Spatial Filtering for Underlay Cognitive SatComs

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Abstract. Herein, we study an underlay beamforming technique for the coexistence scenario of satellite and terrestrial networks with the satellite return link as primary and the terrestrial uplink as secondary. Since satellite terminals are unique in that they always point towards the geostationary satellite, interference received by the terrestrial Base Station (BS) is concentrated in a specific angular sector. The priori knowledge that all the geostationary satellite terminals are facing south for the European coverage can be used in designing a beamformer at the terrestrial BS. Based on this concept, we propose a receive beamformer at the BS to maximize the Signal to Interference plus Noise Ratio (SINR) towards the desired user and to mitigate the interference coming from the interfering satellite terminals. The performances of Minimum Variance Distortionless (MVDR) and Linear Constrained Minimum Variance (LCMV) beamformers are compared for our considered scenario. It is shown that LCMV beamformer is better suited in rejecting interference even in case of Direction of Arrival (DoA) uncertainty of interfering satellite terminals as long as DoA range of the interfering sector is known to the beamformer. Furthermore, it is noted that MVDR beamformer is suitable for a large number of interferers.

Key words: Spatial Filtering, Underlay, Satellite-terrestrial Coexistence, Interference Mitigation

1 Introduction

Recently, cognitive communication has been considered a promising technology for allowing the coexistence of different wireless networks within the same spectrum. Wireless networks may exist within the same spectrum in different ways such as two terrestrial networks or two satellite networks or satellite-terrestrial networks. The most common cognitive techniques in the literature can be categorized into interweave or Spectrum Sensing (SS), underlay, overlay and database related techniques [1]. In SS only techniques, Secondary Users (SUs) are allowed to transmit whenever Primary Users (PUs) do not use a specific band, whereas in underlay techniques, SUs are allowed to transmit as long as they meet the interference constraint of the PUs.

Existing spectrum sharing techniques mostly consider three signal dimensions i.e., frequency, time and area for sharing the available spectrum between primary and secondary systems. However, due to advancement in smart antennas and beamforming techniques, multiple users can be multiplexed into the same channel at the same time and in the same geographical area [2]. In cognitive scenarios, the knowledge of propagation characteristics of the PUs can be used to mitigate interference from Cognitive Radio (CR) transmitter towards the PUs and to mitigate interference from the PUs towards the CR receiver. In this context, angular dimension or directional dimension of spectral space can be considered as more efficient way of exploiting the underutilized primary spectrum for the SUs. To exploit the angular dimension, multi-antenna transceivers are needed. Recently, the spatial dimension for spectrum sharing purpose has received important attention in the literature [2, 3, 4, 5]. In [3], the angular dimension of spectral space is used to detect the presence of a PU and to estimate the Direction of Arrival (DoA) of the PU signal. In [4], propagation characteristics of the rays arriving in clusters is exploited for SS purpose. In [5], a directional SS using a single radio switched beam antenna structure is proposed to enhance the sensing efficiency of a CR.

Beamforming is a signal processing technique used in antenna arrays with the advantages of spatial discrimination and spatial filtering capabilities [6]. Multi-antenna beamforming is an effective means to mitigate co-channel interference and has been widely used in traditional fixed spectrum based wireless systems. In the context of a CR, beamforming techniques have been investigated for the secondary network for various objectives such as controlling interference [7], capacity maximization [8], SINR balancing [9]. The beamforming design problem in the context of an underlay CR is challenging since the underlay technique requires the interference caused by the SUs to be below the interference threshold level required by the PUs. According to author's knowledge, beamforming techniques have been considered for various objectives mostly in the coexistence scenario of two terrestrial networks in the existing CR literature. In the context of cognitive satellite communications, SS techniques for dual polarized channels have been proposed in [10, 11]. In [12], interference alignment technique has been proposed for spectral coexistence of monobeam and multibeam satellite systems. In [13], different transmit beamforming techniques have been proposed for spectral coexistence of satellite and terrestrial networks. In this paper, we apply beamforming technique for spatial filtering in the spectral coexistence scenario of satellite and terrestrial networks with the satellite return link as primary and the terrestrial uplink as secondary. The main difference is that although interference is concentrated in an angular sector, we do not specifically know the number of interferers and the DoA of their signals.

Geostationary (GEO) satellites are located in the geosynchronous orbit above the equator and therefore transmit in a northerly direction if we consider the European continent. The GEO satellite terminals have therefore the special propagation characteristic to always point towards the GEO satellites (south). While considering the coexistence of a satellite network with the terrestrial cellular network, the interference received by the terrestrial Base Station (BS) is concentrated in a specific angular sector. Furthermore, this interference becomes more prominent as we move towards the polar region from the equator due to reduction in the elevation angles of the satellite terminals [1]. Similar scenario was considered in [14] while reusing the satellite broadcast spectrum for terrestrially broadcast signals in the United States and the use of different directional antennas at the user location was proposed to allow the spectrum reuse. In this paper, we propose a receive beamforming technique at the BS to maximize the SINR towards the desired terrestrial user and to mitigate the interference coming from interfering satellite terminals. The prior knowledge that all the ground satellite terminals are pointing south is the cognition that we exploit in this study. Since this is an inherent characteristic of SatComs, no interaction is needed between primary and secondary systems. In this context, we apply widely used Linear Constrained Minimum Variance (LCMV) and Minimum Variance Distortionless (MVDR) beamformers for our scenario and analyze their performances in terms of pattern response and output SINR. Furthermore, we consider link budget analysis of satellite and terrestrial link considering the path loss between satellite terminals and the BS and between terrestrial terminals and the BS.

The paper is structured as follows: Section 2 presents the considered system and signal models. Section 3 provides the theoretical analysis of LCMV and MVDR techniques in the context of our proposed scenario. The proposed spatial filtering technique is presented in Section 4. Section 5 describes the simulation environment and evaluates the performance of the beamformers with the help of numerical results. Section 6 resumes the conclusions.

2 System and Signal Model

2.1 System Model

We consider a practical coexistence scenario of satellite and terrestrial networks with both networks operating in normal return mode as shown in Fig. 1. The satellite link is considered as primary and the terrestrial link as secondary i.e., satellite terminals are PUs and terrestrial terminals are SUs. In this context, we consider a Fixed Satellite System (FSS) with fixed ground terminals (i.e., dishes) operating in the C-band. Furthermore, a terrestrial WiMax network is considered providing broadband services to the fixed users within the same spectrum. The interference from terrestrial terminals to the satellite is assumed to be negligible due to large distance as well as low elevation angles of the terrestrial terminals while the interference from satellite terminals to the terrestrial BS should be taken into account [1]. Due to unique propagation characteristic of GEO satellite terminals, the interference received by the BS is concentrated in a specific angular sector and the BS receives interference due to geostationary satellite terminals from its northern sector. In this scenario, we consider the satellite coverage over Europe (not the regions which are near to the equator). In this context, we apply a receive beamforming technique at the BS to maximize SINR towards the desired user, which is located in the south and to mitigate the interference coming from the northern sector as illustrated in the layout (Fig. 2). Furthermore, the exact locations and the number of the interfering satellite terminals are unknown to the beamformer in our considered scenario.

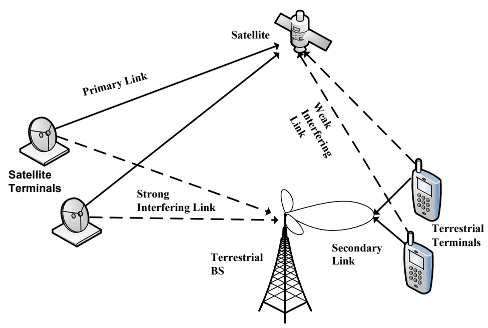

Fig. 1. Satellite-terrestrial coexistence scenario

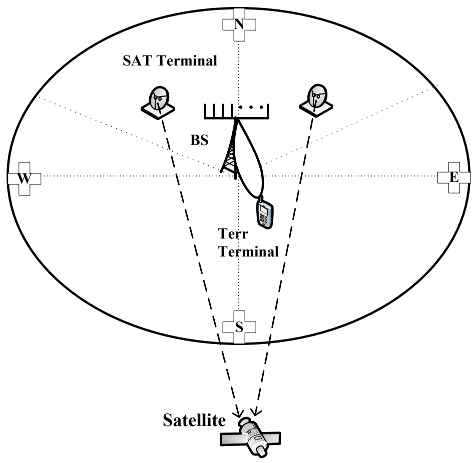

Fig. 2. Layout of the considered scenario (N,W,S and E denote North, West, South and East)

2.2 Signal Model

Let M be the number of antennas in the BS antenna array and K be the number of total users in the considered system including both the PUs and SUs. In the uplink, each user can be viewed as a transmit antenna in a point to point Multiple Input Multiple Output (MIMO) system and the same receiver architecture can be used at the BS to separate each user's data by applying a receive beamforming technique. The received signal vector $\mathbf{y}$ at the BS can be written as:

$$\mathbf{y} = \sum_{k=1}^{K} h_k \mathbf{a}(\theta_k) s_k + \mathbf{z}, \tag{1}$$

where h_k represents the channel gain for k-th user and it is assumed that it remains constant for all antennas in the array assuming that there is strong line of sight between the array antenna and user antennas, s_k is the transmitted symbol by k-th user, $\mathbf{a}(\theta_k)$ is the $M \times 1$ array response vector, θ_k being the angle of arrival for k-th user, $\mathbf{z}$ is $M \times 1$ independent and identically distributed (i.i.d.) Gaussian noise vector. The array response vector $\mathbf{a}(\theta_k)$ can be written as [15]:

$$\mathbf{a}(\theta_k) = \left[1, e^{\frac{-j2\pi d sin(\theta_k)}{\lambda}}, ..., e^{\frac{-j2\pi(M-1)d sin(\theta_k)}{\lambda}}\right]^T, \tag{2}$$

where d is the inter-element spacing of the antennas at the BS array, λ represents the wavelength of radio frequency signal. The receiver at the BS can separate signals transmitted from different users because of their different spatial signatures on the received antenna array. Consider that there is only one desired user [1] i.e., single SU and $(K-1)$ interfering users i.e., PUs. Then (1) can be expressed as:

$$\mathbf{y} = h_1\mathbf{a}(\theta_1)s_1 + \mathbf{q}, \tag{3}$$

where h_1 is the channel towards the desired user, $\mathbf{a}(\theta_1)$ is the array response vector for the desired user, s_1 is desired user's transmitted symbol and $\mathbf{q} = \sum_{k=2}^{K} h_k\mathbf{a}(\theta_k)s_k + \mathbf{z}$. For the purpose of receive beamforming, the received signal vector $\mathbf{y}$ is then linearly combined through a complex weight vector $\mathbf{w} \in \mathcal{C}^N$ to yield the array output $\hat{s}_1$ as:

$$\hat{s}_1 = \mathbf{w}^H\mathbf{y}. \tag{4}$$

The weight vector $\mathbf{w}$ should be chosen in such a way that the first term of (3) is maximized and the second term is minimized.

3 Beamforming Techniques

Several array signal processing techniques have been presented in the literature [16, 17, 7]. Beamformers can be classified into data independent or statistically optimum depending on how the combining weights are chosen [6]. The later technique can be divided into different categories such as Multiple Side-lobe Canceler (MSC), MVDR and LCMV beamformers. In this section, we review the most widely used MVDR and LCMV beamformers from the literature for their use in our scenario [17].

3.1 MVDR technique

The received signal at the BS antenna array from (1) can also be written as:

$$\mathbf{y} = \mathbf{A}\mathbf{s} + \mathbf{z}, \tag{5}$$

where $\mathbf{A} = [\mathbf{a}(\theta_1), \mathbf{a}(\theta_2), ..., \mathbf{a}(\theta_K)]$ is called the Signal Direction Matrix (SDM), $\mathbf{s} = [s_1, s_2, ..., s_K]^T$, each s_k being the symbol associated with the k-th user.

[1] Multiple desired users can be supported by using some form of scheduling techniques.

The beamformer response to the desired user at an angle θ_d can be denoted by $\mathbf{w}^H\mathbf{a}(\theta_d)$. Let us consider that noise over each element of the array is white with variance σ^2. Then the SINR for user k can be written as:

$$SINR_k = \frac{\gamma|\mathbf{w}^H\mathbf{a}(\theta_d)|^2}{\mathbf{w}^H(\sum_{i=1,i\neq k}^{K}\mathbf{R}_i + \sigma^2)\mathbf{w}} = \frac{\gamma|\mathbf{w}^H\mathbf{a}(\theta_d)|^2}{\mathbf{w}^H\mathbf{R}_{i+n}\mathbf{w}}, \quad (6)$$

where γ is the SNR of the desired incoming signal, $\mathbf{R}_{i+n}$ is the covariance matrix of interference plus noise. The optimization problem for MVDR beamformer can be written as:

$$\min_{\mathbf{w}} \mathbf{w}^H\mathbf{R}_{i+n}\mathbf{w}$$
$$\text{subject to } \mathbf{w}^H\mathbf{a}(\theta_d) = 1. \quad (7)$$

Since in practical scenarios, $\mathbf{R}_{i+n}$ is unavailable and only sample covariance matrix $\mathbf{R}_y$ is available, which can be expressed as:

$$\mathbf{R}_y = \frac{1}{N}\sum_{i=1}^{N}\mathbf{y}(n)\mathbf{y}^H(n). \quad (8)$$

Using $\mathbf{R}_y$ instead of $\mathbf{R}_{i+n}$, the optimization problem for MVDR beamformer can be written as:

$$\min_{\mathbf{w}} \mathbf{w}^H\mathbf{R}_y\mathbf{w}$$
$$\text{subject to } \mathbf{w}^H\mathbf{a}(\theta_d) = 1. \quad (9)$$

When the desired signal is uncorrelated to the interference, minimization problem in (9) is same as the minimization problem in (7) [18]. The solution of constrained optimization problem (9) using Lagrange multipliers is obtained as:

$$\mathbf{w} = \frac{\mathbf{R}_y^{-1}\mathbf{a}(\theta_d)}{\mathbf{a}^H(\theta_d)\mathbf{R}_y^{-1}\mathbf{a}(\theta_d)}. \quad (10)$$

3.2 LCMV Technique

In this beamformer, the weights are chosen to minimize the output variance or power subject to the response constraints. To allow any desired signal coming from an angle θ with response g, the weight vector can be linearly constrained in such a way that $\mathbf{w}^H\mathbf{a}(\theta) = g$, where g is a complex constant [6]. Similarly, the contributions of signals coming from the interfering sector to the array output can be minimized by choosing the weights in such a way that the output power or variance $E[|\mathbf{w}^H\mathbf{y}|^2] = \mathbf{w}^H\mathbf{R}_y\mathbf{w}$ is minimized. The LCMV problem for choosing the weights can be written as:

$$\min_{\mathbf{w}} \mathbf{w}^H\mathbf{R}_y\mathbf{w}$$
$$\text{subject to } \mathbf{w}^H\mathbf{a}(\theta) = g, \quad (11)$$

where $\mathbf{w}^H \mathbf{a}(\theta) = g$ is a single linear constraint. Using Lagrange multiplier as in the above subsection, (11) can be solved to yield the following [6]:

$$\mathbf{w} = g \frac{\mathbf{R}_y^{-1}\mathbf{a}(\theta)}{\mathbf{a}^H(\theta)\mathbf{R}_y^{-1}\mathbf{a}(\theta)}. \tag{12}$$

To include the multiple constraints in the above single constraint problem, the following constraint equation can be written:

$$\mathbf{C}^H \mathbf{w} = \mathbf{f}, \tag{13}$$

where $\mathbf{C}$ is a $M \times L$ constraint matrix and $\mathbf{f}$ is $L \times 1$ response vector, $L = K$ is the number of constraints. We consider the following constraint equation in our scenario:

$$\begin{bmatrix} \mathbf{a}^H(\theta_1) \\ \mathbf{a}^H(\theta_2) \\ \vdots \\ \mathbf{a}^H(\theta_K) \end{bmatrix}^H \mathbf{w} = \begin{bmatrix} 1 \\ 0 \\ \vdots \\ 0 \end{bmatrix}. \tag{14}$$

Then the LCMV beamforming problem can be written as:

$$\begin{aligned} &\min_{\mathbf{w}} \mathbf{w}^H \mathbf{R}_y \mathbf{w} \\ &\text{subject to } \mathbf{C}^H \mathbf{w} = \mathbf{f}. \end{aligned} \tag{15}$$

The solution of above problem can be written as [17]:

$$\mathbf{w} = \mathbf{R}_y^{-1}\mathbf{C}(\mathbf{C}^H\mathbf{R}_y^{-1}\mathbf{C})^{-1}\mathbf{f}. \tag{16}$$

4 Proposed Spatial Filtering Technique

We assume that BS antenna array is oriented horizontally i.e., East-West direction as shown in Fig. 2. We consider a desired user to be located at angle θ_d at the south of the BS. Due to special propagation characteristic of satellite terminal antennas looking towards the GEO satellite (south), the angular sector in which interfering satellite terminals are located is known to the beamformer beforehand. Then we design a receive beamformer at the BS to mitigate the interference coming from the interfering sector i.e., from northern sector of the BS and to maximize the SINR towards the desired user. Following assumptions are made during the analysis:

- The DoA of the desired user is known. [2]
- The incident wave arrives at the array in the horizontal plane $\phi = \pi/2$ so that azimuthal direction completely determines the DoA.

[2] In practice, the DoA of the desired user can be estimated by using some DoA estimation algorithms such as MUSIC algorithm.

– The distance between the BS and the user is large enough to be user at the far field region so that spherical waves approximate the plane waves.

Furthermore, we consider that only the angular sector in which interfering terminals are located is known to the BS while the number of interfering terminals and their exact locations are unknown. Let us define DoA range for the interfering signals from the satellite terminals to lie in the range $[\theta_{min}\ \theta_{max}]$. The values of θ_{max} and θ_{min} at a particular geographical location can be calculated by geometric analysis of a GEO satellite link [1]. To design a beamformer, we uniformly sample this range in the interval of $\theta_i = \Delta/(K-1)$, where $\Delta = \theta_{max} - \theta_{min}$.

We consider the arrival angle along the array axis as $0°$ and the arrival angle along broadside direction as $90°$. The position of satellite terminals are generated randomly with uniform distribution in the angular sector from $0°$ to $180°$. Based on the received signal at the BS, we calculate the received signal's covariance matrix and based on this, weights for MVDR and LCMV beamformer are calculated using (10) and (16) respectively. These weights are then used for calculating SINRs in the considered scenario. If the received SINR at the BS is above the target SINR, the desired user can be served by that particular BS. If the received SINR is less than the target SINR, the desired user can not be served by that particular BS and some other nearby BS should be involved to serve that user [3]. The performance of a beamformer can be specified in the form of its response pattern and the output SINR. The response pattern specifies the response of the beamformer to an incoming signal as a function of DoA and frequency. The response pattern in θ direction can be calculated as:

$$\mathrm{G}(dB) = 20\log_{10}(|\mathbf{w}^H \mathbf{a}(\theta)|). \tag{17}$$

In the considered scenario, the actual array response vector for the interfering users differ from the array response vector used in the design of the beamformers since the user positions have been generated randomly. Therefore, there occurs uncertainty in the interference response vectors. In this context, firstly, we calculate the beamformer weights considering one interferer in each quantized angle and based on the assumption that the array response vectors for the desired user and interfering users are exactly known. Then we apply these weights to the considered scenario to evaluate the performance of these LCMV and MVDR beamformers. For a particular beamformer, we calculate the average SINR by considering several Monte-Carlo simulations as:

$$\overline{SINR} = \frac{1}{N_s} \sum_{n=1}^{N_s} \frac{\gamma |\mathbf{w}^H \mathbf{a}(\theta_d)|^2}{\mathbf{w}^H \mathbf{R}_{i+n} \mathbf{w}}, \tag{18}$$

where N_s is the number of Monte-Carlo simulations. Using Friss transmission formula, the received power (P_r) at the BS from the satellite/terrestrial terminal located at a distance r is calculated as:

$$P_r = \frac{P_t G_t G_r}{(4\pi r/\lambda)^2} = P_t G_t G_r L_p^{-1}, \tag{19}$$

[3] This would be the responsibility of the scheduling algorithm.

where G_t and G_r are gains of transmit and receive antennas respectively, P_t is the transmitted power and the term $L_p = (4\pi r/\lambda)^2$ represents the free space path loss. Let us define the β_k be the path loss coefficient of the link between k-th user and the terrestrial BS. Then we modify the SDM in the following form to take into account of the path loss and we assume the path loss to be same for all the antennas in the array.

$$\mathbf{A}^T = \beta \odot \begin{bmatrix} \mathbf{a}(\theta_1) \\ \mathbf{a}(\theta_2) \\ \vdots \\ \mathbf{a}(\theta_K) \end{bmatrix}, \tag{20}$$

where $\beta = [\beta_1 \ \beta_2 \cdots \beta_K]^T$.

5 Numerical results

1) Simulation Environment: Let us consider that all the satellite terminals are seen at azimuth angle range of 10° to 85° from the BS. We consider a single desired user at an angle of −30° and a Uniform Linear Array (ULA) at the BS with the layout shown in Fig. 1. The simulation and link budget parameters for both the links (i.e., link between SAT terminal and the BS and the link between terrestrial terminal and the BS) are provided in Table I. To design a LCMV beamformer, we need DoAs of the interfering users. For this purpose, we quantize the considered interfering sector in the interval of 5° and consider one terminal in each quantized angle. It can be noted that the pattern generated in 0° to 90° quarter is repeated in another quarter 90° to 180° due to symmetric nature of ULA pattern. Therefore, the response pattern generated within the region 10° to 85° is repeated over the region 170° to 95°.

2) Results: Figure 3 shows the array response versus azimuth angles plot for MVDR and LCMV beamformers. The number of interferers considered was 16 and the transmit power for each interfering terminal was considered to be 30 dBm. From the figure, it can be observed that by considering the interfering range from 10° to 85°, we can create the array response about −50 dB to −110 dB down the desired response for MVDR beamformer and about −80 to −200 dB down the desired response for LCMV beamformer. Figure 4 shows the SINR versus azimuth angles plot of LCMV and MVDR beamformers for $M = 20$ and $K = 17$ in the considered simulation environment in which the random interfering users have been generated with uniform distribution and the interfering power at the BS from these terminals is different due to different DoAs and distances to the BS. From the figure, it can be observed that the LCMV beamformer provides similar SINR as that of MVDR beamformer towards the desired user and can provide very low SINR towards the interfering sector than the MVDR beamformer. From this result, it can be concluded that LCMV beamformer can reject the interference more effectively than MVDR beamformer in the considered scenario.

Figure 5 shows the SINR versus number of interferers for $M = 18$ and $K = 17$. The SINR for both beamformers decreases as the number of interfering users increases in the considered interfering sector. From the figure, it can be noted that the LCMV beamformer shows better performance compared to MVDR for low number of interferers (< 9 in Fig. 5) and for higher number interferers, MVDR shows better performance than the LCMV beamformer. Figure 6 shows the SINR versus mismatch azimuth angles of the desired user for the considered scenario with $M = 18$ and $K = 17$. From the figure, it can be noted that up to 3° mismatch, MVDR beamformer's performance is slightly better than LCMV beamformer's performance. When the mismatch angle increases beyond the 3°, MVDR beamformer's SINR performance becomes worse than the that of LCMV beamformer.

3) Discussion: In our considered scenario, the DoA of the desired user and

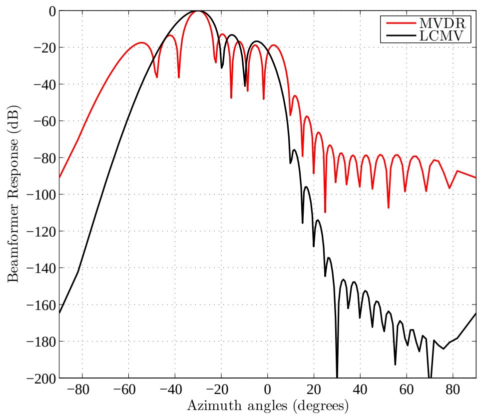

Fig. 3. Response versus azimuth angle for LCMV and MVDR beamformers, $M = 20$, $K = 17$

the range in which interferers are located is known while the exact locations of the interferers are unknown to the beamformer. Simulation results show that performance of both the beamformers is similar in the desired direction while the performance of the LCMV beamformer is much better in terms of rejecting the interference coming from the interfering sector. Mathematically, the LCMV beamformer places unit response constraint in the desired direction and zero response constraints in the interfering regions while the MVDR beamformer places only unit response constraint in the desired direction and tries to minimize total interference plus noise. Furthermore, it has been noted from the results that even in case of uncertainty of exact locations of the interfering users, the LCMV beamformer is capable of creating low response towards the considered interfering region. In practical situations, exact DoA of the desired signal may deviate from the estimated one causing DoA mismatch of the desired signal. The response of the LCMV beamformer in case of angular mismatch can be maximized by placing multiple unit response directional constraints while the performance of MVDR beamformer becomes worse in this case. However, the performance of the LCMV beamformer becomes worse for a large number of interferers and it deteriorates rapidly when the number of antennas becomes less than the number of interferers while the performance of the MVDR beamformer is better than that of the LCMV in this condition. Therefore, the LCMV beamformer is suitable in terms of rejecting interference effectively for a small number of interferers and the MVDR beamformer is suitable for a large number of interferers.

Table 1. Simulation & Link Budget Parameters

Parameter	**Value**
Satellite longitude	28.2^o E
Considered latitude range	35^o to 70^o
Considered longitude range	-10^o to 45^o
Elevation angle range [1]	7.07^o to 49.40^o
Carrier frequency	4 GHz
SAT terminal to BS link	
SAT Terminal Tx power	30 dBm
SAT Terminal Gain range	20 to -9.5047 dB
SAT Terminal EIRP range	50 to 21.50 dBm
Distance bet SAT terminal and BS	0.5 km to 10 km
Path loss range $\propto r^{-2}$	98.47 to 124.49 dB
BS antenna Gain	10 dB
Noise power @ 8 MHz	-104.96 dBm
INR range at BS	10.97 to 66.49 dB
Terrestrial terminal to BS link	
Terrestrial terminal Tx power	20 dBm
Terrestrial terminal antenna gain	10 dB
Distance bet desired terminal and BS	0.05 km to 5 km
Path loss range $\propto r^{-2}$	78.46 to 118.48 dB
BS antenna Gain	10 dB
Noise power @ 8 MHz	-104.96 dBm
SNR range for desired signal at BS	26.48 to 66.5 dB

6 Conclusion

In this work, an underlay beamforming technique has been proposed for the spectral coexistence scenario of satellite and terrestrial networks. By using the priori knowledge about the interfering sector which arises due to special propagation characteristics of the satellite terminals, we have porposed a receive beamformer at the terrestrial BS to maximize the SINR towards the desired user and to mitigate the interference from the interfering satellite terminals. In this context, the performances of MVDR and LCMV beamformers have been compared. It has been shown that LCMV beamformer is better suited in terms of rejecting interference even in case of DoA uncertainty of the interfering signals as long as the sector in which interfering users are located is known to the beamformer. Furthermore, it can be concluded that the MVDR beamformer is better suited for a

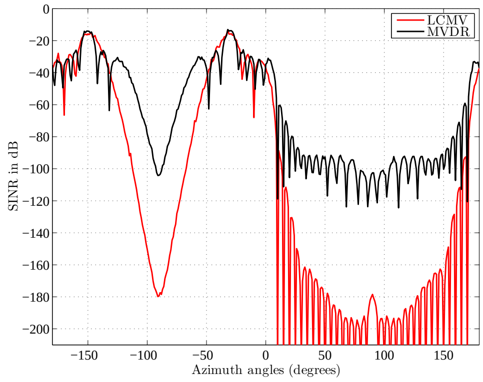

Fig. 4. SINR versus Azimuth angles plot of LCMV and MVDR beamformers for the considered scenario, M=20, K=17

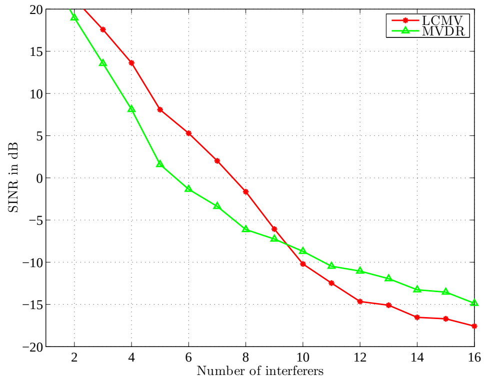

Fig. 5. SINR versus number of interferers for proposed scenario with beamformers designed for $M = 18$, $K = 17$

large number of interfering terminals. In our future work, we plan to investigate the robustness on the proposed methods as well as to apply other beamforming techniques for the proposed scenario.

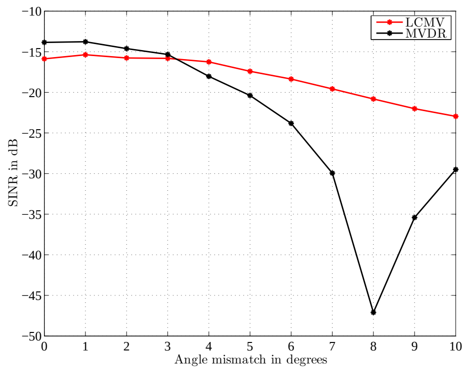

Fig. 6. SINR versus angular mismatch for the desired user

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