Spatial Division Multiple Access with DOA based Digital Beam-forming in Mobile Satellite Communications

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Abstract:- This paper proposes a new scheme for spatial division multiple access (SDMA) in mobile satellite communication by using DOA based digital multiple beam forming with uniform circular antenna array. The schem extends Weight Subspace Fitting algorithm to two dimensions so as to estimate the azimuth and elevation angles of the signals received at the satellite. With these angle estimates and using multiple digital beam forming technique, the signals arriving at the satellite can be well separated from one another and communication channels to the different users within different geographical areas can thus be provided to realize SDMA scheme. This technique can be used to complement existing FDMA, TDMA or CDMA schemes in current mobile satellite systems.

Key-Word:- Signal Separation; Channel Assignment; DOA; Digital Beam-forming; Mobile Satellite Communication; SDMA; Weight Subspace Fitting (WSF) algorithm; Antenna Array CSCC'99 Proc.pp.3751-3755

1 Introduction

In recent years, in mobile satellite communications, the applications of on board processing (OBP) techniques are receiving considerable attention. In order to cope with the ever increasing demand for mobile communications, ways are being sought to improve spectral efficiency and more efficient channel reuse. In respect of the latter, a new multiple access technique, called Spatial Division Multiple Access (SDMA), has been used in some mobile communication systems. SDMA is already being realized in terrestrial mobile system, by use of adaptive digital beaming forming (DBF) technology. For mobile satellite communication systems, the adaptive digital beam forming (DBF) is set to become a key OBP technique in realizing SDMA. Its use make it possible to achieve good separation of signals arriving the satellite and significant suppression of co-channel inferences, such technology will improve the quality and capacity of mobile satellite communication systems.

This paper proposes a scheme for handling the problem of signal separation and dynamic channel assignment by use of DOA based digital multiple beam forming with uniform circular antenna array to realize adaptive SDMA in mobile satellite systems.

In this scheme, the DBF network consists of parallel sub-beamformers, which can work in both downlink and uplink mode. Fig.1 shows one DOA based sub-beamformer configuration. For signal separation in uplink mode, each sub-beamformer selects out one desired signal while nulling other co-channel signals. On the downlink, for dynamic channel assignment, on board uniform circular antenna array produces multiple dynamic spot beams to cover different zones within a cluster, each zone being similar to a cell in the land cellular system. The performance of this scheme is examined by means of simulations.

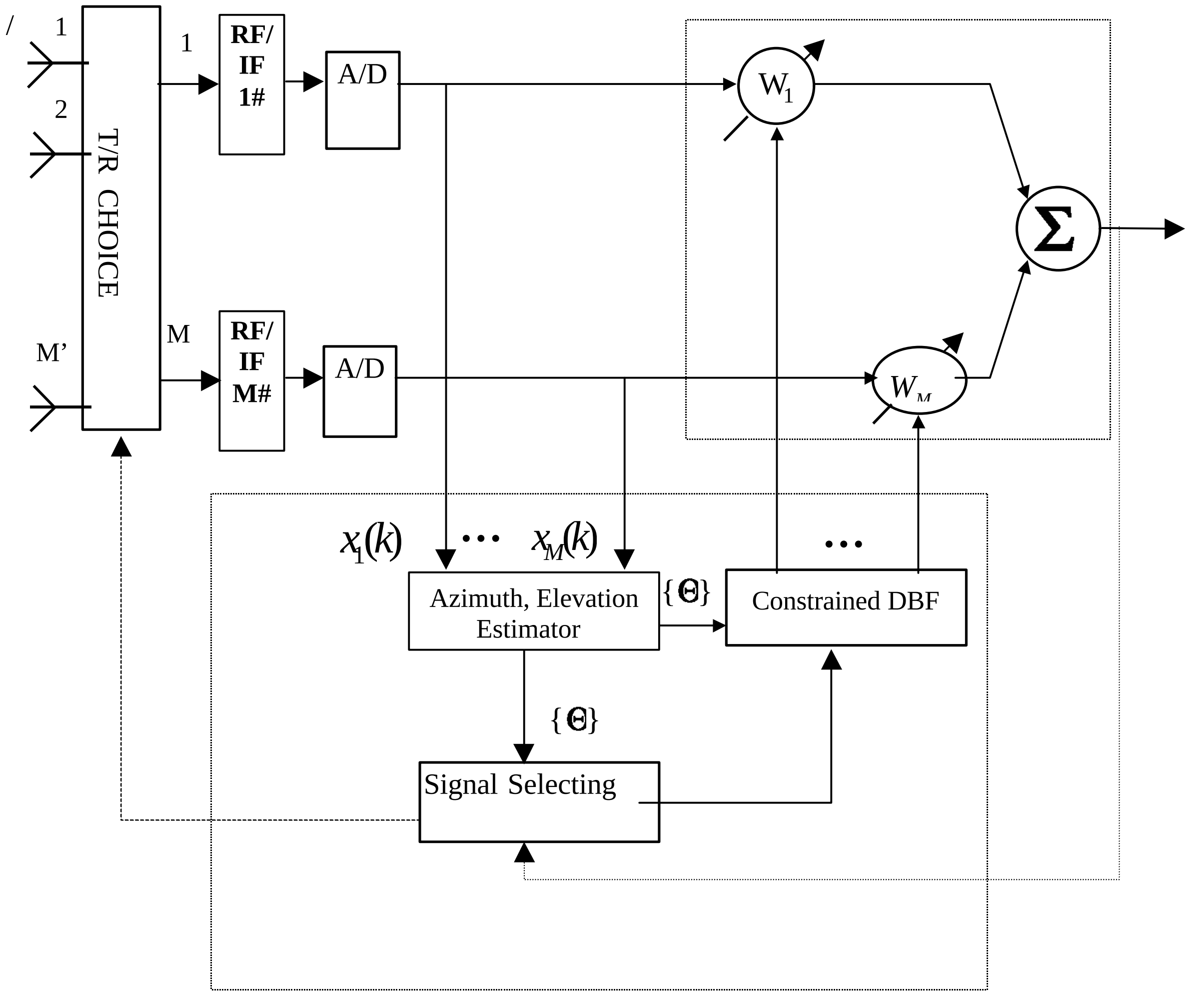


Fig. 1 Block diagram configuration of a sub-beamformer (Uplink Mode)

The rest of this paper is organized as follows. In section 2 we described the array data model, signal separation and channel assignment method. In section 3 we provide some simulation results to illustrate the performance of the proposed scheme and finally, section 4 contains our conclusion.

2 Signal Separation and Channel Assignment Method

The assumptions, which are almost standard, underlying the method are first noted :

(1) Given the geometry of a satellite-to-terrestrial mobile system, it is reasonable to assume zero or negligible multipath environment.

(2) In the same time slot, the number of co-channel signals arriving at the antenna array, N, is assumed to be known and less than the number of the beams, M, in a cluster to be handled.

(3) In the downlink mode, the position of users, azimuth and elevation angles are known.

The proposed approach for co-channel signal separation and dynamic channel assignment can be briefly described, as a two step process:

(1) Estimation of the 2D DOA at satellite (azimuth-elevation) of the co-channel signal sources in the uplink and formation of the antenna steering matrix, based on these 2D directions estimated in the uplink or desired in the downlink.

(2) Use of constrained DBF based on above steering matrix to select one user's signal

and null the other co-channel users or to produce the multiple spot beams to cover different areas.

2.1 2D DOA estimation with Weight Subspace Fitting Method

Over the last two decades a number of high-resolution direction estimation algorithms have been developed. In this paper, a 2D Weight Subspace Fitting (WSF) algorithm is used with the uniform circular array to estimate the azimuth and elevation angles of the signals arriving within a cluster of beams.

For given array configuration, the array output can be expressed as follows:

where, $\boldsymbol{S(t)}$ are received signals and $\boldsymbol{N(t)}$ are

$$\mathbf{X}(t) = \mathbf{A}(\Theta)\mathbf{S}(t) + \mathbf{N}(t) \quad (1)$$

additive noises, and

$\mathbf{A}(\Theta) = [\mathbf{a}_1(\Theta), \mathbf{a}_2(\Theta), \cdots, \mathbf{a}_M(\Theta)]^T$ is the array manifold, the collection of the received signal vector for all possible directions. For the *k-th* co-channel signal, the 2D direction is denoted as $\Theta_k = [\theta_k, \varphi_k]^T$, where θ_k and φ_k represent azimuth and elevation angles of the signal arriving at the antenna and vector $\mathbf{a}_i(\Theta_k)$, called the steering vector, the response of the *i-th* sensor of the uniform circular array to the *k-th* signal, may be written:

$$\mathbf{a}_i(\Theta_k) = \exp(\frac{2\pi R}{\lambda}\cos(\frac{2\pi(i-1)}{M} - \theta_k)\sin\varphi_k) \quad (2)$$

for $i = 1, 2, \ldots, M$, *and* $k = 1, 2, \ldots, N$

where λ is the signal wavelength, R is the radius of uniform circular array

Therefore, the covariance matrices of the signal, noise and observation vector are given by:

$$\mathbf{R}_s = E\{\mathbf{S}\mathbf{S}^H\}; \quad \sigma^2\mathbf{I} = E\{\mathbf{N}\mathbf{N}^H\} \quad (3)$$

$$\mathbf{R}_{xx} = E\{\mathbf{X}\mathbf{X}^H\} = \mathbf{A}(\Theta)\mathbf{R}_s\mathbf{A}(\Theta) + \sigma^2\mathbf{I}$$
$$= \mathbf{E}_s\mathbf{\Lambda}_s\mathbf{E}_s^H + \mathbf{E}_n\mathbf{\Lambda}_n\mathbf{E}_n^H \quad (4)$$

where $\boldsymbol{Es}$ and $\boldsymbol{En}$ are signal and noise subspaces, respectively, obtained by eigenvalue decomposition (EVD) to observation covariance matrix $\boldsymbol{R}xx$ and Λs, Λn are corresponding eigenvalues of signal and noise subspaces.

To get azimuth and elevation angles of arrival signals, there is a choice of some high-resolution direction-finding methods. However, maximum likelihood estimation algorithms are computationally too complex to be implemented in two-dimensional estimation problems. Simpler algorithms, such as MUSIC, have poor threshold behavior performance. Hence, the Weight Subspace Fitting (WSF)[7] method is extended into a two-dimensional version to estimate the azimuth and elevation angles:

$$\hat{\Theta} = \arg\min_{\Theta} \left\| \hat{\mathbf{E}}_s - \mathbf{A}(\Theta)\mathbf{A}(\Theta)^+ \hat{\mathbf{E}}_s \right\|_{\mathbf{W}}^2$$
$$= \arg\min_{\Theta} \left\| \mathbf{\Pi}_A^{\perp} \hat{\mathbf{E}}_s \right\|_{\mathbf{W}}^2 = \arg\min_{\Theta} Tr\{\mathbf{\Pi}_A^{\perp} \hat{\mathbf{E}}_s \mathbf{W}_{opt} \hat{\mathbf{E}}_s^H\} \quad (5)$$

where $\mathbf{\Pi}_A^{\perp} = \mathbf{I} - \mathbf{\Pi}_A = \mathbf{I} - \mathbf{A}(\Theta)\mathbf{A}(\Theta)^+$, is the orthogonal projector onto the null space of $\boldsymbol{A}(\boldsymbol{\Theta})$ and $\boldsymbol{W}_{opt}$ is optimal weight matrix, given by:

$$\mathbf{W}_{opt} = (\mathbf{\Lambda}_s - \sigma^2\mathbf{I})^2 \mathbf{\Lambda}_s^{-1} \quad (6)$$

where σ^2 is the average of the eigenvalue $\mathbf{\Lambda}_n$.

After getting 2D directions, we can form the steering vector of N co-channel signals and perform direction-constrained digital beamforming to separate the desired signal from the set of co-channel signals.

2.2 The Constrained Digital Beam forming

In this step, we form the estimated steering vectors $\mathbf{a}_i(\Theta_k)$, ($i = 1,2, \ldots M$) from the estimated azimuth and elevation angles and perform the following constrained beamforming:

$$\min_{\mathbf{w}} P(\mathbf{w}) = \arg\min_{\mathbf{w}} E\{\left|\mathbf{w}^H\mathbf{x}(t)\right|^2\}$$
$$s.t: \quad \mathbf{G}^H\mathbf{w} = \mathbf{u} \quad (7)$$

where, $\boldsymbol{W}$ is the beam forming weight vector, the columns of matrix $\mathbf{G}$ are the estimated N steering vectors, and $\boldsymbol{u}$ denotes the constrained vector.

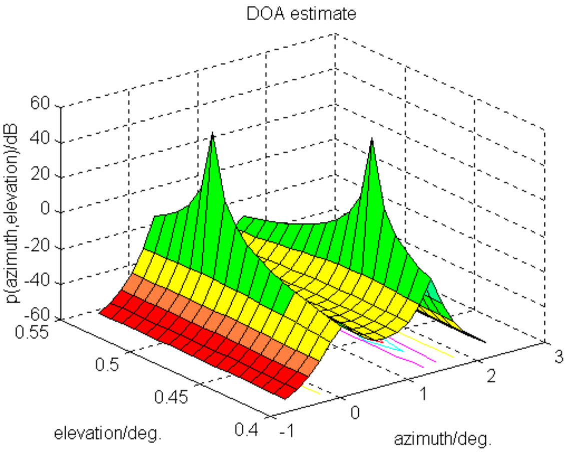
To realize constrained beamforming, we set constrained vector $\boldsymbol{u}$ to the selected signals or users, i.e. in both uplink and downlink mode, to receive *k-th* signal or transmit to the *k-th* user, the *k-th* element of $\mathbf{u}$ is set to one, which constrains the ideal response of the sensor the beam of which covers the *k-th* user, and the other elements are set to zero.

3 Simulation

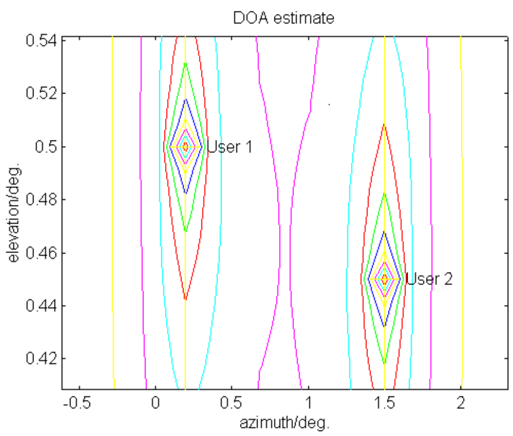
Space constrains us to present here a small of selection of performance results obtained through simulation studies.

Simulation Condition: Two co-channel signals arrive at uniform circular array with azimuth and elevation Θ_1=[0.2,0.5] and Θ_1=[1.5, 0.45], and SNR=10 dB. 100 samples are accumulated (Snapshot =100).

The DOA estimation and Constrained DBF pattern show in Fig. 2 and Fig. 3, respectively.



(a) DOA estimation spectrum

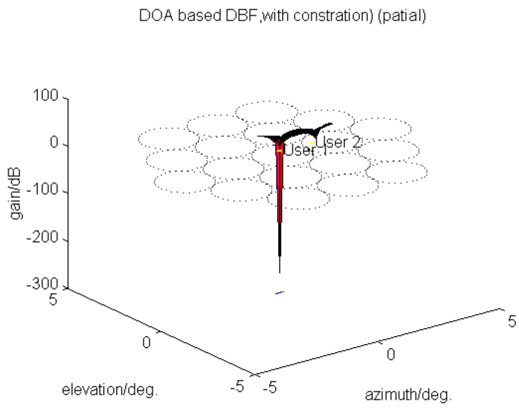


(b) 2-D DOA Estimation

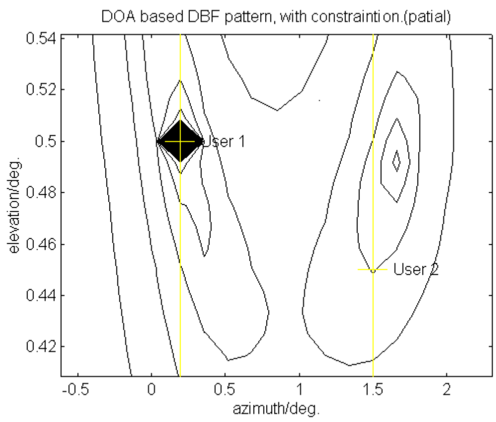
Fig. 2 Azimuth and elevation angle estimation with 2D WSF method

4 Conclusion

In this paper, an approach to realize SDMA with DOA based digital beamforming technique in mobile satellite communication system is reported. The two main problems for SDMA, separation and suppression co-channel signals in the uplink and dynamic channel assignment in the downlink, are considered.



(a) DOA based DBF pattern



(b) 2-D DOA based DBF pattern

Fig.3 DOA based constrained DBF pattern

With proposed approach, once the 2D direction estimates are obtained, the DBF will work well in separating out desired signals and suppressing undesired co-channel signals in the uplink, or in producing the dynamic multiple narrow beams to realize SDMA in the downlink. For co-channel signal separation and suppression, even if the direction estimates are inaccurate, the signal power received is still better than the performance yielded by the side lobe interference-suppressing scheme alone. Simulation results show that this present method has good resolution, even in low SNR case.

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