot h^u_{(\Omega,i,m)}, \tag{1}$$

where $h^u_{(\Omega,i,m)}$ is the magnitude of the channel gain of u with respect to the corresponding sector and it can be expressed in terms of the respective antenna gain, $G^u_{(\Omega,i,m)}$, and total propagation loss, $L^u_{(\Omega,i,m)}$, as $h^u_{(\Omega,i,m)} = G^u_{(\Omega,i,m)}/L^u_{(\Omega,i,m)}$. A user terminal selects its best serving sector based on the measured Reference Signal Received Power (RSRP) and this association is expressed by a connection function $s(u)$, i.e.

$$s(u) = \underset{(\Omega,i,m)}{\operatorname{argmax}} \, \{P^u_{(\Omega,i,m)}\} \tag{2}$$

The number of active users connected to a sector is given by $N_{(\Omega,i,m)}$. The Signal to Interference plus Noise Ratio (SINR) performance of a user terminal while connected to a conventional sector, i.e. $m = 0$, is given by γ_u.

$$\gamma_u = \frac{P^u_{s(u)}}{\sum\limits_{\substack{\Omega=1 \\ (\Omega,i,1)\neq s(u)}}^{N_{\mathrm{s}}} \sum\limits_{i=1}^{N_\Omega} \zeta_{\Omega,i,0} \cdot P^u_{\Omega,i,0} + \mathrm{N}_o} \tag{3}$$

and:

$$\zeta_{(\Omega,i,m)} = \begin{cases} 1, & N_{(\Omega,i,m)} \neq 0 \\ 0, & N_{(\Omega,i,m)} = 0 \end{cases} \tag{4}$$

where N_o refers to noise power and $\zeta_{(\Omega,i,m)}$ is the sector load situation used for interference calculation. Considering a full buffer traffic, sector load is 100% if it is serving at least a single user, it is zero otherwise.

A. Vertical Sector Activation and User Reconnection

When vertical sector is activated, an additional vertical sector beam is generated from the same sector AAS. The new sector, also called inner-sector, broadcasts a unique Physical Cell ID (PCI) and configured with a higher elevation tilt angle setting in order to minimize the degree of overlap between the inner-sector ($m = 2$) and the original intra-site sector, referred as outer-sector ($m = 1$). Since VS is activated on demand, the activation/ deactivation status of a sector beam generated from antenna i mounted on BS site Ω is indicated by a status flag denoted by $s(\Omega, i)$:

$$s(\Omega,i) = \begin{cases} 1, & \text{VS=ON} \\ \\ 0, & \text{VS=OFF} \end{cases} \tag{5}$$

In order to derive fundamental relationship for system performance comparison, the transmitted power level per each sector beam after VS activation is described in terms of the total power assigned for the conventional sector beam as $P^{tx}_{(\Omega,i,m)} \propto P^{tx}_{(\Omega,i,0)}$, $\forall m | m \neq 0$, and the inner/outer sector power split is done with total power constraint criteria, i.e., $\sum_{m,\, m\neq 0} P^{tx}_{(\Omega,i,m)} \leq P_T$. Thus, given α_m is the power split factor, $P^{tx}_{(\Omega,i,m)} = \alpha_m \cdot P^{tx}_{(\Omega,i,0)}$ satisfying constraint $\alpha_1 + \alpha_2 \leq 1/\beta$ where β fraction of the total power that has been assigned for the conventional sector, $P^{tx}_{(\Omega,i,0)} = \beta \cdot P_T$.

When VS is activated, UEs on the conventional sector layout are associated to one of the new vertical sector which is dominant over the underlying coverage. A so-called coverage dominance criterion k_u is introduced which is determined by the relative strength of the RSRP measured by a UE with respect to each sector: $k_u = P^u_{(\Omega,i,2)}/P^u_{(\Omega,i,1)}$.

Considering VS is activated at a sector antenna of index j mounted on base station site identified by ω, a user is handed-over to the new inner sector if its measured RSRP is better than that of the outer-sector, i.e., $k_u > 1$, accordingly, the cell re-selection can be expressed as:

$$s(u) = \begin{cases} (\omega, j, 1), & k_u \leq 1 \\ \\ (\omega, j, 2), & k_u > 1 \end{cases} \tag{6}$$

Since the decision of inner-sector activation should be autonomous to a specific site or conventional sector, it is required not to introduce unnecessary deployment layout change in the neighborhood of a stable and optimized network. Therefore, the model assumes total sector power of the outer sector is maintained and is the same as the original conventional sector power, i.e. $\alpha_1 = 1$. As a result, the total conventional sector coverage will be taken over by the inner and outer sectors yielding $N_{(\omega,j,1)} + N_{(\omega,j,2)} \approx N_{(\omega,j,0)}$. The resulting user reconnection between the sub-sectors depends on the size of the dominant inner-sector coverage and the nature of the spatial user distribution over the conventional sector layout and the UE load distribution by $\lambda_{(\omega,j)}$ is defined as the ratio of the number of users connected to the inner to that of the outer sector: $\lambda_{(\omega,j)} = N_{(\omega,j,2)}/N_{(\omega,j,1)}$.

B. Radio Resource Allocation and Achievable Resource Gain

A resource fair allocation strategy is employed at each sector to share the available resource among users in a proportional fair manner [5]. Accordingly, all users gets equal fraction of the total resource $M_{s(u)}$ available at the serving sector, i.e.:

$$R_u = \frac{1}{N_{(\omega,j,m)}}, \quad \text{For:} \quad s(u) = (\omega, j, m), \tag{7}$$

<u>Note:</u> R_u and γ_u are used to refer to values when VS=OFF, and R'_u and γ'_u are for VS=ON case, from now onwards.

VS is expected to yield a better resource share per user, i.e. $R'_u > R_u$. The resource gain is proportional to $\lambda_{(\omega,j)}$ for the users connected to the outer sector whereas inner sectors' user share decreases with increase in $\lambda_{(\omega,j)}$. This relationship can be illustrated with resource share ratio as:

$$\frac{R'_u}{R_u} = \begin{cases} 1 + \lambda_{(\omega,j)}, & s(u) = (\omega, j, 1) \\ \\ \frac{1+\lambda_{(\omega,j)}}{\lambda_{(\omega,j)}}, & s(u) = (\omega, j, 2) \end{cases} \tag{8}$$

The resource gain both at the inner and outer sector is maximized and becomes 100% when the two sectors serve equal number of users, i.e. $\lambda_{(\omega,j)} = 1$

C. SINR Performance Prediction

After a vertical sector is activated, the SINR performance of a user located in the conventional sector layout undergoing VS becomes different depending on the k_u value and the extra intra-site co-channel interference experience from the newly activated inner sectors. Due to the steeper inner sector tilt setting Θ_m, i.e. $\Theta_2 > \Theta_1$, the interference coming from the inner sectors of other-sites where VS is activated has insignificant impact as indicated in [2] and also justified in next subsection with SINR change map, Figure 2. Thus, the interference signal power term from any VS activated site can be generally approximated using only the outer sector signal power as:

$$\sum_{\substack{\Omega=1 \\ \Omega\neq\omega}}^{N_s} \sum_{i=1}^{N_\Omega} \sum_{m=1}^{2} \zeta_{\Omega,i,m} \cdot P^u_{\Omega,i,m} \approx \sum_{\substack{\Omega=1 \\ \Omega\neq\omega}}^{N_s} \sum_{i=1}^{N_\Omega} \zeta_{\Omega,i,1} \cdot P^u_{\Omega,i,1}$$
$$\text{and} \quad : \quad P^u_{\Omega,i,1} = \alpha_1 \cdot P^u_{\Omega,i,0} \tag{9}$$

Hence, incorporating both the inter- and intra-site interference, the SINR experience of a UE after VS described by γ'_u

is modeled as:

$$\gamma'_u = \begin{cases} \frac{P^u_{\omega,j,1}}{\mathbb{I}'_u + \sum\limits_{i=1}^{N_\omega} s(\omega,i)\cdot\zeta_{\omega,i,2}\cdot P^u_{\omega,i,2} + \mathrm{N}_o}, & k_u \leq 1 \\ \\ \frac{P^u_{\omega,j,2}}{\mathbb{I}'_u + \zeta_{\omega,j,1}\cdot P^u_{\omega,j,1} + \sum\limits_{\substack{i=1\\ i\neq j}}^{N_\omega} s(\omega,i)\cdot\zeta_{\omega,i,2}\cdot P^u_{\omega,i,2} + \mathrm{N}_o}, & k_u > 1 \end{cases} \tag{10}$$

where $\mathbb{I}'_u$ is the total interference signal power received at u excluding the intra-site inner sectors' interference contribution:

$$\mathbb{I}'_u = \sum_{\substack{\Omega=1\\ (\Omega,i,1)\neq s(u)}}^{N_s}\sum_{i=1}^{N_\Omega} \zeta_{\Omega,i,0}\cdot P^u_{\Omega,i,0}\cdot\left[1 - s(\Omega,i)\cdot(1-\alpha_1)\right] \tag{11}$$

With further manipulations of Equation 10, γ'_u model can be simplified to derive a vital SINR performance relationship as a function of the SINR experienced with VS=OFF state, γ_u. Thus, an SINR predictor function denoted by $\mathcal{F}(\gamma_u)$ is defined which is employed to estimate γ'_u, i.e. $\gamma'_u = \mathcal{F}(\gamma_u)$ by using k_u and other network parameters prior to decision of vertical sector activation. k_u can be determined at the eNB by relying on realistic information from the network based on RSRP measurement reports collected from the UEs in the conventional sector. While being in VS=OFF state, the RSRP information can be collected by a mechanism called sector probing where a special sector beam is temporarily activated for a certain specified time window only to broadcast reference signal and control information of the inner sector planned to be activated later with the SON decision. Thus, $\mathcal{F}(\gamma_u)$ is expressed as:

$$\mathcal{F}(\gamma_u) = \begin{cases} \frac{\alpha_1\cdot\gamma_u}{1+\alpha_1\cdot k_u\cdot\gamma_u\cdot\Psi_1}, & k_u \leq 1 \\ \\ \frac{\alpha_1\cdot k_u\cdot\gamma_u}{1+\alpha_1\cdot\gamma_u\cdot\Psi_2}, & k_u > 1 \end{cases} \tag{12}$$

where Ψ_1 and Ψ_2 are parameters used to include the interference contribution from an outer and intra-site inner sectors respectively as given by:

$$\begin{aligned} \Psi_1 &= l_{(\omega,j,2)} + \frac{1}{\alpha_1\cdot k_u\cdot P^u_{(\omega,j,0)}}\cdot\sum_{\substack{i,\\ i\neq j}}^{N_\omega}\zeta_{(\omega,i,2)}\cdot P^u_{(\Omega,j,2)} \\ \Psi_2 &= l_{(\omega,j,1)} + \frac{1}{\alpha_1\cdot P^u_{(\omega,j,0)}}\cdot\sum_{\substack{i,\\ i\neq j}}^{N_\omega}\zeta_{(\omega,i,2)}\cdot P^u_{(\omega,i,2)} \end{aligned} \tag{13}$$

The VS activation process should evaluate the impact on the SINR performance as well, hence, the SINR change measuring parameter described by $\Delta_{\gamma(u)} = 10\cdot\log_{10}(\gamma'_u/\gamma_u)$ is computed using Equation 12 and setting $\alpha_1 = 1$ for aforementioned reason:

$$\Delta_{\gamma(u)} = \begin{cases} -10\cdot\log_{10}(1+k_u\cdot\gamma_u\cdot\Psi_1), & k_u \leq 1 \\ \\ 10\cdot\big(\log_{10}(k_u) - \log_{10}(1+\gamma_u\cdot\Psi_2)\big), & k_u > 1 \end{cases} \tag{14}$$

For vertical sector deactivation case, while being in VS=ON operation state, since k_u can be directly available at the eNB as both vertical sectors are actively serving, the estimation of the γ_u from γ'_u can be performed using a corresponding SINR predictor function described by $\mathcal{G}(\gamma'_u)$ which is an inverse of Equation 12, i.e. $\mathcal{G}(\gamma'_u) = \mathcal{F}^{-1}(\gamma_u)$:

$$\mathcal{G}(\gamma'_u) = \begin{cases} \frac{\gamma'_u}{\alpha_1\cdot(1-k_u\cdot\gamma'_u\cdot\Psi_1)}, & k_u < \frac{1}{\gamma'_u\cdot\Psi_1} \wedge k_u \leq 1 \\ \\ \frac{\gamma'_u}{\alpha_1\cdot(k_u-\gamma'_u\cdot\Psi_2)}, & k_u > \gamma'_u\cdot\Psi_2 \wedge k_u > 1 \\ \\ \gamma'_u, & [k_u \geq \frac{1}{\gamma'_u\cdot\Psi_1} \wedge k_u \leq 1]\vee \\ & [k_u \leq \gamma'_u\cdot\Psi_2 \wedge k_u > 1] \end{cases} \tag{15}$$

III. Strategies for Automated Sectorization

Automated activation and deactivation procedure requires a triggering condition to initiate the process and sufficient criteria to make evaluation and validation of the final decision.

A. Triggering Condition

The demand for an extra capacity is attributed to an overload situation, therefore, the load condition at the conventional sector is employed as a trigger to initialize an activation process. Considering a non-GBR full buffer traffic and a minimum acceptable user data rate requirement, τ_u, the sector load is defined as the sum of the fraction of the radio resource demand that can be allocated for each user with best effort, i.e $\mathbf{min}(R^{min}_u, R_u)$, where R^{min}_u is the minimum resource demand of a user to achieve the target TP, τ_u, whereas R_u is the maximum resource share a user can be granted depending on the load status. Accordingly, R^{min}_u is evaluated as:

$$R^{min}_u = \frac{R_u\cdot\tau_u}{TP_u} \tag{16}$$

where TP_u is the actual achievable throughput of the user given by $TP_u = R_u\cdot M_{s(u)}\cdot f(\gamma_u)$ and $f(\cdot)$ is a function of user SINR and gives the spectral efficiency performance. Thus, the sector load $\mathcal{L}_{(\omega,j,m)}$ is:

$$\mathcal{L}_{(\omega,j,m)} = \sum_{\substack{u\\ s(u)=(\omega,j,m)}} \mathbf{min}\Big(\frac{\tau_u}{N_{(\omega,j,m)}\cdot TP_u}, \frac{1}{N_{(\omega,j,m)}}\Big) \quad \leq 1 \tag{17}$$

Thus, the activation process is triggered if the conventional sector load is above a defined load threshold level, $\mathcal{L}_{thr}$, i.e. $\mathcal{L}_{(\omega,j,0)} > \mathcal{L}_{thr}$.

On the other hand, the deactivation process in VS=ON state is triggered if either of the sub-sectors are no longer serving a user for a certain period of time t_ω, i.e $N_{(\omega,j,1)} = 0$ or $N_{(\omega,j,2)} = 0$.

B. Decision Criteria

The decision whether to activate or deactivate a vertical sector depends on the improvement in the system performance that can be achieved over the corresponding conventional sector layout. To evaluate the system performance, a proportional fair based utilities, $\mathbb{U}_{\omega,j}$ and $\mathbb{U}'_{\omega,j}$, are defined over the conventional sector layout as the sum of the logarithm of the TP performance of all the users connected to either the conventional sector (VS=OFF) or the vertical sectors (VS=ON), respectively [4], and which are expressed as:

$$\mathbb{U}_{\omega,j} = \sum_{\substack{u, \\ s(u)=(\omega,j,0)}} \log(TP_u) \quad , \quad \mathbb{U}'_{\omega,j} = \sum_{\substack{u, \\ s(u)=(\omega,j,1)\vee \\ s(u)=(\omega,j,2)}} \log(TP'_u) \tag{18}$$

Based on Equation 18, the VS state with a better utility value is provides an improved system performance, hence, a decision metric denoted by $\Delta_{\omega,j}$ is defined as the difference in the utility performances:

$$\begin{aligned}\Delta_{\omega,j} &= \mathbb{U}'_{\omega,j} - \mathbb{U}_{\omega,j} \\ &= \sum_{u} \log\left(\frac{R'_u}{R_u} \cdot \frac{f(\gamma'_u)}{f(\gamma_u)}\right)\end{aligned} \tag{19}$$

From the expression in Equation 19, $\Delta_{\omega,j}$, value depends on the achievable resource gain as well as the ratio of the spectral efficiency performance of the users. Despite the increased in the interference level due to the activation of a new inner sector which deteriorates the SINR performance, the expected overall system performance gain with VS=ON is attributed to the improvement in the achievable resource share. As can be seen in Equation 14, the outer sector users' SINR is always worse and this degradation is more critical when a user with high γ_u performance is located closer to the inner/outer sector border where k_u is very small. Such users are very sensitive for vertical sector activation and are typically limiting system performance. Therefore, a sensitivity measure parameter Γ_u is defined as the ratio of the spectral efficiency performance of a user before and after activation, i.e.

$$\Gamma_u = \frac{f(\gamma_u)}{f(\gamma'_u)} \tag{20}$$

Incorporating Γ_u and using Equation 8 in Equation 19, $\Delta_{\omega,j}$ can be redefined for $\lambda_{(\Omega,i)} \neq 0$ as:

$$\begin{aligned}\Delta_{\omega,j} &= \sum_{\substack{u, \\ s(u)=(\omega,j,1)}} \log\left((1+\lambda_{(\omega,j)}) \cdot \frac{1}{\Gamma_u}\right) \\ &+ \sum_{\substack{u, \\ s(u)=(\omega,j,2)}} \log\left(\frac{1+\lambda_{(\omega,j)}}{\lambda_{(\omega,j)}} \cdot \frac{1}{\Gamma_u}\right)\end{aligned} \tag{21}$$

For those sensitive users with $\Gamma_u > 1$, the resource share that satisfied $R'_u/R_u > 1/\Gamma_u$ must be achieved to compensate their SINR degradation and an improvement on overall performance requires $\lambda_{(\omega,j)}$ condition that can fairly maximize the resource gain at both vertical sectors. Hence, additional necessary condition is defined from Equation 21 on top of $\Delta_{\omega,j}$ metric to ensure acceptable utility performance level of δ_1 and δ_2 are maintained at the outer and inner sector, respectively. Taking average sensitivity level performance of all UEs connected at each sector, the necessary condition is described as:

$$N_{(\omega,j,1)} \cdot \log\left(\frac{1+\lambda_{(\omega,i)}}{\hat{\Gamma}_1}\right) \geq \delta_1, \tag{22}$$

$$N_{(\omega,i,2)} \cdot \log\left(\frac{1+\lambda_{(\omega,i)}}{\lambda_{(\omega,i)} \cdot \hat{\Gamma}_2}\right) \geq \delta_2, \tag{23}$$

where:

$$\log(\hat{\Gamma}_1) = \frac{1}{N_{(\omega,i,1)}} \cdot \sum_{\substack{u, \\ s(u)=(\omega,i,1)}} \log(\Gamma_u) \quad , \tag{24}$$

$$\log(\hat{\Gamma}_2) = \frac{1}{N_{(\omega,i,2)}} \cdot \sum_{\substack{u, \\ s(u)=(\omega,i,2)}} \log(\Gamma_u) \tag{25}$$

$$\Longrightarrow \hat{\Gamma}_1 = \left[\prod_{\substack{u, \\ s(u)=(\omega,i,1)}}^{N_{(\omega,i,1)}} \Gamma_u\right]^{\frac{1}{N_{(\omega,i,1)}}}, \quad \hat{\Gamma}_2 = \left[\prod_{\substack{u, \\ s(u)=(\omega,i,2)}}^{N_{(\omega,i,2)}} \Gamma_u\right]^{\frac{1}{N_{(\omega,i,2)}}} \tag{26}$$

Based on Equation 22 and 23, the range of $\lambda_{(\omega,i)}$ satisfying the necessary condition for VS activation becomes:

$$e^{\frac{\delta_1}{N_{(\omega,i,1)}}} \cdot \hat{\Gamma}_1 - 1 \;\leq\; \lambda_{(\omega,i)} \;\leq\; \frac{1}{e^{\frac{\delta_2}{N_{(\omega,i,2)}}} \cdot \hat{\Gamma}_2 - 1} \tag{27}$$

The $\lambda_{(\omega,i)}$ range is a decisive factor in determining the situation where $\Delta_{\omega,j}$ is improved by offsetting the SINR degradation with the resource gain. To explain this situation, the $\Delta_{\omega,j}$ metric defined in Equation 21 is decomposed into a sum of two terms: the first term showing the gain from the resource and the second term describes the degradation in user spectral efficiency by using the average UE sensitivity value at each vertical sector, $\hat{\Gamma}_m$, as:

$$\begin{aligned}\Delta_{\omega,j} =& N_{(\omega,j,1)} \cdot \left[\lambda_{(\omega,j)} \cdot \log\left(\frac{1+\lambda_{(\omega,j)}}{\lambda_{(\omega,j)}}\right) + \log(1+\lambda_{(\omega,j)})\right] \\ &- \left[N_{(\omega,j,2)} \cdot \log(\hat{\Gamma}_2) + N_{(\omega,j,1)} \cdot \log(\hat{\Gamma}_1)\right]\end{aligned} \tag{28}$$

Apparently, for fixed $\lambda_{(\omega,i)}$ case, the $\Delta_{\omega,j}$ value varies considerably when the nature of the spatial UE distribution situations at each vertical sector is altered as it determines the severity of the experienced SINR change thereby impacting $\hat{\Gamma}_m$.

Consequently, there is a limited range of $\hat{\Gamma}_1$ and $\hat{\Gamma}_2$ values that can yield a utility gain at a certain $\lambda_{(\omega,i)}$. This is demonstrated in Figure 1 with plots of UEs' achieved resource share and sensitivity value ranges at each vertical sector which result in $\Delta_{\omega,j} > 0$ for sample $\lambda_{(\omega,i)}$ values. The plots depicts the resource gain term of Equation 28 with Λ while the color the map represents the corresponding SINR degradation term determined by the sensitivity range. Accordingly, for each Λ case, VS=ON always improves the utility as long as $\hat{\Gamma}_1$ and $\hat{\Gamma}_2$ values are within the light color region. However, for the red color area, VS should be deactivated as it yields a deteriorated utility performance that results $\Delta_{\omega,j} < 0$. As illustrated in Figure 1, the inner sector UEs are more

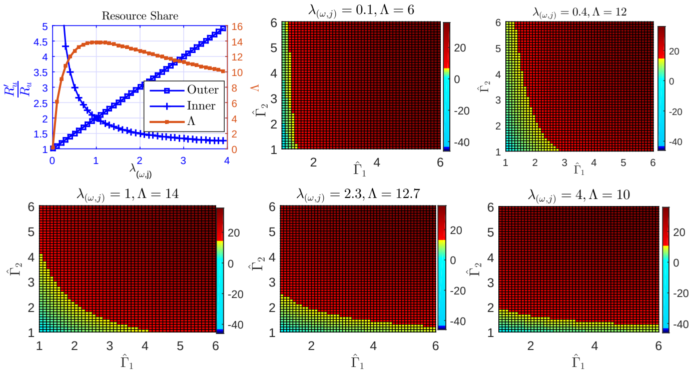

Fig. 1. VS Activation/Deactivation region based on resource gain and sensitivity

used for the $\Delta_{\omega,j}$ and outer/inner sub-sector performances, respectively.

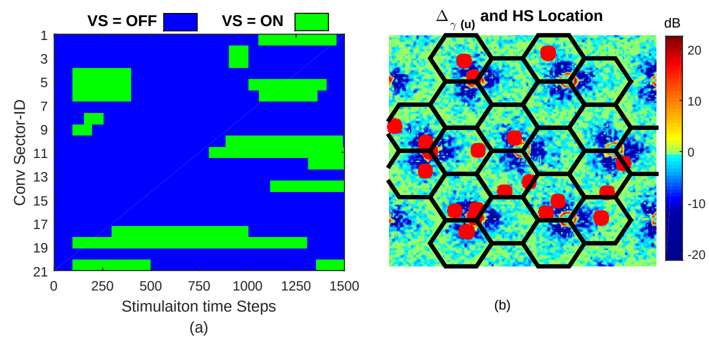

Fig. 2. (a) VS Status (OFF/ON), (b) Change in SINR and HS Scenario

favored when $\lambda_{(\omega,i)} < 1$ that wide range of $\hat{\Gamma}_2$ is tolerable, whereas, only relatively a limited sensitivity level degradation is acceptable at the outer sector. This situation is, however, changed for $\lambda_{(\omega,i)} > 1$ case where the outer sector UEs' resource share gets increased as more load is shifted to the inner thereby increasing the tolerable sensitivity range at the outer sector. In overall, the figure has clearly demonstrated that that the operation range that ensures $\Delta_{\omega,j} > 0$ is fairly balanced between inner and outer when the load ratio is equal, $\lambda_{(\omega,i)} = 1$

Having Equation 27 satisfied, $\Delta_{\omega,j}$ metric is evaluated for final activation/deactivation decision applying a defined threshold $\delta_{\Delta} > 0$ to react only when there is only a sensible performance difference on the utility.

Pseudo-code 1 : VS: Activation/Deactivation Decision

```
if Δ_{ω,j} ≥ δ_Δ then
    VS=ON
else
    VS=OFF
end if
```

IV. Performance Analysis

A system level simulator of AAS-based LTE-A deployment with 7 tri-sectored fixed sites consisting of 21 conventional sectors is used for evaluation purpose. A macro sector layout with an Inter-Site Distance (ISD) of 1732 m is used and propagation models are employed as defined by the 3rd Generation Partnership Project (3GPP) [6]. To create a non-homogeneous spatial user distribution, a traffic hot-spot (HS) containing 50% of the users from the conventional sector is utilized and the HS locations are changing temporarily within the conventional sector layout to let users experience various level of inner/outer sector interference situation over time [2].

One criterion for triggering the VS actiivation process is the cell load compared against a threshold value of $\mathcal{L}_{thr} = 0.8$ which has to be exceeded continuously for a reaction time window of $t_{reaction} = 100$ simulation time steps. Decision metric threshold of $\delta_{\Delta} = 2.5$, and $\delta_1 = \delta_2 = -1$ are

In the investigation, the initial state of the sectorization is set to the default state (VS=OFF) and the SON algorithm is let to run network-wide at all sites. The load situation is monitored autonomously at each conventional sector during each simulation time step. The sensitive region in the network where users experience critical SINR degradation due to VS is illustrated at all sites with a change in SINR map ($\Delta_{\gamma(u)}$) in Figure 2 (b) with one time snapshot of HS spatial location. The sector-VS status for the complete simulation time is depicted in Figure 2 (a) where VS process is recorded for each cell when activation/deactivation process is based on the conditions and criteria defined. In this particular exemplary scenario, it can be seen that a static-VS scheme where all cells are in VS=ON state irrespective of the actual traffic situation may rather lead to system performance degradation when much of the HS traffic lies in the interference critical region depicted in Figure 2 (b).

Throughput performances from a conventional sector area over simulation time are shown in Figure 3 for two selected sectors (5, 15) where user TP statistics is collected and evaluated using a sliding time window of 100 simulation time steps while tracking the traffic variation. The performances at the 5% and 50% CDF level are compared for the three VS status cases: default Always-VS=OFF, Always-VS=ON and the SON based Automated-VS. At Sector-5, Figure 3, the SON mechanism has activated the vertical sector at different times. In comparison, the Automated-VS is outperforming the Always-VS=ON case by 35% at the 5% UE TP level following the Always-VS=OFF performance during the second time vertical sector was activated. Moreover, it can be clearly seen that the Automated-VS mechanism is outperforming the Always-VS=ON by activating the vertical sectors only when it is beneficial and achieves significant TP gain of over 80% at the 50% CDF level.

For Sector-15, Figure 2 shows that the SON mechanism strictly decides turning off the vertical sector at all times as favorable conditions have not been met. This performance can be manifested in Figure 3 where the Automated-VS has been following the Always-VS=OFF both at the 5% and 50% CDF level. In this case, the Automated-VS is able to provide again

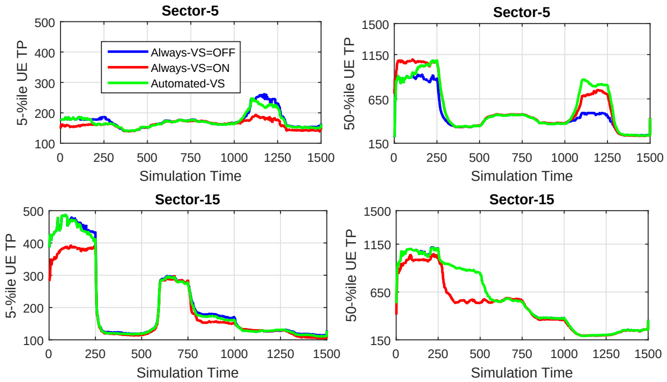

Fig. 3. Throughput Performance Comparison for selected Sectors

of up to 37% and 57% achieved over the Always-VS=ON approach at the 5% and 50% CDF level respectively. This clearly demonstrates that the static VS=ON approach could lead to significant performance degradation in some situations like in Sector-15. It is worth noting that the static VS=ON is the unwanted and costly over-provisioning solution as it keeps the vertical sector always activated irrespective of the load situation.

V. Conclusion

A SON mechanism to enable an automated vertical sectorization is presented in this paper. The proposed framework has been evaluated utilizing a system level simulator for the case of various non-homogeneous user distribution. Simulation results have clearly demonstrated that the proposed scheme is able to control the activation/deactivation process thereby providing a significant performance gain over the static over-provisioning approach where vertical sectorization is always activated.

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