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Direction of Arrival Estimation for Smart Antenna using a Combined Blind Source Separation and Multiple Signal Classification Algorithm

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Abstract

Smart antenna system after determination of Direction of Arrival (DOA) of signal, generates beam toward user and null toward interferer and enhances the security and capacity in mobile network. The objective of the present work is to determine weaker coherent and non-coherent signals with low Signal-to-Ratio (SNR) in heavily faded areas, where performances of other conventional algorithms are not good. For the determination of weaker signal accurately, a combined method using Blind Source Separation (BSS) based Joint Approximation Diagonalisation of Eigen matrices (JADE) and Multiple Signal Classification (MUSIC) algorithm is used. From simulated results, it is found that the resolution of MUSIC algorithm can be enhanced using this combined method. Also the capability of detection of angle of incoming signal can be enhanced using this proposed method. Since, smart antenna system is one of the main technologies in fourth generation mobile communication and beyond, the proposed method may be useful for next generation mobile communication.

Keywords: Blind Source Separation, Coherent and Non-Coherent Signals, Direction of Arrival, Multiple Signal Classification, Smart Antenna

1. Introduction

Smart antenna technology is used in mobile communication. The coverage area, spectral efficiency, reduction in interference and channel capacity can be enhanced by using smart antennas in mobile wireless communication[1]. Smart antenna is basically one type of adaptive antennas that are used various signal processing algorithms to identify the location of the user by the estimation of Direction of Arrival of signal. After the finding of Direction of Arrival, antenna beam is located towards the mobile using beam forming network of the antenna array[2]. Smart antennas radiate maximum power in the direction of main beam which is in the direction of the user and produce nulls in the interference direction[3]. The two main functions in smart antenna are Direction of Arrival (DOA) estimation and the adaptive beam forming.

The improvement of received signal quality depends on the determination of Direction of Arrival (DOA) of that signal, by accepting signal only from the desired direction and neglecting the interferences[4]. The correct determination of signal direction, also known as received input signal DOA is very important aspect which needs in the formation of beam pattern only towards the desired direction from antenna, thereby minimizing the interference[5]. The estimation of signal direction is important in various radio communication[6,7]. The objective of DOA estimation is to utilize the signals received by the antenna array sensors to determine the signals direction from the actual users[6]. Thus, the DOA based algorithms which are used for estimation of angular position of a signal effects on the increment of received signal quality. The algorithm of DOA or super resolution analyse the antenna array arrangements to better diagnose the received signals and they also can identify multiple location of targets. In other words, the success of smart antenna design depends on the precise

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estimation of angle by DOA algorithms[8]. The purpose of DOA based algorithms is to introduce a function, known as pseudospectrum which represents angle of arrived signal incident on the antenna array[6,7]. There are two types of DOA estimation based algorithms available such as conventional and subspace methods[9]. Conventional methods are non-subspace method which determine a pseudospectrum first, then find the DOAs by searching the peaks in spectrum. The conventional methods[10] are limited by the poor resolution of angular position. For this reason, subspace based algorithms like MUSIC[11] and ESPRIT[12] that estimate the angular position correctly are mostly used. Eigen analysis of covariance matrix of input signal is the basic concept of subspace based algorithms[13]. MUSIC and Estimation of Signal Parameter via Rotational Invariance Technique (ESPRIT) are widely incorporated in smart antenna design for their accurate detection of angle and high resolution[14]. MUSIC algorithm can be applied in any array arrangement if the steering vector of arrays is not incomplete[15]. MUSIC algorithm provides more stable and precise incident signal direction as compared to the ESPRIT[9,16]. MUSIC algorithm gives priority to know the number of signal sources[17]. Blind Source Separation (BSS) separates the blindly combined source signals, coming from different directions, received by an array sensors[18]. BSS algorithm deals with the separation of noise components from the mixture of source signal[19,20]. The effectiveness of MUSIC is lost when it detects the angle of arrival of correlated or coherent signal[21]. Using BSS, this limitation of MUSIC is solved by extracting the noise from the actual signal[17,22,23]. Direction of Arrival estimation for wireless sensor network is also reported[24,25]. Recently, a two-dimensional Direction of Arrival estimation method for a combination of circular and non-circular sources is reported[26].

This paper concentrates on the combination of MUSIC and a particular category of BSS to upgrade subspace partition, performed by the MUSIC algorithm. The performance of MUSIC algorithm for coherent signals is not good. Here, combined approach using BSS and MUSIC algorithms is used both for coherent and non-coherent signals for DOA estimation. Appreciable improvement is achieved for DOA estimation for non-coherent signals using this combined algorithm.

2. DOA Estimation Algorithms

MUSIC algorithm[10,14,21] assumes that the S number of signals sensed by the T number of uniformly spaced linear antenna array sensors are radiated from the far field point sources. Two consecutive sensor elements are separated by 'b' distance. Impinging signals make an Angle of Arrival (AOA) or Direction of Arrival (DOA), Ψ, with the line connecting the sensors in the linear array. It is assumed that T>S.

The total signal is a combination of original signal and noise received by the antenna array and is expressed as[16]:

$$y(t)=\sum_{k=0}^{S-1}a(\Psi_k)h_k(t)+n(t) \tag{1}$$

Where, $h^T(t) = [h_0(t), h_1(t), ..., h_{S-1}(t)]$, is the matrix of impinging signals, $n(t) = [n_0(t), n_1(t), ..., n_{S-1}(t)]$ is the noise matrix and A is the antenna array steering vector related to the AOA of the signals.

Uncorrelated noise in the MUSIC algorithm makes the covariance diagonal matrix. MUSIC algorithm split this covariance matrix into two orthogonal subspace matrices i.e. signal subspace and noise subspace. Evaluation of DOA is achieved from noise subspace matrix.

The T x T input signal covariance matrix (V_{yy}) is expressed as[16]:

$$\begin{aligned} V_{yy} &= E[y.y^H] = E[(A\,h + n)(h^H A^H + n^H)] \\ &= AE[h.h^H]A^H + E[n.n^H] \\ &= AR_{S1} A^H + R_{n1} \end{aligned} \tag{2}$$

R_{s1} states the signal covariance matrix (S x S sensors), $R_{n1}=\sigma_n^2 I$ states the noise covariance matrix (T x T sensors), I is the identity matrix (T x T sensors) and A is the steering vector (T x S sensors).

After decomposition, V_{yy} has T eigen value ($\lambda_1, \lambda_2, ..., \lambda_T$) along with related eigen vectors $I = [u_1, u_2, ..., u_T]$. Organizing the T eigen values in ascending order, the matrix I is divided into two subspaces: $I = [C_N C_S]$. C_S is the TxS signal subspace matrix which consists of eigen vectors related with incident signals and C_N is Tx(T-S) noise subspace matrix consisting of eigen vectors related with noise. Orthogonality condition between array steering vector and noise subspace makes the matrix product $a^H(\Psi)C_N C_N^H a(\Psi)=0$ at the arriving angles $\Psi_1, \Psi_2, ..., \Psi_S$,

The reciprocal of matrix product obtains sharp peaks which estimate the Direction of Arrival of striking signal. Thus pseudospectrum of MUSIC is expressed as[16]:

$$P_{Music}(\Psi)=\frac{1}{a^H(\Psi)C_N C_N^H a(\Psi)} \tag{3}$$

The blind source separation method[27] utilizes the 4th order cumulant matrices in order to get source signals from combined signals known as JADE[28] algorithm. This method extracts the noise from source signals and determines the number of source signals without knowing the original source signals or mixing system. BSS[20] assumes some properties of stochastic which are present in the independent source signals and based on that BSS, extracts signals from the mixture where separated signals are satisfied the assumed properties of stochastic. Simplest model of BSS is represented by[27]:

$$E = LD + N \tag{4}$$

E is the combined signal, L is the mixing matrix, D is the independent source signal matrix and N is the Gaussian noise. The aim of BSS algorithm is to estimate L from E. The demixing matrix W is used in the separation process to compute the independent source signals $\widehat{D}$ from the combination of signals as:

$$G = EW = WLD + NW = \widehat{D} + \widehat{N} \quad \text{where, } \widehat{D} = WD \text{ and } \widehat{N} = NW \tag{5}$$

JADE algorithm[19] is applied to estimate the source signal D. Because of the presence of noise, which is an unknown distribution, recovery of exact D is not possible[19]. After calculating mixing matrix L, the source signals are estimated[19] as $\widehat{D} = \hat{L} - E$. Here, $\hat{L} = RP^{-1}$ where R is the rotation matrix and P is the whitening matrix.

In this paper, a combination of BSS and MUSIC algorithm is proposed for smart antenna. Features of BSS algorithm are used with MUSIC algorithm for angle of arrival detection. In this approach BSS extracts the noise from the blind mixture of received signals and recovers the original signals. MUSIC algorithm is then used to separate the noise subspace and signal subspace providing better pseudospectrum estimation of incident signal direction. By this approach the spectral resolution of MUSIC is increased. This BSS-MUSIC algorithm helps to estimate the direction of weaker signals (signals with low SNR) which is difficult to estimate by using MUSIC algorithm only.

The steps of the combination of BSS and MUSIC algorithm are described below:

Step 1: The BSS algorithm is applied on the received signal (composition of original signal plus white Gaussian noise) by the sensors of antenna array to calculate the noiseless signals present in the mixture by utilizing the BSS. This process does not need any prior knowledge of the number of non-Gaussian source signals. The identification of non-Gaussian signal will be possible easily after BSS process.

Step 2: Then apply MUSIC algorithm on the non-Gaussian signal to estimate the Direction of Arrival of these signals by utilizing the eigen structure of input covariance matrix.

3. Direction of Arrival Estimation using Combined BSS and MUSIC Algorithms

In this section, DOA is estimated using BSS-MUSIC algorithm. The flowchart for the application of this proposed BSS-MUSIC algorithm is shown in Figure 1.

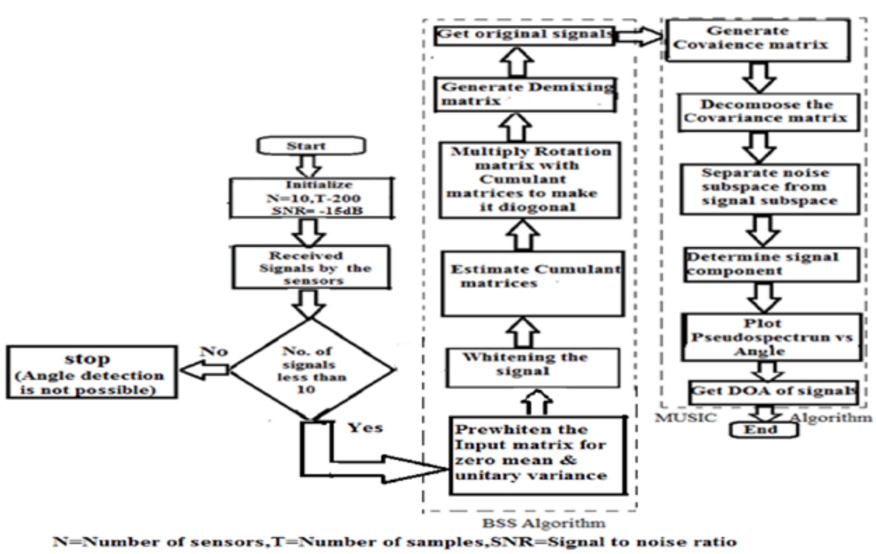

Figure 1. Flow chart for combined BSS-MUSIC algorithm.

The performances of the proposed approach depend on various parameters. The linear array, which is considered uniform for the experiments, has 10 number of array sensors. The distance between the antenna elements is considered as 0.5λ. Additive white Gaussian is considered as noise in simulation. The number of snapshots has taken 200 for all the cases. Three complex Quadrature Amplitude Modulation (QAM) signals, generated for experiments are shown in Figure 2 (a-c). Three complex signals have generated using MATLAB software to investigate the efficiency of the proposed algorithm as shown in Figure 2.

Then these signals are mixed with mixing matrix and added with Gaussian white noise. Three such mixed signals are shown in Figure 3 (a-c).

BSS algorithm has applied on these signals based on the dominating frequency components, present in the signals. As a result BSS algorithm removes the noise from the mixture of signals and separates the original signal components without knowing the original signals or mixing system. Three such separated signals are shown in Figure 4 (a-c).

The performance of MUSIC algorithm for DOA estimation degrades for coherent signals. Simulation result, using MUSIC algorithm, for DOA estimation of coherent signals at angular positions -30^0, 30^0, 60^0 are shown in Figure 5.

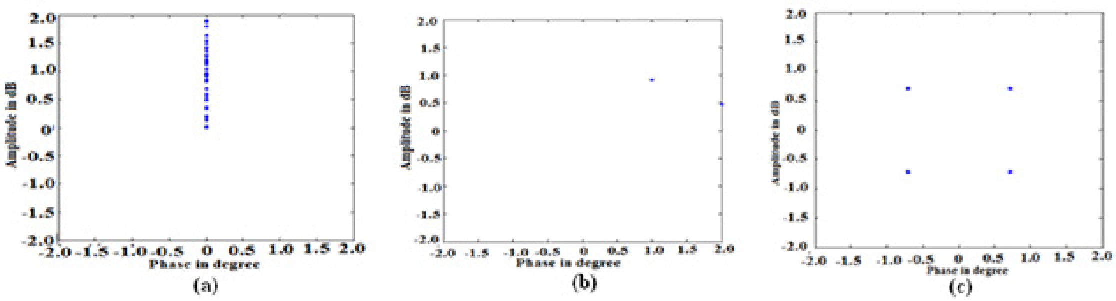

Figure 2. Three complex source signals generated for the experiments.

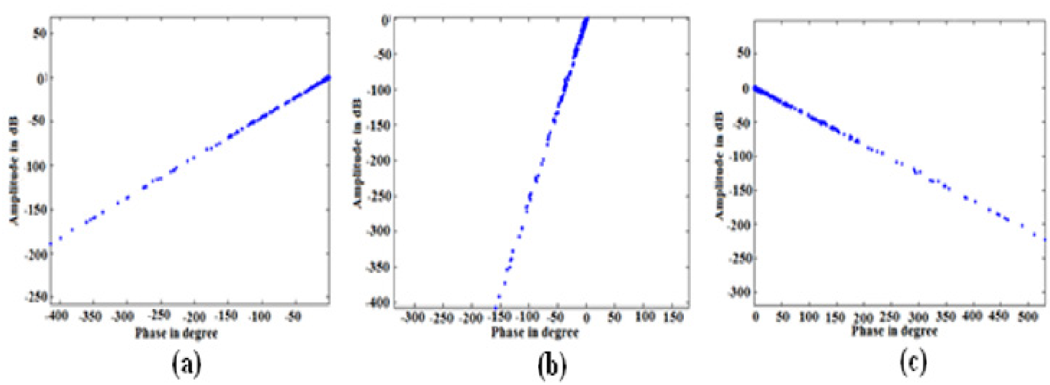

Figure 3. Three mixed signals.

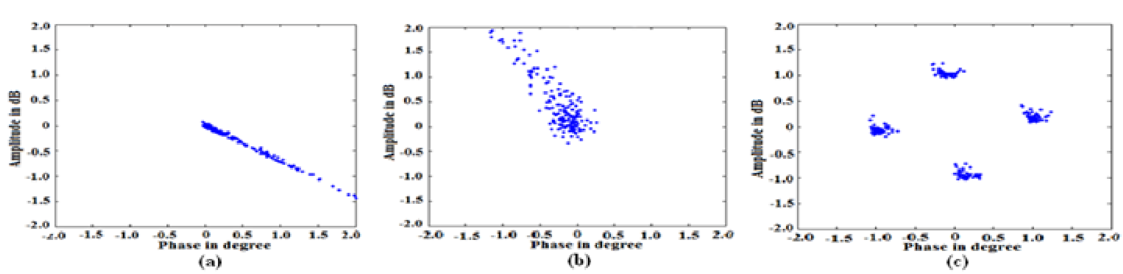

Figure 4. Three seperated signals.

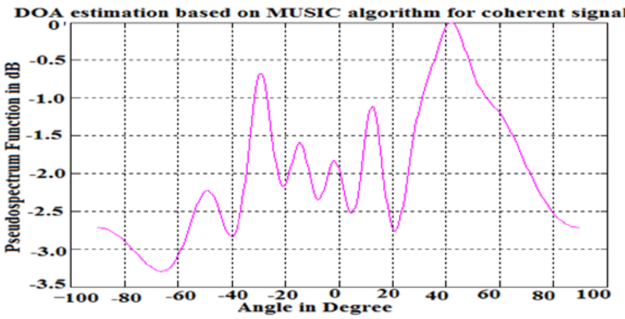

Figure 5. Music pseudospectrum using coherent signal with angles -30°, 30°, 60°.

This limitation is solved by the proposed BSS-MUSIC algorithm and is shown in Figure 6. The proposed approach raises the performance of MUSIC algorithm for the DOA estimation of coherent signal in terms of making the peaks more sharp. The BSS algorithm determines number of source signals and MUSIC algorithm utilizes that determined result to increase the spectral efficiency. The noise level considered for the above simulations is -15 dB. It also obtains better resolution for weaker signal than MUSIC alone.

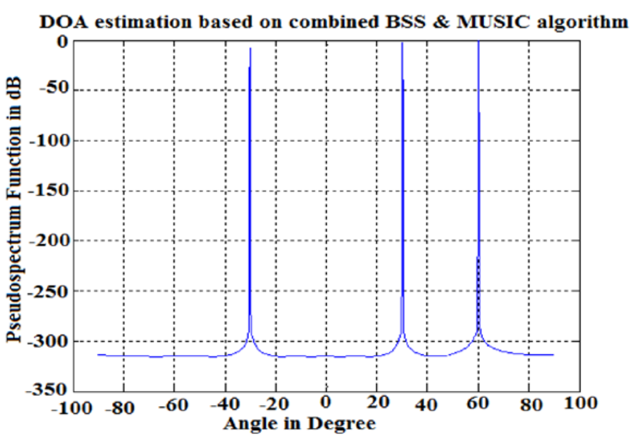

Figure 6. Pseudospectrum for coherent signal using BBS-MUSIC at angles -30° 30°, 60°.

Figure 7 represents the pseudospectrum function of proposed BSS-MUSIC approach with closely related sources where coherent signals are impinging with angles -30^0, 33^0, 36^0 and with Signal to Noise Ratio (SNR) of -15 dB. From the above simulation it is evident that the proposed method still gives better spectral resolution even with closely related sources.

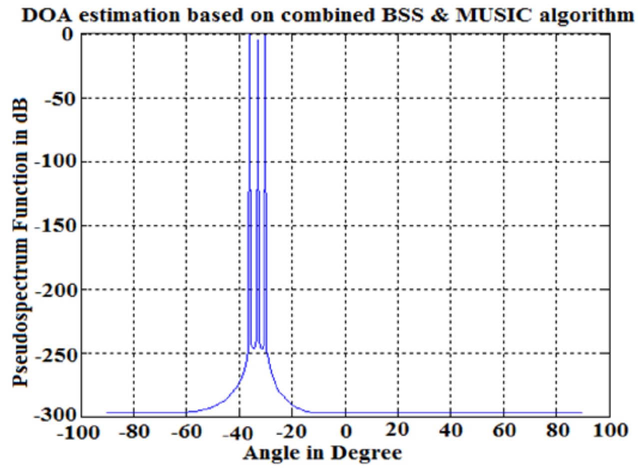

Figure 7. Pseudospectrum of BBS-MUSIC approach with closely spaced sources.

Figure 8 shows simulation of MUSIC pseudospectrum using non-coherent signal with angles -30^0, 30^0, 60^0 and Figure 9 shows simulation result for proposed approach using non-coherent signal with incident angles -30^0, 30^0, 60^0. Comparing Figure 8 with Figure 9 based on spectral beamwidth, it is found that the proposed BSS-MUSIC approach gives better resolution for non-coherent signal in terms of narrower beamwidth than that of the MUSIC algorithm for non-coherent signals. In the above simulations SNR is -15 dB with white Gaussian noise.

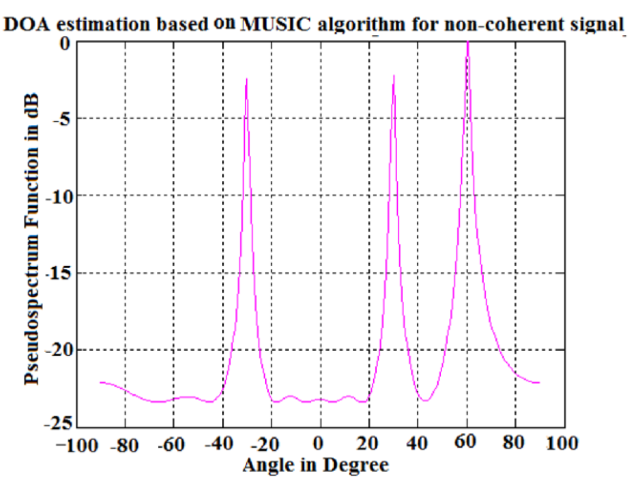

Figure 8. Pseudospectrum for non-coherent signal using MUSIC at angles -30° 30°, 60°.

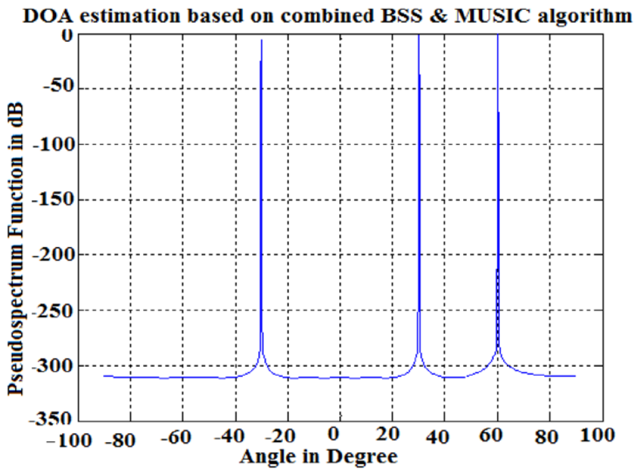

Figure 9. Pseudospectrum for non-coherent signal using BSS-MUSIC at angles -30° 30°, 60°.

The angle of arrival determination for coherent signals, incident with angles -30^0, 30^0, 60^0 for SNR = -30 dB and SNR = -50 dB are plotted in Figure 10 and in Figure 11 respectively. From the simulations it is depicted that even in a more noisy environment the proposed approach has not lost its effectiveness which means it is capable to estimate the angular positions of incident signals (having low SNR value) in noisy situations.

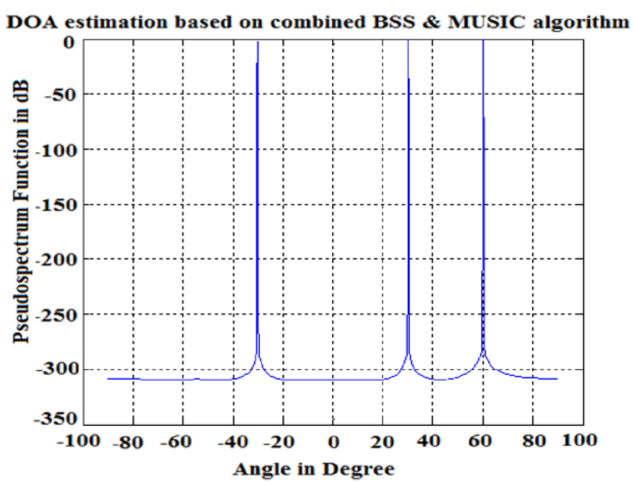

Figure 10. Pseudospectrum for coherent signals using BSS-MUSIC with SNR = -30db.

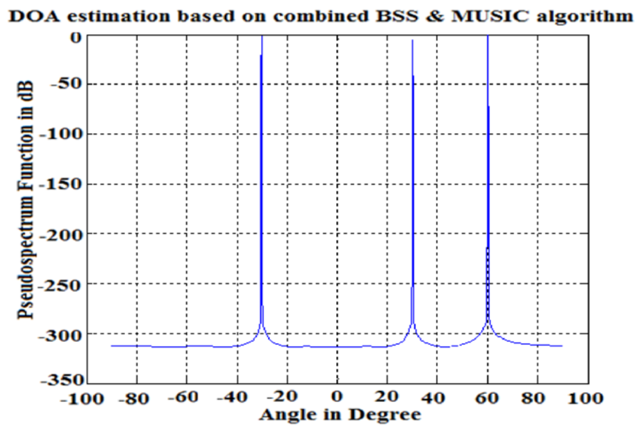

Figure 11. Pseudospectrum for coherent signals using BSS-MUSIC with SNR = -50db.

Figure 12 represents the spectrum of non-coherent signal estimated using MUSIC algorithm incident at angles -30^0, 30^0, 60^0 using MUSIC algorithm with array sensors spacing λ and SNR = -15 dB. In MUSIC algorithm, when antenna array sensors spacing is less than λ/2, estimated spectrum beamwidth becomes narrow when number of sensors of array increases. But when array sensors spacing exceed λ/2, false peaks appear in the spectrum which indicates degradation of estimation accuracy of MUSIC algorithm. Appearance of false peaks, for array sensor spacing greater than λ/2, is shown in Figure 12.

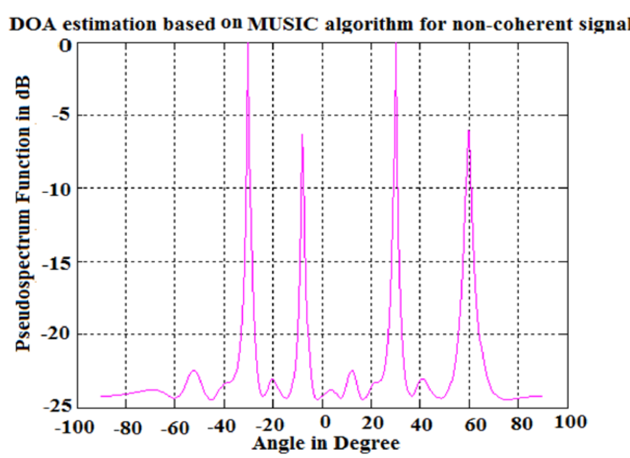

Figure 12. Spectrum for non-coherent signal using MUSIC algorithm for array sensors spacing λ.

Spectrum of non-coherent signal incident with angles -30^0, 30^0, 60^0 using BSS-MUSIC algorithm for array sensors spacing λ is plotted in Figure 13. Though we have taken array sensors spacing greater than λ/2, the appearance of false peaks is less in Figure 13 as compared to the case of Figure 12 while same parameters are considered for both the simulations. So, false peaks will be reduced using the proposed BSS-MUSIC algorithm.

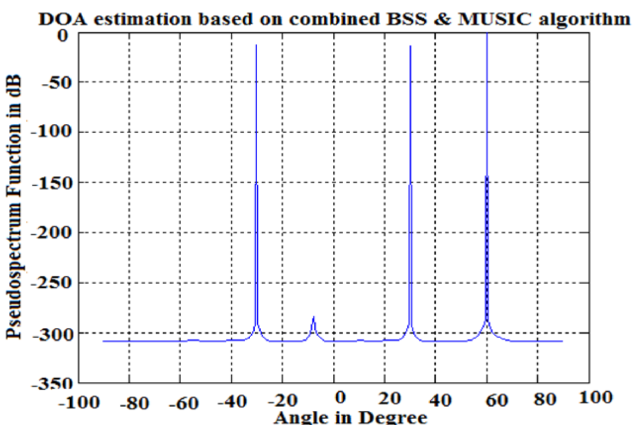

Figure 13. Spectrum for non-coherent signal using proposed algorithm for array sensors spacing λ.

The results for Direction of Arrival (DOA) determination by proposed BSS-MUSIC algorithm, after 1^{st}, 2^{nd} and 3^{rd} estimations, are tabulated in Table 1.

Table 1. AOA estimation using BSS-MUSIC algorithm

Input Angle (Degree)	Estimated AOA after 1st Estimation	Estimated AOA after 2nd Estimation	Estimated AOA after 3rd Estimation
-30	-30	-30	-30
30	30	30	30
60	60	60	60

The angles are calculated three times from the simulation results for input angles of -300, 300, 600 and other parameters have taken as number of snapshots = 200, number of sensors = 10, SNR = -15 dB. From the table, it is evident that the proposed approach detects the signals coming from different directions angular position accurately.

4. Conclusions

The proposed combined BSS-MUSIC algorithm for DOA estimation is showed excellent improvement over MUSIC algorithm resolution. Prior knowledge about the number of source signals is not needed in this method. The combination of BSS and MUSIC helps to remove the white noise from non-Gaussian source signals by BSS algorithm. Then MUSIC algorithm finds the DOAs of those non-Gaussian signals only. This combinational work impacts on the enhancement of resolution of the proposed algorithm. From the simulations results it is observed that remarkable improvement visible in the proposed approach when coherent signal are used, when noisy environment is considered. Also false peaks are reduced when array sensors spacing is greater than λ/2. The performance of this proposed approach is better for non-coherent signals compared to the MUSIC algorithm alone.

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