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# MISO 하향 능동 안테나 시스템에서의 수직 섹터분할 기법

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# Vertical Sectorization Techniques in MISO Downlink Active Antenna Systems

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## 요 약

이 논문에서는 MISO 하향 능동 안테나 시스템에서 수직 분할 기법을 연구하였다. 능동 안테나 시스템에서는 각 섹터에서 안테나 빔 패턴을 조절 가능 할 뿐만 아니라 복수의 수직 안테나 빔을 통해 수직 섹터분할도 가능하다. 수직 섹터 분할을 위한 최적 빔 기울기를 구하기 위해 기존의 전역 탐색 기법은 매우 높은 계산 복잡도를 요구하기 때문에 이 논문에서는 이러한 계산 복잡도를 낮추기 위해 두 가지 알고리즘을 제안하였다. 먼저 불규칙 행렬이론에서의 광범위 시스템 근사치를 이용하여 근사 전송률 합에 기반을 둔 알고리즘을 제안하였다. 또한, 기존의 하나의 섹터 전송 기법에서의 결과를 이용한 폐쇄 형태 표현을 가진 알고리즘도 제안하였다. 실험결과를 통해 제안된 알고리즘들이 기존의 전역 탐색 알고리즘에 비해 복잡도를 매우 감소시킴에도 불구하고 거의 비슷한 성능을 가짐을 확인하였다.

**Key Words :** Active antenna system, Vertical sectorization, MISO downlink

## ABSTRACT

In this paper, we study vertical sectorization techniques in multiple-input single-output (MISO) downlink active antenna systems (AAS). In the AAS, antenna beam patterns can be adjusted in each sector and multiple vertical beams can form the vertical sectorization. Since an exhaustive search based vertical sectorization algorithm requires high computational complexity to find the optimal tilt angles, we propose two vertical sectorization algorithms to reduce the complexity. First, we provide an asymptotic sum rate based algorithm which utilizes a large system approximation of the average sum rate based on the random matrix theory. Next, by using the result in the single sector transmission, the single sector based algorithm is proposed. In the simulation results, we confirm that the proposed algorithms are close to the performance of the exhaustive search algorithm with much reduced complexity.

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## Ⅰ. Introduction

Next generations of wireless cellular networks are expected to provide higher data rates in the order of tens of Gbps[1-4]. To meet the stringent demands, directional antenna techniques have been considered as one of promising solutions[5-11]. This enables us to steer the transmitted signal toward a desired direction and also reduce the unwanted signal from an undesired direction. In [5] and [6], the authors investigated beamforming techniques for the directional antennas. Also, deploying the directional antenna systems can reduce the inter-cell interference and thus it can bring out the enhanced system performance[8].

An active antenna system (AAS) is a recent technology that helps in getting more control on directional antenna elements individually. The AAS whose antenna elements are integrated with a separable radio-frequency (RF) transceiver provides remote control to the antenna elements electronically[10]. Using the AAS at the base station (BS), the antenna beam pattern can be adjusted in each sector and multiple vertical beams can also be generated to support multiple users or cover multiple regions. Then, the electronic beam-tilt feature of the AAS can be combined with cell sectorization which improves the network performance. Compared to the conventional sectorization methods which are formed in the horizontal plane, employing two vertical tilt angles at each sector enables an additional sectorization, which is called vertical sectorization[8].

In this paper, we investigate a system where a BS with multiple directional antennas supports two vertical sectors, each of which is covered by a vertical antenna beam. Due to the complicated antenna beam pattern, it is hard to find the optimal tilt angles. To obtain the optimal tilt angles, an exhaustive search based vertical sectorization (EVS) algorithm has a prohibitive computation complexity. In order to reduce the complexity, we propose two vertical sectorization algorithms.

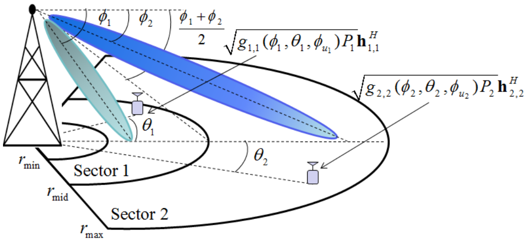

Fig. 1. System model for MISO downlink AAS

First, we derive a large system approximation of the average sum rate by employing the asymptotic results of random matrix theory. The random matrix theory has been widely used as an analytical tool in many literature and the asymptotic results in large system limit often serve as a good approximation of the actual performance even in the finite dimensional case[12-14]. Using the large system approximation of the average sum rate, we provide an asymptotic sum rate based vertical sectorization (AVS) algorithm. The proposed AVS algorithm relies only on the user distribution thanks to the asymptotic sum rate. Thus, the computational complexity is significantly reduced compared to the EVS algorithm which requires the calculation of sum rate for each channel realization and user position. Unfortunately, the AVS algorithm still needs the exhaustive search method to obtain the optimum title angles. Thus, it is necessary to develop the closed-form solution in order to reduce the search size of tilt angles.

Next, we provide an alternative approach to obtain tilt angles by exploiting the single sector transmission in [9]. When users are uniformly distributed within sector, the optimal title angle of the single sector transmission is derived as the closed-form expression. Using this result, we propose a single sector based vertical sectorization (SVS) algorithm where tilt angles are independently optimized in each vertical sectors. Numerical results show that the proposed algorithms exhibit the performance very close to the exhaustive algorithm with reduced complexity.

## Ⅱ. System model and problem formulation

We consider wireless multiple-input single-output

(MISO) downlink active antenna systems (AAS) where a BS has multiple directional antennas and each user has single receive antenna as shown in Fig. 1. In the AAS, each array antenna element is integrated with a RF transceiver unit which enables remote control to the antenna beam pattern electronically[10]. Using the AAS, the vertical radiation pattern can also be adjusted in each sector and multiple elevation beams can also be generated to support multiple regions, and thus this enables the vertical sectorization.

Due to implementation complexity, we consider two elevation beams which support two vertical regions as shown in Fig. 1. Assuming that each vertical beam serves a single-user, the received signal at user $i$ is written as

$$\begin{aligned} \mathrm{y}_i = & \sqrt{\mathrm{g}_{i,i}(\phi_i,\theta_i,\phi_{u_i})P_i r_i^{-\alpha}}\,\mathbf{h}_{i,i}^H\mathbf{x}_i \\ & + \sqrt{\mathrm{g}_{j,\mathrm{i}}(\phi_j,\theta_i,\phi_{u_i})P_i r_i^{-\alpha}}\,\mathbf{h}_{j,i}^H\mathbf{x}_j + \Gamma_i + n_i \end{aligned} \tag{1}$$

where $\mathrm{h}_{i,j}$ and $\mathbf{x}_i$ are the channel vector from the $j$ th beam to user and the transmit vector for user $i$, respectively. Also, $r_i$ denotes the distance, $\mathrm{g}_{i,j}(\phi_i,\theta_j,\phi_{u_j})$ stands for the beam gain between user $j$ and the $i$th beam with the vertical angle of user $\phi_{u_j}$ and the horizontal angle of user $\theta_j$, and $\Gamma_i$ is the sum of other cell interference (OCI).

We assume that outer cells still operate in a conventional cellular network and users within a cell have only statistical information about the OCI as in [12], $\Gamma_i + n_i$ is treated as an additive white Gaussian noise with variance,

$$\mathrm{var}(\Gamma_i + n_i) = \sum_{m=1}^{6} \widetilde{P_m}\,\tilde{r}_m^{-\alpha} + \sigma_i^2$$

where $\widetilde{P_m}$ is transmit power at the $m$th BS and $\tilde{r}_m$ indicates the distance between the $m$th BS and user $i$. In this paper, we employ the 3D antenna beam pattern proposed in [6] which simplifies 3D representation of the actual 3D antenna beam pattern. Then, the antenna radiation pattern given user's direction is defined by [6]

$$\begin{aligned} & G(\phi,\theta,\phi_u) = \\ & G_{max} + \max\left[-12\left(\frac{\phi-\phi_u}{\phi_{3dB}}\right)^2, SLL_v\right] - \min\left[-12\left(\frac{\theta_u}{\theta_{3dB}}\right)^2, FBR_h\right] \end{aligned}$$

where $\mathrm{g}(\phi,\theta,\phi_u) \overset{\triangle}{=} 10^{G(\phi,\theta,\phi_u)/10}$, $G_{\max}$ is the maximum antenna gain at the bore-sight direction, $\phi_{3dB}$ and $\theta_{3dB}$ denote the 3dB beam-width of the vertical and horizontal patterns, respectively.

Then, employing maximal ratio transmission, the signal-to-interference-plus-noise (SINR) is computed by

$$\mathrm{SINR}_i = \frac{\mathrm{g}_{i,i}(\phi_i,\theta_i,\phi_{u_i})P_i r_i^{-\alpha}\left|\mathbf{h}_{i,i}^H\mathbf{w}_i\right|^2}{\mathrm{g}_{j,i}(\phi_j,\theta_i,\phi_{u_i})P_j r_i^{-\alpha}\left|\mathbf{h}_{j,i}^H\mathbf{w}_j\right|^2 + \sum_{m=1}^{6}\widetilde{P_m}\,\tilde{r}_m^{-\alpha} + \sigma_i^2}$$

where $\mathrm{w}_i$ is beamforming vector for user $i$.

To establish an efficient vertical sectorization, our goal is to find optimal tilt angles which maximize the average sum rate as

$$\begin{aligned} & \max_{\phi_1,\phi_2} E_{\mathbf{h},r,\theta}\left[\log_2(1+\mathrm{SINR}_1) + \log_2(1+\mathrm{SINR}_2)\right] \\ & \mathrm{s.t.}\ \tan^{-1}(\mathrm{z}/\mathrm{r}_{\max}) \le \phi_2 < \phi_1 \le \tan^{-1}(\mathrm{z}/\mathrm{r}_{\min}) \end{aligned} \tag{2}$$

where $\mathrm{z}$ denotes the height difference between the BS and the user. Since this problem is non-convex, it is very difficult to obtain the optimal tilt angles. The exhaustive search based vertical sectorization (EVS) algorithm which accounts for combinations all possible tilt angles has prohibitive computational complexity since it needs to compute the average sum rate in each tilt angle. To reduce the complexity, we propose efficient vertical sectorization algorithms in the following sections.

## Ⅲ. Asymptotic sum rate based vertical sectorization

In this section, we first derive a large system approximation of the average sum rate to reduce the complexity of the EVS algorithm. To this end, we employ useful results of random matrix theory developed in [13-15]. The large system approximation is based on the assumption that the system dimensions ( the number of users $K$ and the number of Tx antennas $N$) all grow large at the same speed (i.e., $\lim_{N,K\to\infty} N/K=\beta$). Nevertheless, this approximation is well matched even for small dimensions[13].

To derive large system results, we first utilize the following lemma.

*LEMMA 1*[14] : Let $\mathrm{A}\in\mathbb{C}^{N\times N}$ and let $\mathrm{x}\in\mathbb{C}^{N}$ be random vectors of independent identically entries with zero mean, variance $1/N$ and finite eight-order moment, which is independent of $\mathrm{A}$. Then,

$$(i)\ \mathbf{x}^H\mathbf{A}\mathbf{x}-\frac{1}{N}\mathrm{tr}(\mathrm{A})\xrightarrow{N\to\infty}0,$$
$$(ii)\,\mathrm{E}\left[\left|(\mathbf{x}^H\mathbf{A}\mathbf{x})^2-\left(\frac{1}{N}\mathrm{tr}(\mathrm{A})\right)^2\right|\right]\xrightarrow{N\to\infty}0.$$

Denoting the average sum rate as $R_{sum}(\phi_1,\phi_2)$, we provide a large system approximation of $R_{sum}(\phi_1,\phi_2)$ by using the lemma 1.

*Theorem 1* : As $N$ goes to infinity with fixed ratio $N/2K$, $R_{sum}(\phi_1,\phi_2)$ converges to $R_{sum}^o(\phi_1,\phi_2)$ as

$$R_{sum}(\phi_1,\phi_2)\xrightarrow{N\to\infty}R_{sum}^o(\phi_1,\phi_2)$$

where

$$R_{sum}^o(\phi_1,\phi_2)=K\sum_{i=1}^{2}\int\log_2(1+\mathrm{SINR}_i^o)\,\mathrm{f}_{R,\theta}(r,\theta)\,dr\,d\theta$$

with

$$\mathrm{SINR}_i^o\triangleq\frac{\mathrm{g}_{i,i}(\phi_i,\theta_i,\phi_{u_i})P_i r_i^{-\alpha}N}{\gamma^o+\Omega^o+\sum_{m=1}^{6}\widetilde{P}_m\widetilde{r}_m^{-\alpha}+\sigma_i^2},$$
$$\gamma^o\triangleq(K-1)\mathrm{g}_{i,i}(\phi_i,\theta_i,\phi_{u_i})P_i r_i^{-\alpha},$$
$$\Omega^o\triangleq K\mathrm{g}_{j,i}(\phi_j,\theta_i,\phi_{u_i})P_j r_i^{-\alpha}.$$

*Proof)* In order to applying the random matrix theory, we consider multiuser systems where each sector has $K$ user. By considering multiuser systems, the average sum rate of $2K$ users

$$R_{sum}(\phi_1,\phi_2)=E\left(\sum_{i=1}^{2}\sum_{k=1}^{K}\log_2(1+\mathrm{SINR}_{\mathrm{k_i}})\right)$$

where $k_i$ denotes the $k$-th user in the $i$-th sector. Here, $\mathrm{SINR}_{k_i}$ is given as

$$\mathrm{SINR}_{k_i}=\frac{\mathrm{g}_{i,k_i}(\phi_i,\theta_i,\phi_{k_i})P_{k_i}r_{k_i}^{-\alpha}\left|\mathbf{h}_{i,k_i}^H\mathbf{w}_{k_i}\right|^2}{\mathrm{IUI}_{k_i}+\mathrm{ISI}_{k_i}+\sum_{m=1}^{6}\widetilde{P}_m\widetilde{r}_m^{-\alpha}+\sigma_{k_i}^2}\tag{3}$$

where inter-user interference (IUI) and inter-sector interference (ISI) are defined as

$$\mathrm{IUI}_{k_i}=\sum_{m\neq k}^{K-1}\mathrm{g}_{i,k_i}(\phi_i,\theta_i,\phi_{k_i})P_{m_i}r_{k_i}^{-\alpha}\left|\mathbf{h}_{i,k_i}^H\mathbf{w}_{m_i}\right|^2$$
$$\mathrm{ISI}_{k_i}=\sum_{m=i}^{K}\mathrm{g}_{j,k_i}(\phi_j,\theta_i,\phi_{k_i})P_{m_j}r_{k_i}^{-\alpha}\left|\mathbf{h}_{j,k_i}^H\mathbf{w}_{m_j}\right|^2.$$

Then, considering the transmit power constraint, the MRT beamforming vector is obtained as

$$\mathbf{w}_{k_i}=\sqrt{\zeta}\,\mathbf{h}_{k_i}\ \text{with}\ \zeta=\frac{P_i}{\mathrm{tr}(\mathbf{P}_i\mathbf{W}_i\mathbf{W}_i^H)},$$

where $\mathrm{W}_i=[\mathrm{w}_{1_i},\cdots,\mathrm{w}_{K_i}]$ and $\mathrm{P}_\mathrm{i}=\mathrm{diag}\{\mathrm{p}_{1_\mathrm{i}},\cdots,\mathrm{p}_{\mathrm{K}_\mathrm{i}}\}$. Utilizing the deterministic approximations in [13] and [14], we have that

$$\frac{1}{N}\left|\mathbf{h}_{k_i}^H\mathbf{h}_{k_i}\right|\xrightarrow{N\to\infty}N,\ \text{and}\ \frac{1}{N}\left|\mathbf{h}_j^H\mathbf{h}_{k_i}\right|\xrightarrow{N\to\infty}1.\tag{4}$$

Also, for large $N$, $K$ such that $0<\lim\inf_N K/N\le\lim\sup_N K/N<\infty$, we expect to have

$$\mathrm{tr}(\mathbf{P}_i\mathbf{W}_i\mathbf{W}_i^H)-NP_i\to\infty.\tag{5}$$

Applying the results in (4) and (5) to (3), we have

$$\mathrm{SINR}_{k_i}-\mathrm{SINR}_{k_i}^o\xrightarrow{N\to\infty}0.$$

since $\mathrm{SINR}_{k_i}^o$ equals $\mathrm{SINR}_i^o$, the proof is completed.

In this case, $\mathrm{f}_{R,\theta}(r,\theta)$ denotes a user distribution within a cell. Then, we provide an asymptotic sum rate based vertical sectorization algorithm in the following. In the AVS algorithm, $\tilde{R}_{sum}$ denotes the auxiliary variable to update the maximum the average sum rate at each iteration.

```
Asymptotic sum rate based algorithm:
$\tilde{R}_{sum} = 0$, $\Delta\phi$ is step size for searching $\phi$,
For $\phi_1 = \phi_{\min} : \Delta\phi : \phi_{\max}$
    For $\phi_2 = \phi_{\min} : \Delta\phi : \phi_1$
        Calculate the asymptotic sum rate $R^o_{sum}(\phi_1, \phi_2)$
        If $R^o_{sum}(\phi_1, \phi_2) \geq \tilde{R}_{sum}$
        Update $\tilde{R}_{sum} = R^o_{sum}(\phi_1, \phi_2)$
        $\phi_1^* = \phi_1$ and $\phi_2^* = \phi_2$
        End
    End
End
```

In the simulation results, we will confirm that the performance of the AVS algorithm is close to that of the EVS algorithm with reduced complexity, since the AVS algorithm does not need to compute the sum rate for each channel realization. However, the proposed AVS scheme still requires the exhaustive search method for obtaining the tilt angles $\phi_1^*$ and $\phi_2^*$. In order to reduce the search size of tilt angles, we propose the single sector based vertical sectorization algorithm in the following section.

## Ⅳ. Single sector based vertical sectorziation

In [9], the authors have proposed the optimal tilt angle of a single vertical sector regime in single-cell downlink systems without the OCI. Exploiting the results in [9], the optimal tilt angle for single sector transmission is obtained by $\phi^* = E[\phi_u]$. In particular, when users are uniformly distributed within a cell, the closed-form expression of the optimal tilt angle is derived as

$$\begin{aligned}\phi^* &= \int_0^{2/3\pi}\int_{r_{min}}^{r_{max}} r\tan^{-1}(\mathrm{z}/\mathrm{r})\,\mathrm{f}_{R,\theta}(r,\theta)\,\mathrm{d}r\,\mathrm{d}\theta,\\ &= \frac{1}{r_{max}^2 - r_{min}^2}\begin{pmatrix}\mathrm{z}(r_{max}-r_{min}) + (r_{max}^2+\mathrm{z}^2)\tan^{-1}(\mathrm{z}/r_{max})\\ \qquad -(r_{min}^2+\mathrm{z}^2)\tan^{-1}(\mathrm{z}/r_{min})\end{pmatrix}\\ &\overset{\triangle}{=} \varPhi(r_{min}, r_{max}, \mathrm{z})\end{aligned} \tag{6}$$

where $\mathrm{f}_{R,\theta}(r,\theta) = 3/[\pi(\mathrm{r}_{\max}^2 - r_{\min}^2)]$. In this case, the optimal tilt angle for single sector transmission is simply determined by $\varPhi(r_{\min}, r_{\max}, \mathrm{z})$.

However, in case of the vertical sectorization, the average sum rate is calculated by

$$\begin{aligned}&E[R_1+R_2] =\\ &\int_0^{2/3\pi}\int_{r_{\min}}^{r(\phi_1,\phi_2)} \log_2(1+\mathrm{SINR}_1)\mathrm{c}_1 f_{R,\theta}(r,\theta)\,\mathrm{r}\,\mathrm{d}r\,\mathrm{d}\theta\\ &+\int_0^{2/3\pi}\int_{r_{\max}}^{r(\phi_1,\phi_2)} \log_2(1+\mathrm{SINR}_2)\mathrm{c}_2 f_{R,\theta}(r,\theta)\,\mathrm{r}\,\mathrm{d}r\,\mathrm{d}\theta\end{aligned}$$

where $c_1$ and $c_2$ are normalizing factors for satisfying the probability of user distribution 1 in each sector. Since the average sum rate for the vertical sectorization is coupled by $\phi_1$ and $\phi_2$, it is difficult to derive a closed-form solution. Hence, we provide an alternative approach to solve the problem in (2) by exploiting the closed-form expression for single sector transmission in (6).

When we assume that $r_{mid}$ is given and the ISI is neglected, the vertical sectors are independent each other. Then, $\phi_1$ and $\phi_2$ can be independently optimized in each vertical sector, which are obtained as

$$\phi_1 = \varPhi(r_{\min}, r_{mid}, \mathrm{z}) \text{ and } \phi_2 = \varPhi(r_{mid}, r_{\max}, \mathrm{z}). \tag{7}$$

Using the results, we propose the single sector based vertical sectorization (SVS) algorithm as following:

In the SVS algorithm, $\phi_1^*$ and $\phi_2^*$ are determined to maximize the sum rate and thus we will show in Section V that the SVS algorithm achieves almost the same performance of the EVS algorithm in spite of employing the single sector transmission result. Compared to the EVS algorithm which has the complexity $O(M^2)$ with respect to search size $M$, the proposed SVS algorithm reduces the complexity to

```
Single sector based vertical sectorization algorithm:
    $\tilde{R}_{sum}=0$, $\Delta r$ is step size for searching $r_{mid}$,
    For $r_{mid}=r_{min}:\Delta r:r_{\max}$
        $\phi_1=\Phi(r_{\min},r_{mid},z)$ and $\phi_2=\Phi(r_{mid},r_{\max},z)$
        Calculate the average sum rate $R_{sum}(\phi_1,\phi_2)$
        If $R_{sum}(\phi_1,\phi_2)\geq\tilde{R}_{sum}$
            Update $\tilde{R}_{sum}=R_{sum}(\phi_1,\phi_2)$
            $\phi_1^*=\phi_1$ and $\phi_2^*=\phi_2$
        End
    End
```

$O(M)$ which leads to a significant complexity reduction. Thanks to the closed-form expression in (7) and given $r_{mid}$, the SVS algorithm is more efficient of reducing the complexity than the AVS algorithm in the previous section. However, the AVS scheme is used for general user distributions, since the SVS is limited to the uniformly distributed users.

*Discussion* : In this paper, we assume that the BS knows perfect channel knowledge. However, in case of a high-mobility environment, the BS generally has imperfect knowledge of the instantaneous channel realization. Then, the channel estimation error might lead to the performance loss of the AVS algorithm since the theorem 1 does not consider the channel estimation error. On the other hand, the result in (7) of SVS algorithm does not affected by instantaneous channel realization and thus the SVS algorithm would be robust to the high-mobility environment.

## Ⅴ. Simulation Results

In this section, we present the efficiency of the proposed schemes compared to the EVS scheme through Monte-Carlo simulation. Users are uniformly distributed in all cells, and the BS has perfect channel state information to compute transmit beamforming vectors. Table I illustrates the simulation settings.

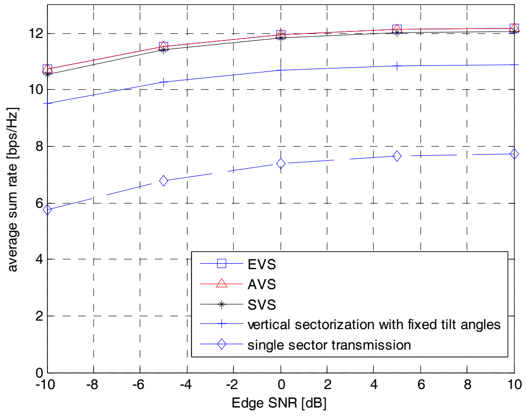

Fig. 2. Average rate performance comparison as a function of cell-edge SNR

Table 1. Simulation Settings

| z [m] | $r_{\min}[m]$ | $r_{\max}[m]$ | $\phi_{3dB}(^o)$ | $\theta_{3dB}(^o)$ |
|---|---|---|---|---|
| 28.5 | 30 | 500 | 6 | 65 |
| $G_{\max}$ [dBi] | $FBR_h$ [dB] | $SLL_v$ [dB] | $\alpha$ | $N_t$ |
| 18 | 30 | -18 | 3.4 | 4 |

Fig. 2 exhibits the average rate performances with respect to the cell-edge SNR which is defined as the received SNR at the cell boundary. Also, we show the performance of single vertical sector scheme with a single vertical beam. In this case, the optimal tilt angle of single vertical sector scheme is obtained from exhaustive search. We can verify that vertical sectorization method with two vertical beams gives rise to a significant performance improvement. We also present the performance of the naive vertical sectorization scheme which is evaluated by fixed tilt angles $\phi_1=19.6^\circ$ and $\phi_2=8.7^\circ$. In this plot, it is shown that the proposed AVS scheme is close to the performance of EVS scheme with much reduced complexity. Also, the proposed SVS algorithm shows a small performance loss compared to the EVS algorithm. From the simulation results, we confirm that our proposed vertical sectorization algorithms are efficient for MISO downlink AAS.

## Ⅵ. Conclusion

In this paper, we have proposed low complexity vertical sectorization algorithms for MISO downlink AAS. First, we have provided the asymptotic sum rate based vertical sectorization algorithm which employs a large systems approximation. In addition, exploiting the closed-form expression in case of the single sector transmission, the single sector based vertical sectorization algorithm has been developed to reduce the search size for obtaining the optimum tilt angles. From the simulation results, we have confirmed that the proposed schemes show the average sum rate performance almost identical to the exhaustive search based sectorization algorithm with significantly reduced complexity.

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