Direction of Arrival Algorithms for Mobile User Detection

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Abstract— Smart antennas involve processing of signals induced on an array of sensors such as antennas, microphones, and hydrophones. They have applications in the areas of Radar, Sonar, Medical Imaging and Mobile Communication. Smart antennas have the property of spatial filtering, which makes it possible to receive energy from a particular direction while simultaneously block energy from other direction. This property makes smart antennas a very effective tool in detecting, locating sources and finally forming the main beam in the look direction and nulls in the interfering signal directions. In this work, we studied the performance of various direction of arrival (DOA) algorithms for direction estimation of incoming source signals. Namely, Maximum Likelihood Method (MLM), Maximum Eigen Value (MEV) Method, Bartlett method, Multiple Signal Classification (MUSIC) and Estimation of Signal Parameters via Rotational invariant technique (ESPRIT) for detecting single and multiple mobile user. All the methods are simulated using MATLAB simulation software. The simulation results clearly show that the subspace methods outperform the classical methods.

Key words: DOA, ESPRIT, MLM, MEV, MUSIC, Smart Antenna

I. INTRODUCTION

Angle-of-arrival (AOA) estimation has also been known as spectral estimation, direction of arrival (DOA) estimation, or bearing estimation. Some of the earliest references refer to spectral estimation as the ability to select various frequency components out of a collection of signals. This concept was expanded to include frequency-wave number problems and subsequently AOA estimation. Bearing estimation is a term more commonly used in the sonar community and is AOA estimation for acoustic problems. Much of the state-of-the-art in AOA estimation has its roots in time series analysis, spectrum analysis, period grams, eigen structure methods, parametric methods, linear prediction methods, beamforming, array processing, and adaptive array methods. Some of the more useful materials include a survey paper by Godara [1], spectrum analysis by Capon [2], a review of spectral estimation by Johnson [3], an exhaustive text by Van Trees [4] and a text by Stoica and Moses [5].

Smart antennas involve processing of signals induced on an array of sensors such as antennas, microphones, and hydrophones. They have applications in the areas of Radar, Sonar, Medical Imaging and Mobile Communication. Smart antennas have the property of spatial filtering, which makes it possible to receive energy from a particular direction while simultaneously block energy from other direction. This property makes smart antennas a very effective tool in detecting, locating sources and finally forming the main beam in the look direction and nulls in the interfering signal directions.[6]-[8].

In recent years a substantial increase in the development of broadband wireless access technologies for evolving wireless internet services and improved cellular systems has been observed[9]-[11]. Because of them, it is widely foreseen that in the future an enormous rise in traffic will be experienced for mobile and personal communications systems. This is due to two facts, first is an increase in number of users and second is introduction of high bit rate data services. This becomes a major challenging problem for the service providers to solve [12-14]. There exist certain negative factors in the radiation environment contributing to the limit in capacity and one such negative factor is co-channel interference caused by increase in number of users. The other impairments contributing to the reduction of system performance and capacity are multipath fading, delay spread caused by signals being reflected from structures (e.g. buildings and mountains) and users traveling on vehicles[15]-[16]. The deployment of smart antennas (SAs) for wireless communications has emerged as one of the leading technologies for achieving high efficiency networks that maximize capacity and improve quality and coverage. Based on the objectives, the project problem is chosen as Simulation of Classical and Subspace Angle of Arrival Algorithms for Mobile User Detection which involves simulating the AOA algorithms and comparing their performances. There AOA algorithms are classified into two types Classical Methods and Subspace methods.

II. CLASSICAL METHODS

A. Maximum Eigen Value (MEV) Method

This method finds a power spectrum such that its Fourier transform equals the measured correlation subjected to the constraint that its entropy is maximized. For estimating DOA from the measurements using an array of sensors, the Maximum Eigen value(ME) method finds a continuous function $P_{MEv}(\theta) > 0$ such that it maximizes the entropy function

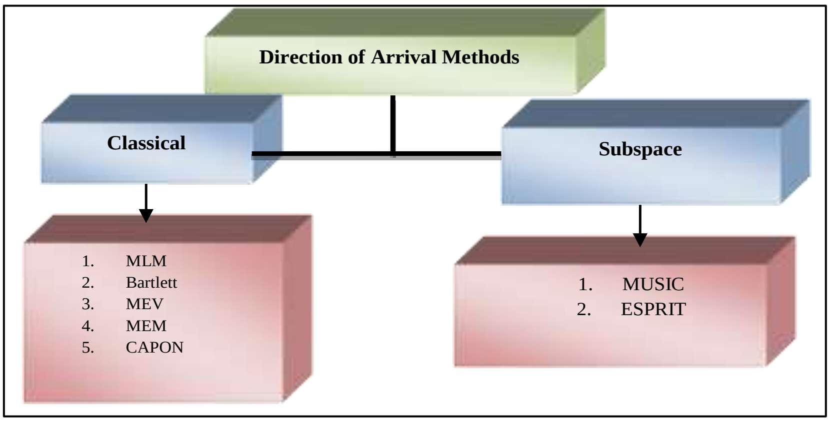


Fig. 1: Types of DOA algorithms

The Maximum Eigen Value (MEV) method power spectrum is given by

$$P_{MEV} = \frac{1}{a^H(\theta) E_S E_s^H a(\theta)} \qquad (1)$$

Where, $E_s = \max imum \quad eigen \ vectors$

$a^H(\theta) = Hermitian \quad transpose \quad of \ steering \quad vector$

B. Maximum Likelihood Method

The Maximum Likelihood estimate is known as a Minimum Variance Distortion less Response(MVDR). It is also alternatively a maximum likelihood estimate of the power arriving from one direction while all other sources are considered as interference. Thus the goal is to maximize the Signal to Interference Ratio (SIR) while passing the signal of interest undistorted in phase and amplitude. The source correlation matrix R_{ss} is assumed to be diagonal. This maximized SIR is accomplished with a set of array weights given by

$$w_{MVDR} = \frac{R_{xx}^{-1} a(\theta)}{a^H(\theta) R_{xx}^{-1} a(\theta)} \qquad (2)$$

Where, R_{xx}^{-1} is the inverse of un-weighted array correlation matrix R_{xx} and $a(\theta)$ is the steering vector for an angle θ. The MLM pseudo spectrum is given by

$$P_{MLM} = \frac{1}{a^H(\theta) R_{inv} a(\theta)} \qquad (3)$$

Where, $a^H(\theta)$ is the hermitian transpose of $a(\theta)$ and R_{inv} is the inverse of autocorrelation matrix.

III. SUBSPACE METHOD OF ANGLE OF ARRIVAL ALGORITHMS

In this section, the high resolution DOA algorithms namely MUSIC and ESPRIT algorithms are discussed.

A. Multiple Signal Classification (MUSIC)

MUSIC [1]–[4] is an acronym which stands for multiple signal Classification. MUSIC promises to provide unbiased estimates of the number of signals, the angles of arrival and the strengths of the waveforms. MUSIC makes the assumption that the noise in each channel is uncorrelated making the noise correlation matrix diagonal. MUSIC is an acronym which stands for Multiple Signal Classification. From array correlation matrix *R,* we can find P eigen vectors associated with the signals and (N-P) eigenvectors associated with the noise.

Let us assume the noise between each array element is zero mean , variance σ^2 is Gaussian white noise and N signal vectors are received. Then the estimation of the covariance matrix is

$$R_x = \frac{1}{N}\sum_{i=1}^{N} X(i) X^H(i) \qquad (4)$$

Let us decompose the above mentioned covariance matrix to eigenvalue as,

$$R_x = [AR_s A^H] + 2\sigma^2 I \qquad (5)$$

Where, σ^2 is the noise variance, and 'I' is an identity matrix and 'A' is matrix of steering vector size N x N.

Let us obtain the noise matrix E_n, by taking M associated eigenvalue and P associated eigenvector which are equal to the number of signal D as signal part of space; M-D eigenvalues and eigenvectors, as noise part of space.

$$E_n = [\bar{e}_1 \quad \bar{e}_2 \quad \ldots\ldots\ldots \quad \bar{e}_P] \qquad (6)$$

The Pseudo-spectrum, a function that gives an indication of the direction of arrival based upon maximum versus angle for MUSIC is given as,

$$P_{MU}(\theta)=\frac{1}{|\; a(\theta)^{H}\; \bar{E}_N\; \bar{E}_N^{H}\; \bar{a}(\theta)\;|} \qquad (7)$$

E_N is the noise eigen vectors

This power spectrum is computed by keeping E_N constant and varying ‘θ’ in the range $-\pi/2<\theta+0.001<\pi/2$.

IV. RESULTS & DISCUSSION

The specifications and requirements of the design are summarized in the Table 1.

Sl. No.	Parameters	Values
1	Type of antenna array	Uniform Linear Array
2	Number of array elements	Variable (8, 10, 30, 70 ,100)
3	Pass band Frequency range	(3-4) GHz
4	Voltage range for AOA	(1-5)v
5	Direction range for AOA	0 to $\pm$ 90^0
6	Simulation Language	MATLAB
7	Simulation Version	MATLAB 2008a

Table 1: parameters user for simulation

In this section simulation result of various DOA algorithms; Beam forming are obtained using MATLAB Here the DOA algorithms namely; MLM, MEV, ESPIRIT and MUSIC are simulated using MATLAB.

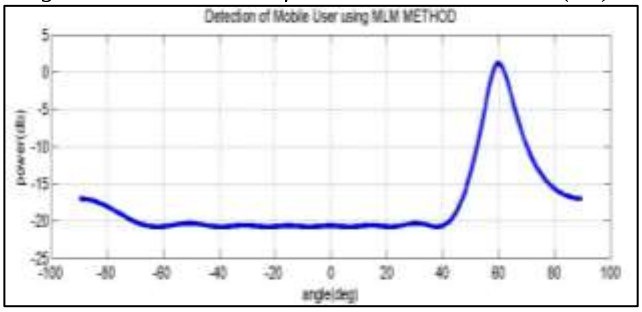
The different cases of simulations are

- Case 1: Single Source Simulation for less antenna elements (AE);
- Case 2: Single Source Simulation for more AE;
- Case 3: Closely spaced sources with less number of AE;
- Case 4: Widely spaced sources with more number of AE;
- Case 5: Closely spaced sources with more number of AE;
- Case 6: Widely spaced sources with less number of AE

A. *Simulation of DOA Algorithms for single source using less Antenna Elements*

In this case, antenna elements are 8, amplitude is 1v and DOA= [20º, 60º, 75º, 30º] for MEV, MLM, MUSIC and ESPIRIT respectively. Figure 2 shows the simulated result of this case.

1) Case 1: Single Source Simulation for less antenna elements (AE)



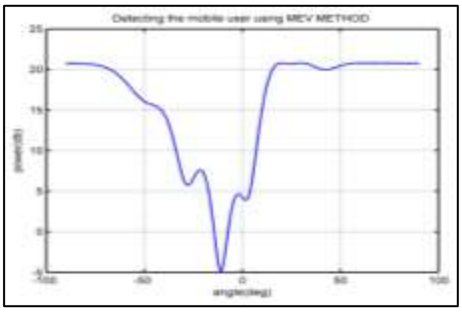
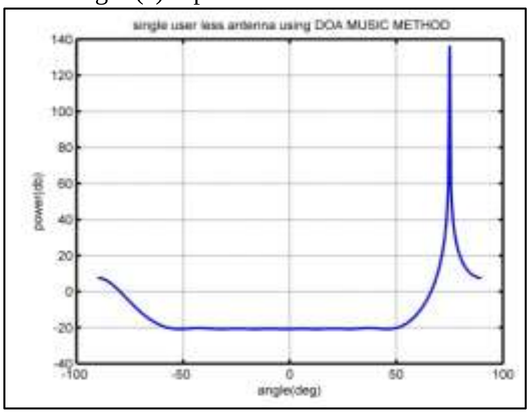


Fig. 2(a): Spectrum of MLM

Fig. 2(b): Spectrum of MEV



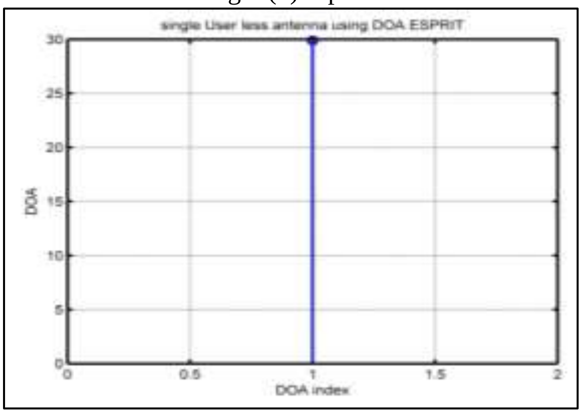


Fig. 2(c): Spectrum of Music

Fig. 2(d): Spectrum of ESPIRIT

2) Case 2: Single Source using more Antenna Elements

In this case, antenna elements are 100, amplitude is 4v and DOA= [60º, 45º, 75º, 30º] for MEV, MLM, MUSIC and ESPIRIT respectively. Figure 3 shows the simulated result of this case.

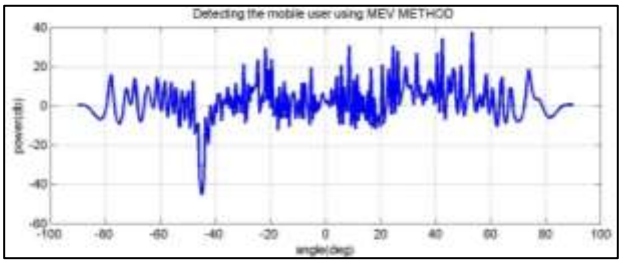


Fig. 3(a): Spectrum of MLM

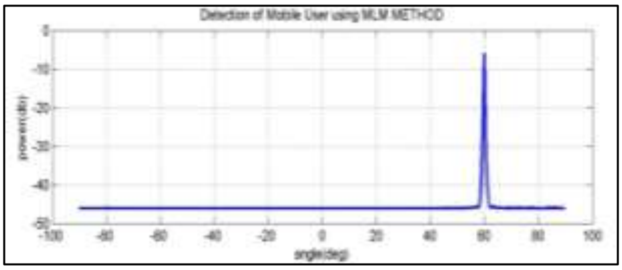


Fig. 3(b): Spectrum of MEV

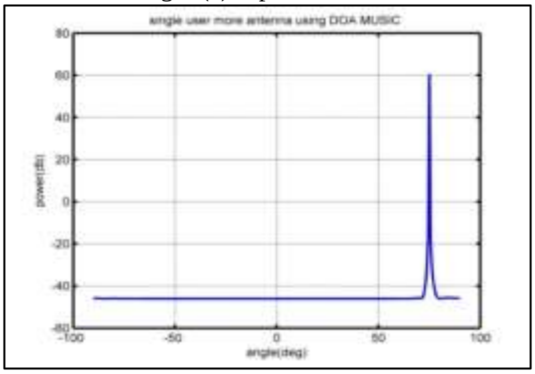


Fig. 3(c): Spectrum of MUSIC

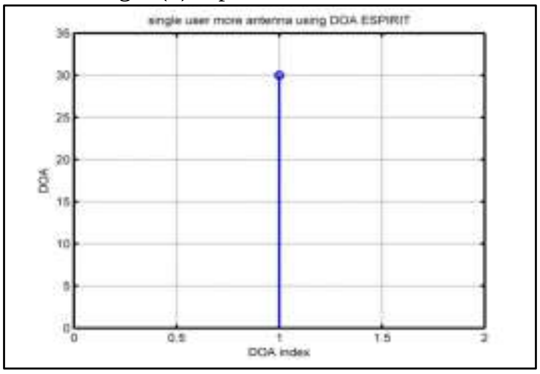


Fig. 3(d): Spectrum of ESPIRIT

3) Case 3: Widely spaced multiple sources with less number of antenna elements

In this case, antenna elements are 10, number of mobile users are 3, amplitudes are [1, 2, 3] v and three directions with DOA= [10º 45º 60º] for all methods. Figure 4 shows the simulated result of this case.

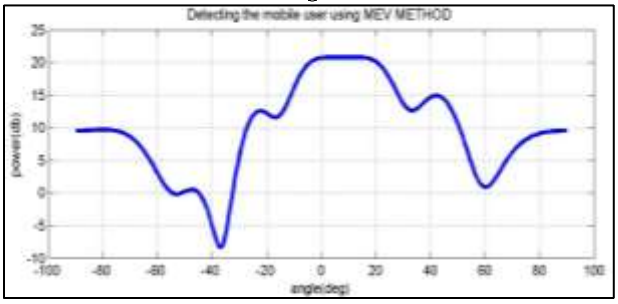


Fig. 4(a): Spectrum of MLM

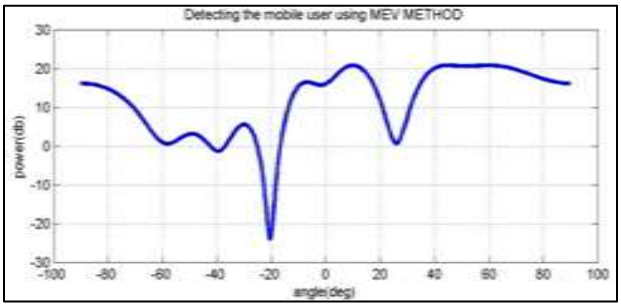


Fig. 4(b): Spectrum of MEV

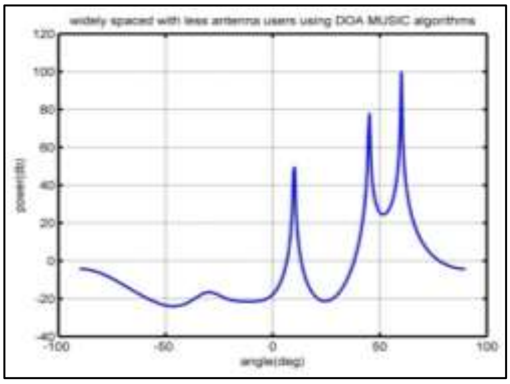


Fig. 4(c): Spectrum of MUSIC

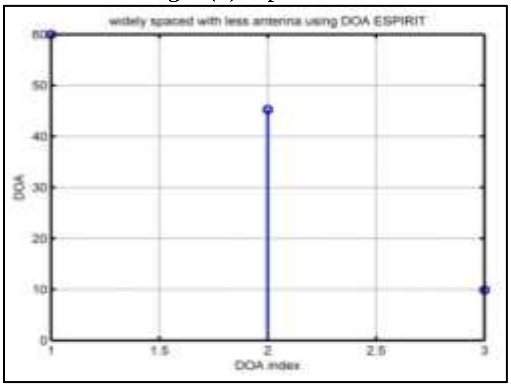


Fig. 4(d): Spectrum of ESPIRIT

4) Case 4: Widely spaced multiple sources with more number of antenna elements

In this case, antenna elements are 100, number of mobile users are 3, amplitudes are [1,2,3]v and three directions with DOA= [10º 45º 60º] for all methods. Figure 5 shows the simulated result of this case.

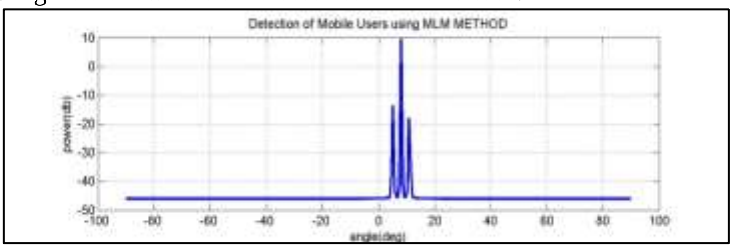


Fig. 5(a): Spectrum of MLM

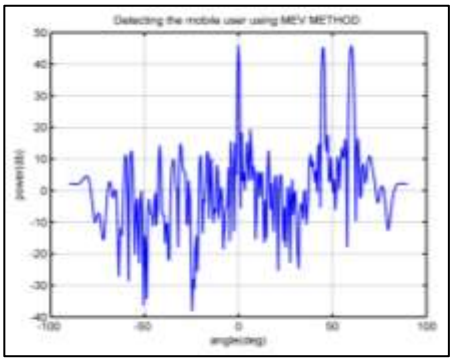


Fig. 5(b): Spectrum of MEV

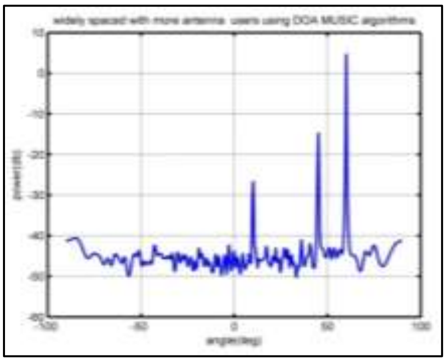


Fig. 5(c): Spectrum of MUSIC

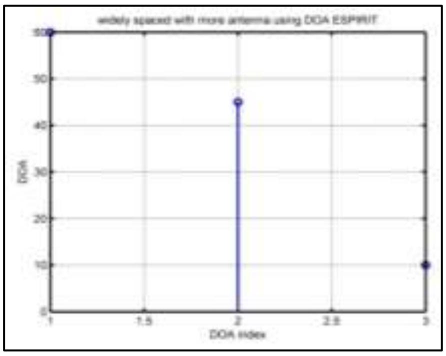


Fig. 5(d): Spectrum of ESPIRIT

5) Case 5: Closely spaced multiple sources with less number of antenna elements

In this case, antenna elements are 8, number of mobile users are 3, amplitudes are [1,2,3]v and three directions with DOA= [5^o 8^o 10^o] for all methods. Figure 6 shows the simulated result of this case.

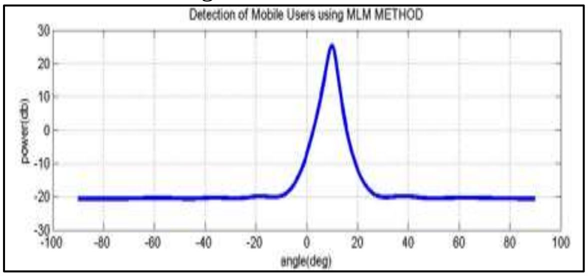


Fig. 6(a): Spectrum of MLM

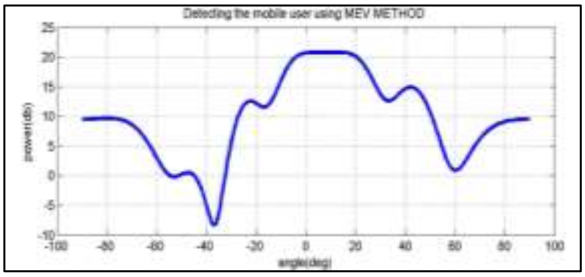


Fig. 6(b): Spectrum of MEV

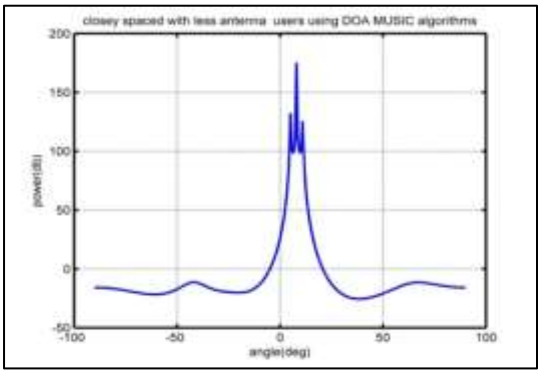


Fig. 6(c): Spectrum of MUSIC

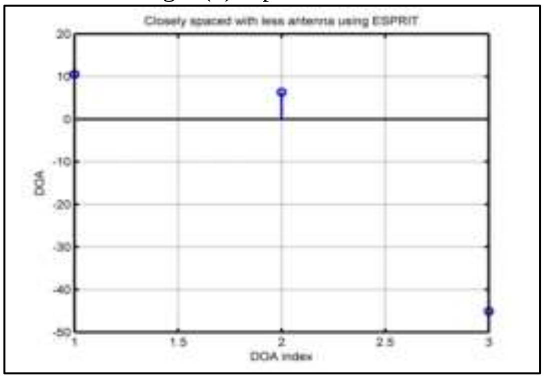


Fig. 6(d): Spectrum of ESPIRIT

6) Case 6: Closely spaced multiple sources with more number of antenna elements

In this case, consider antenna elements are 8, number of mobile users are 3, amplitudes are [1, 2, 3] v and three directions with DOA= [5^o 8^o 10^o] for all methods. Figure 7 shows the simulated result of this case.

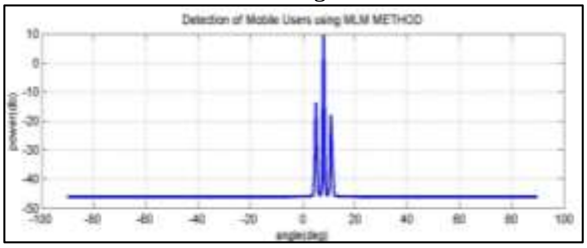


Fig. 7(a): Spectrum of MLM

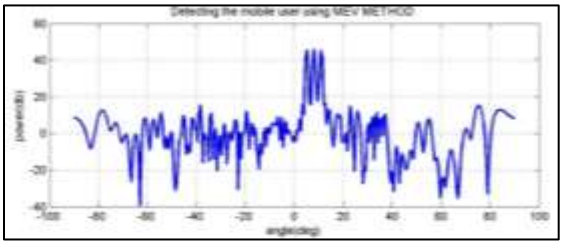


Fig. 7(b): Spectrum of MEV

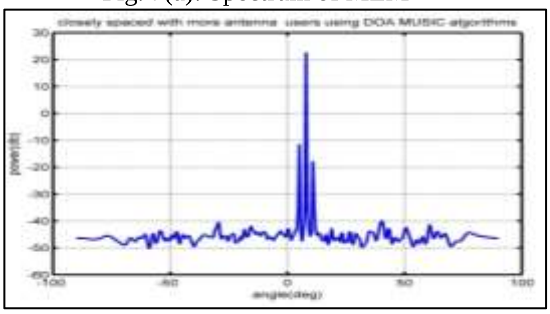


Fig. 7(c): Spectrum of MUSIC

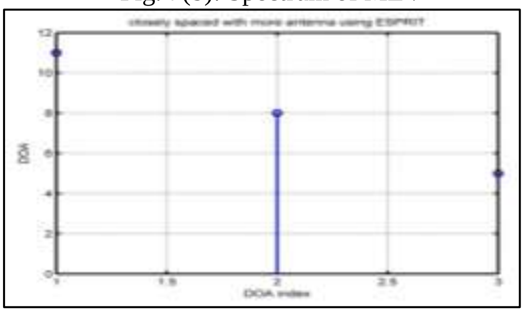


Fig. 7(d): Spectrum of ESPIRIT

Let compare all the methods using antenna elements = 8, number of mobile users are 3, amplitudes are [1, 2, 3] v and three directions with DOA= [20º 45º 60º] for all methods. Figure 8 shows the comparison of DOA methods. Figures 8 and 9 show the comparison of algorithms.

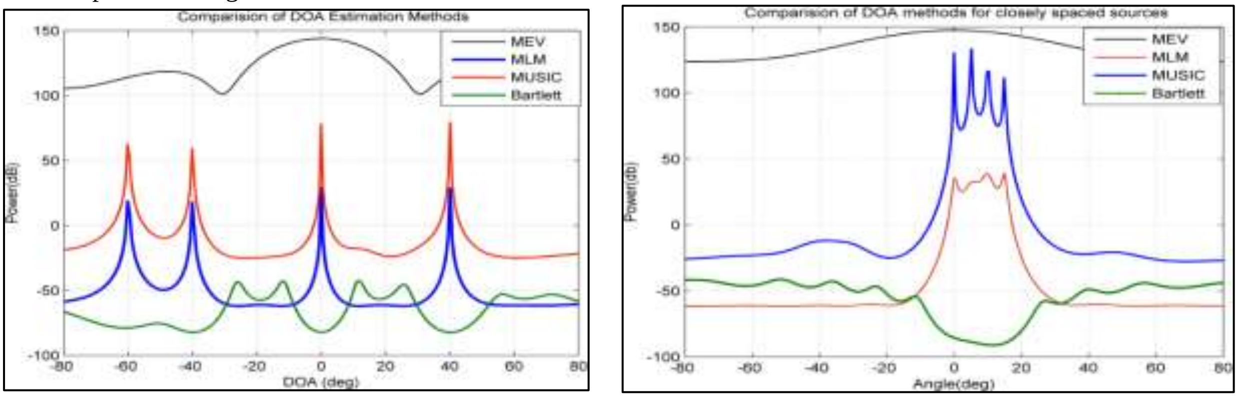


Fig. 8: Comparison of classical and subspace method for DOA estimation.

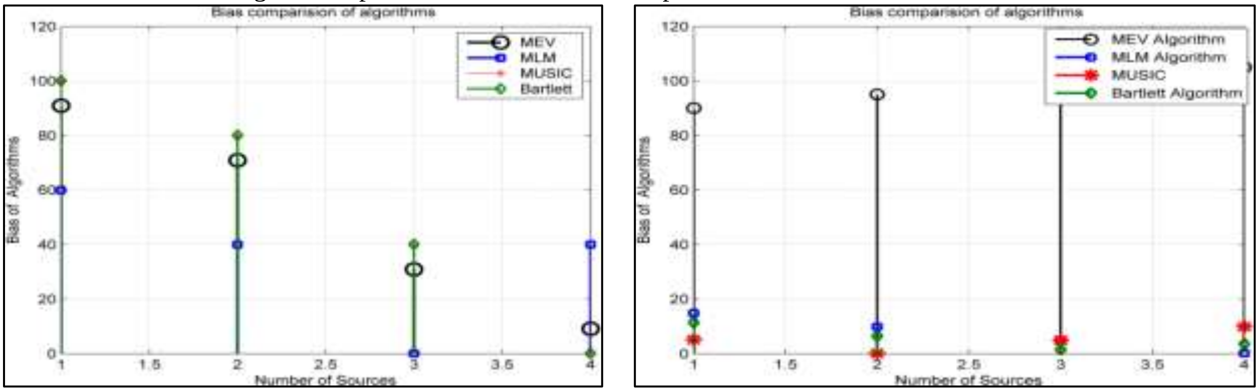


Fig. 9: Bias comparison of classical and subspace method for DOA estimation.

V. CONCLUSION

In this paper, we studied the different DOA algorithms for smart antenna system. All the methods are simulated using MATLAB software. The importance of each method for mobile communication is explained using different conditions.

In this paper, three classical DOA estimation methods, namely, MLM, MEV and Barlett and two popular subspace methods, namely, MUSIC and ESPRIT are studied. Simulation results clearly show that the subspace based methods outperforms the classical methods. The MUSIC algorithm shows the best accuracy but it fails under highly correlated signals. The ESPRIT shows lesser accuracy but due to its construction it assumes no prior correlation between signals.

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