Angle of Arrival Estimation for Smart Antenna using variations in MUSIC algorithms

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***Abstract*— To enhance the performance of wireless system gain should be increased in the desired signal direction. To increase the gain in desired direction smart antenna system is used. Smart antenna system has capability to adjust its radiation pattern in the direction of required signal and nulls in the direction of undesired signals. Angle of arrival(AOA) estimation means determining the direction of an incoming incident signal from required direction. Smart Antennas are phased array antennas having smart signal processing algorithms for finding the AOA of the required signal, which in turn is used to calculate beam-forming vectors to form the radiation pattern in the direction of signal. This paper introduces a study & implementation of algorithms for DOA estimation which are Minimum Variance Distortionless Response (MVDR) and Multiple Signal Classification (MUSIC) in terms of distance between adjacent elements, number of elements and number of snapshots.**

Keywords— smart antenna, AOA, MVDR, MUSIC.

I. Introduction

A. Smart Antenna System:

A smart antenna system includes multiple antenna elements with a signal processing capability to generate its radiation and/or reception pattern automatically in response to the signal environment. A phased array antenna uses an array of simple antennas, such as omni-directional antennas, and combines the signal induced on these antennas to form the array output. Each antenna forming the array is known as an element of the array. The direction where the maximum gain would appear is controlled by adjusting the phase between different antennas.

The phases of signals induced on various elements are adjusted such that the signals due to a source in the direction where maximum gain is required are added in phase. This results in the gain of the array which is equal to the sum of the gains of all individual antennas. The term adaptive antenna is used for the phased array when the gain and the phase of the signals induced on different elements are changed before combining to adjust the gain of the array in a dynamic fashion, as required by the system. In a way, the array adapts to the situation, and the adaption process is normally under the control of the system [1]. A block diagram of a typical adaptive antenna array system is shown in Fig. 1.

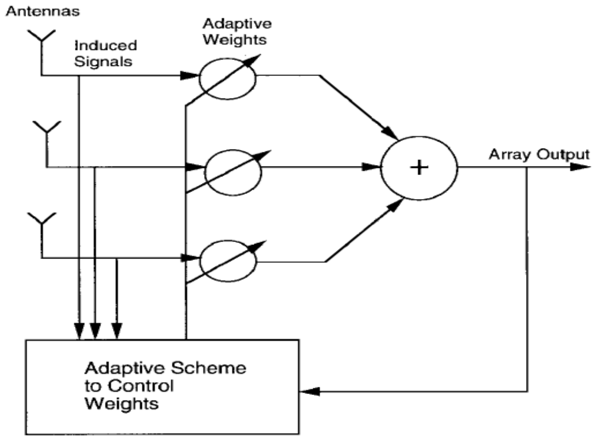

Fig. 1.adaptive antenna array system

Phased arrays will have a greater gain potential than switched lobe antennas because all elements can be used for diversity combining [1][2].

The paper is divided as follows: Section II illustrates the MUSIC and modified MUSIC algorithms followed by the description of MVDR in Section III. Sections II & III show a performance analysis of the algorithms with respect to number of incident signals, effect of signal parameters, inter-element spacing, and number of snapshots. Section IV presents the conclusion.

II. MUSIC algorithm

MUSIC algorithm was first described by Schmidt [2]. It is used for approximating the noise subspace which is from the correlation matrix on which M array steering vectors are projected. Direction vectors represent the required steering vectors. Also, they signify the main response of an ideal array to the sources of the signal. Direction vectors are used to derive the signal sources that are orthogonal to the noise subspace [2].

A. Assumptions for implementation:

1) signal source assumption:

Assume that the signal source is a point source, it is a source of radiation with very small area but having concentrated output. This helps in unique determination of the signal source with respect to the direction of the array.

2) Narrowband signal:

That means that the signal bandwidth is far less. If the signal is narrowband all the array elements in the array can receive a signal at the same time.

3) Array assumptions:

Assume the array is located in the far field region of the source, the wave is projected as a plane wave. Assuming linear array and every element has the same properties, the position is exact and perfect, the array element channel and amplitude and phase follow some relation consistently. This assumption ensures that the array elements and their channel have zero error.

4) Noise assumptions:

We assume the noise between each antenna array element to be zero, variance σ2 which represents Gaussian white noise. This is statistically independent of noise between array elements.

B. Input Variables

- Direction of arrival doa=[30 50]/180*pi
- Snapshots N=200
- Frequency w=[pi/4 pi/3]
- Number of array elements M=4
- The number of signals P=length(w)
- Wavelength λ=150
- Element spacing d= λ /2
- SNR=20
- Phase difference matrix D = zeros(P,M)

C. Mathematical Analysis

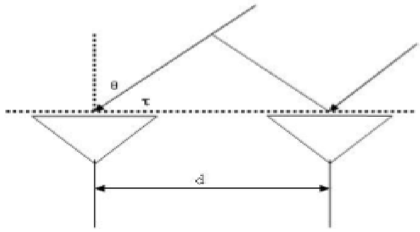

Fig.2 smart antenna array

In the above figure,
d= the distance between the array elements,
c = the speed of light,
θ = the incident angle of the far field signal,
τ = the time delay of the array element.

- The signal received by the antenna due to the path difference is
  $\tau = d\sin\theta / c$,

- Thus one can obtain the phase difference between the array elements as
  $$\varphi = \exp(-j\omega\tau)$$
  $$= \exp(-j\omega d\sin\theta / c)$$
  $$= \exp(-j2\pi d\sin\theta . f / \lambda f0)$$

where fo is the centre frequency.

- For narrow band signals, the phase difference is
  $$\varphi = \exp(-j2\pi d\sin\theta / \lambda),$$

where λ is the wavelength of the signal.

Steps for Basic MUSIC algorithm:

- The first step is to generate a phase difference matrix D with P rows and M columns.
- Sample the data with no. of snapshots N.
- Add White Gaussian noise.
- Calculate the covariance matrix R=X*X'
- Calculate Eigen values & Eigen vectors of R.
- Plot Output Spectrum

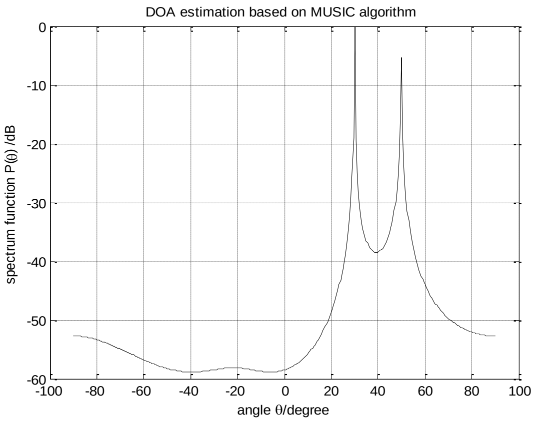

Fig. 3. DOA estimation based on Basic MUSIC algorithm

Steps for Modified MUSIC algorithm:

- Generate signal matrix and add White Gaussian noise to it.
- Calculate data Covariance matrix.
- Eliminate redundancy with the help of anti diagonal identity matrix.
- Find the eigenvalues and eigen vectors.
- Plot spatial spectrum.

Before plotting the spectrum if we add one step to eliminate the redundancy accuracy increases and the graph is as shown in fig.4 for the input angle of 50^0 and 80^0. This is Modified MUSIC Algorithm.

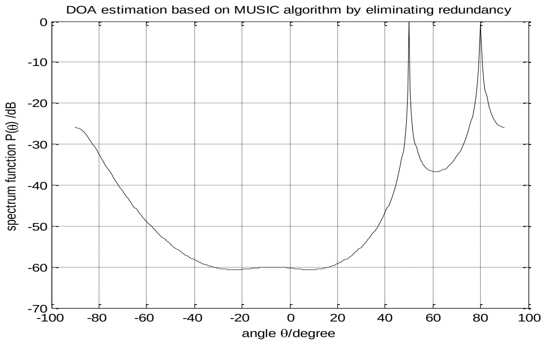

Fig.4. DOA estimation based on Modified MUSIC algorithm by eliminating redundancy

- Effect of variation in No. Of Snapshots N

As the number of snapshots increases resolution increases & spectrum becomes narrow. Fig.5 shows the output spectrum for variation of no. of snapshots i.e. N=10, N=30 & N=300. The simulation is carried out in MATLAB for the input angle of 40^0 and 80^0.

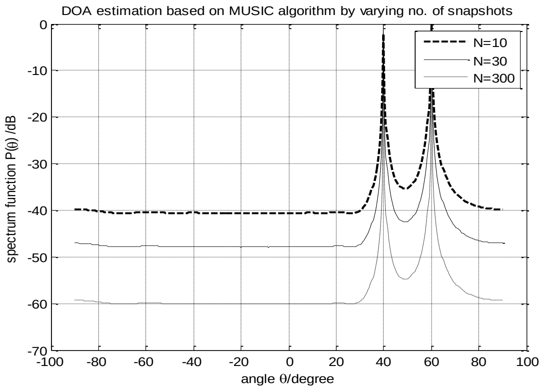

Fig.5 DOA estimation based on MUSIC algorithm by varying no. of snapshots

- Effect of variation in No. Of Array Elements M

Fig.6 shows output for variation in number of array elements M=10, M=50 and M=100. The simulation is carried out in MATLAB for the input angle of 20^0 and 60^0. As number of array element increases accuracy of DOA estimation increases.

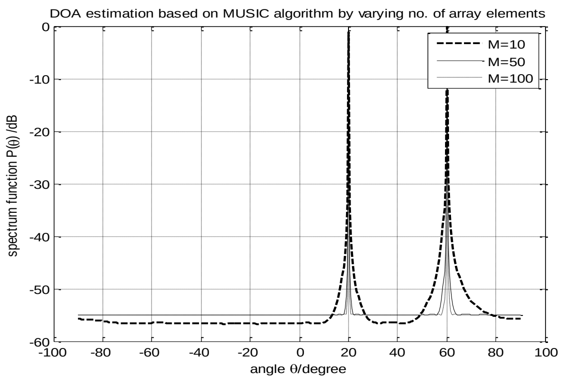

Fig. 6. Effect of variation in No. Of Array Elements M on MUSIC algorithm

- Output for different values of spacing between array elements 'd'

As the d decreases, the main lobes become broader. This reduces the resolution of the MUSIC algorithm as shown in fig.7

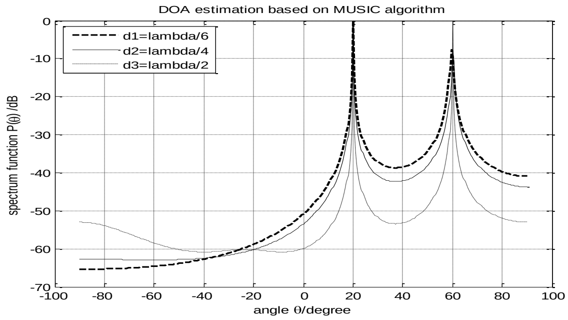

Fig. 7. Effect of variation in values of d on MUSIC algorithm

- Signal-to-Noise Ratio (SNR)

As the SNR decreases, the main lobes become broader. This reduces the resolution of the MUSIC algorithm. Hence, the signal to noise ratio must be high for better DOA estimation. Fig. 8 shows output for different values of signal to noise ratio.

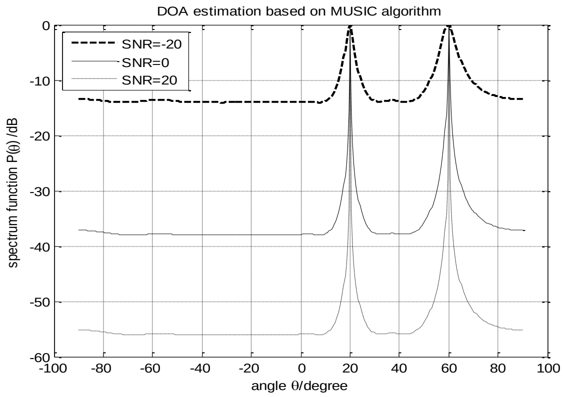

Fig 8. Effect of variation in SNR on MUSIC algorithm

- DOA Spacing

If the difference between the angle of incidence of the incident beam is less then the main lobes in the spectrum will also be closely spaced. DOA spacing plays an important role in determining the resolution of the MUSIC algorithm. Fig.9 shows output for different values of DOA spacing.

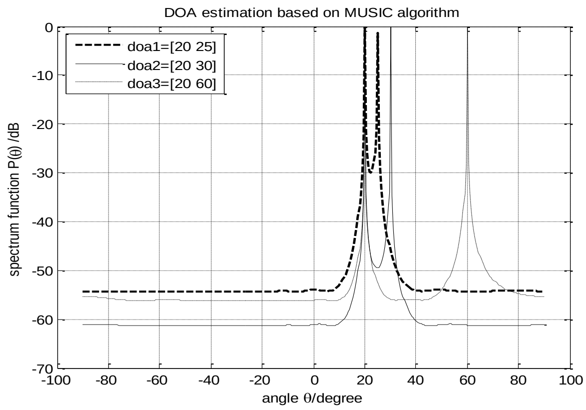

Fig. 9. Effect of variation in DOA spacing on MUSIC algorithm

III. MVDR algorithm for DOA estimation

The MVDR algorithm used for approximating the noise subspace which is from the correlation matrix [4]. Direction vectors represent the steering vectors. Also, they signify the main response of an ideal array to the sources of the signal. Direction vectors are used to derive the signal sources that are considered orthogonal to the noise subspace [4].

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4) Noise assumptions:

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Input Variables

- Velocity c=1500
- Snapshots snap=1024
- Frequency fo=6000
- Sampling Frequency fs=65536
- Number of array elements M=8
- Wavelength λ= c / fo
- Element spacing d=λ/2
- Direction of Arrival=theta=76 degree
- Output Spectrum using MVDR algorithm

Fig.10 & Fig.11 shows comparison of MUSIC & MVDR algorithm for input angle of 76^0.

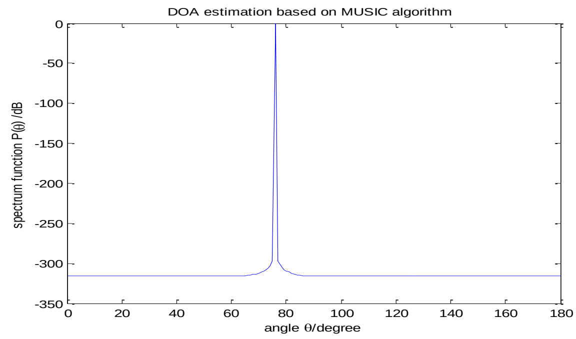

Fig. 10. Output Spectrum using MUSIC

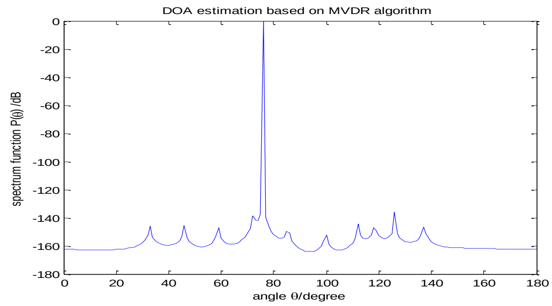

Fig.11. Output Spectrum using MVDR

Factors affecting MVDR Algorithm:

- **Number of array elements:** The number of array elements in basic arrays can affect the estimation performance for MVDR algorithm. Generally speaking, if array parameters are the same, more the number of array elements, better is the estimation performance for MVDR algorithm as shown in fig.12.

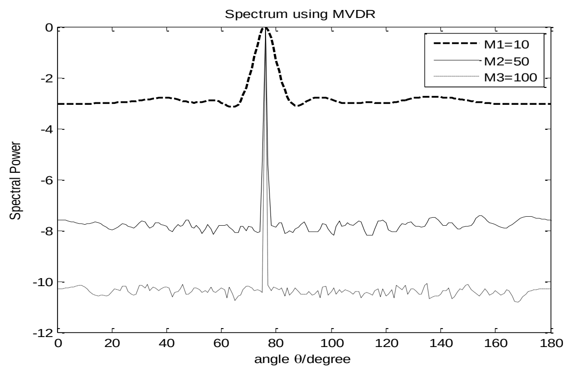

Fig. 12. Output Spectrum using MVDR

- **Snapshots:** In the time domain, the number of snapshots is defined as the number of samples. In the frequency domain, the number of snapshots is defined as the number of time sub segments of discrete Fourier transform (DFT). The more the number of snapshots, better is the estimation performance for MVDR algorithm as shown in fig.13.

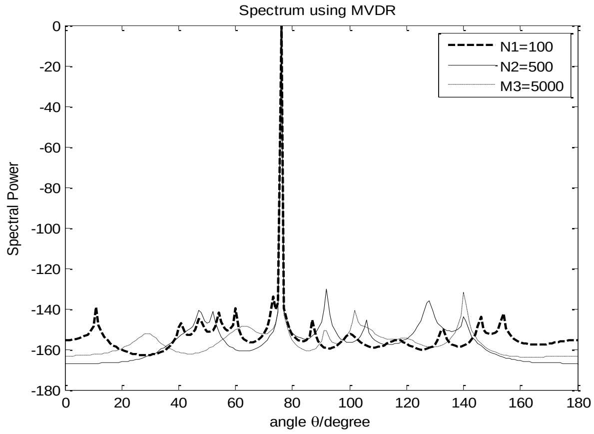

Fig.13. Output Spectrum using MVDR for number of snapshots

There are many algorithms proposed to estimate the Direction-of-Arrival, there must be proper comparison between these algorithms, specifically the two-dimensional estimation algorithms. Comparison of DOA algorithms is necessary for the proper selection of an algorithm for future wireless systems and technologies. In this paper we have presented the evaluation of two sample Direction-of-Arrival estimation algorithms i.e. MUSIC & MVDR.

IV. CONCLUSION

MUSIC gives the direction of arrival of the desired signal accurately when the signals are not closely spaced. On the other hand MVDR is used to find the direction of closely separated signals accurately that helps in maximizing the signal to noise and interference ratio of many antennas.

The performance of MUSIC & MVDR improves with more antenna array elements. Increase in the number of data snapshots results in a high detection accuracy of desired signals. As SNR decreases, main lobes becomes broader. Hence SNR must be high for better detection of angle.

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