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Performance Analysis of MUSIC DOA Algorithm Estimation in Multipath Environment for Automotive Radars

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Abstract: The main focus of the adaptive array smart antennas is to create such a beamforming system in which the main beam is directed towards the desired signal and the nulls is directed towards the interferers. These type of adaptive smart antennas is used widely in Automotive Radars. Various DOA estimation algorithms is used to achieve such objectives. But the challenge is such that we have a fixed number of snapshots available in such application. So it is a difficult task to achieve our desired results while at the same time keeping the restriction of snapshots availability. Here in this paper we will implement the MUSIC algorithm and will show the superiority of such algorithm over another ones being done in the literature. It is shown that by implementing MUSIC algorithm in multipath Environment we obtain higher angular resolutions and hence it is explored in much more detail. The algorithm is implemented by varying various parameters of smart antenna systems. The simulation results shows that MUSIC is more accurate and stable for two closely spaced signals.

Keywords: MUSIC (MUltiple SIgnal Classification) algorithm; DOA estimation; beamforming; multipath environment; automotive radars; smart antennas.

1. Introduction

The adaptive array smart antenna is one of the most promising technique for increasing the capacity of 3G and even 4G wireless communication. The smart antennas technology uses the array of antennas concept in order to enhance power peaks at the desired direction of interest while nulls towards the interferers. The radiation pattern in smart antenna system is changed by adjusting the amplitude and relative phase on different elements. Each source creates many multipath components at the receiver. If several transmitters are operating simultaneously, and hence receive array must be able to estimate the angles of arrival in order to decipher which emitters are present and what are their angular locations. This information in turn can be used by the smart antenna to eliminate or combine signals for greater fidelity or suppress interferers to improve the capacity of cellular mobile communication [1].

In array signal processing Direction of Arrival estimation (DOA) [2], [3] stands for estimating the angles of arrivals of received signals by an array of antennas. One of the important step in many sensors systems, i.e. Measure Electronic Surveillance (MSE), radar, sonar, submarine acoustics, optical interferometry, geodesic location, etc.

Various DOA Estimation Algorithm has been proposed such as Capon, Barlett, Min-Norm, MUSIC, Root MUSIC, and ESPRIT (Estimation of Signal Parameters via Rotational Invariance

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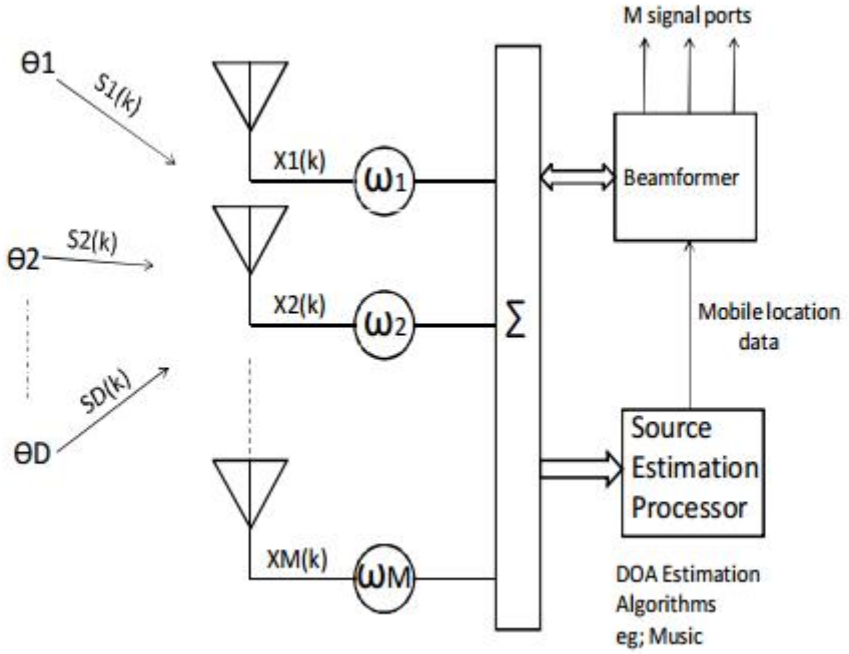
Technique). The high resolution and accurate methods are MUSIC and ESPRIT algorithms which are widely used in the design of smart antennas system. Implementation of MUSIC algorithms in smart antennas add a new possibility of user separation by space through space division multiple access (SDMA) [4].

2. MUSIC

MUSIC stands for Multiple Signal Classifier. MUSIC is one of the well-known high resolution DOA Algorithm. The Algorithm is able to find DOAs of multiple sources. This highly spatial algorithm requires few antennas with high accuracy as compared to other ones. The algorithm can be implemented for narrowband signal sources. The MUSIC algorithm is based on exploiting the Eigen structure of input covariance matrix. The supposition here is such that noise in each channel is highly uncorrelated which makes the correlation matrix diagonal.



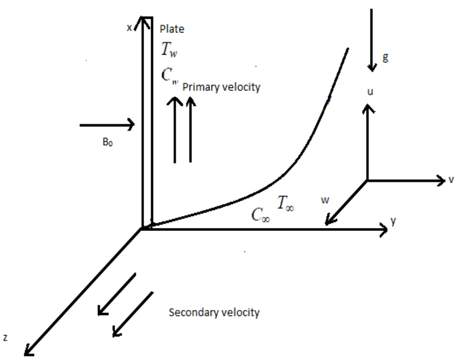


Figure 1. M Element Antenna array with D arriving sources

Consider the number of incoming signals impinging on M element array is D, the number of signal eigenvalues and eigenvectors is D and number of noise eigenvalues and eigenvectors is M-D. The array correlation matrix with uncorrelated noise and equal variances is then given by

$$R_{xx} = 1/K \sum_{K-1}^{K} x(k) * x(k)^{H} \quad (1)$$

where A= [a(θ$_1$) a(θ$_2$) --- a(θ$_D$)] is M x D array steering matrix, H = “Hermitian” means conjugate transpose and I is identity matrix

$R_{ss} = [s_1(k)\ s_2(k)\ ----\ s_D(k)]^T$ is D x D source correlation matrix

R_{xx} has D eigenvectors associated with the incoming signals and M – D eigenvectors associated with the noise. We can then construct the M x (M-D) subspace spanned by the noise eigenvectors such that.

$$VN = [v_1\ v_2\ -------\ v_{M-D}] \quad (2)$$

The noise subspace eigenvectors are orthogonal to array steering vectors at the angles of arrivals θ_1, θ_2, θ_D and the MUSIC Pseudo spectrum is given by the relation.

$$P_{MUSIC(\theta)} = 1/abs((a(\theta)^H * V_N * V_N^{H*} a(\theta)) \quad (3)$$

However for the case when signal sources are coherent or noise variances vary the resolution of MUSIC diminishes. To overcome it we must collect several samples of received signal plus noise, suppose the ergodicity and estimation of the correlation matrices via time averaging as

$$R_{xx} = 1/K \sum_{K-1}^{K} x(k) * x(k)^{H} \quad (4)$$

$$R_{xx} = A^* R_{ss} {}^* A^H + A^* R_{sn} + R_{ns} {}^* A^H + R_{nn} \quad (5)$$

The MUSIC Pseudo spectrum using equation (3) with time averages now provides high angular resolution for coherent signals.

3. Problem statement

Generally, at the receivers’ the signal received is a superposition of multipath components combined with interferers signals along with the introduce noise at the channel. Thus, detection of the Signal-of-interest (SoI) is a tough task. The Smart Antenna System embeds the antenna elements and the digital signal processing unit which enables it to form a beam to a desired direction taking into account the multipath signal components. Hence, Signal to-Interference-and-Noise Ratio (SINR) can be improved by creating nulls in the direction of interferers or in the direction of Signal-of-no-Interest (SONI) [5-7] and overall spectrum efficiency can be increased. Now to form beam in the desired or SOI direction, estimate of the number of plane waves arriving at the antenna array and the angle at which the waves are incident on antenna array is essential. The angle of wave incidence on antenna array is calculated using Direction of Arrival (DOA) estimation algorithms [5-7]. Thus the performance of Smart Antenna System greatly depends on the performance of its DOA estimation algorithm implemented.

Different DOA Estimation Algorithms has been used by different authors for this purpose such as Capon, Barlett, ESPRIT and MVDR (Minimum variance distortion less response) [8-12]. These authors have implemented these algorithms but in case when the problem of two closely spaced signals such as AOA of 1st incoming signal is 28 degree and 2nd is 32 degree than they increase the number of snapshots and array elements together. If they try to fix one parameter they fail to resolve the two closely spaced signals. However in many practical applications, for example, in sonar processing, due to physical constraints, e.g., sound speed, only a very small number of snapshots are available. Another application in which the number of available snapshots is a critical parameter is the DOA estimation in automotive radar systems. So we have proposed the MUSIC algorithm for such a systems and that can be investigated in further detail in the simulation section. For such a problem we fix either one of the parameter which is critical in the particular application and vary another one and achieve the desired results of resolving the two closely spaced signals. The implemented DOA estimation is very powerful and can be easily used in the future SDMA systems for such applications as a module of Parameter estimator.

4. Simulation results

The MUSIC DOA Estimation Algorithm has been simulated in this section using MATLAB.

4.1. Response for fixed array elements and varied snapshots

Figures 2 and 3 clearly show the MUSIC spectrum for uniform linear array with fixed number of array elements while varying number of snapshots. The AOAs are supposed to be 30, 35, 60 degrees. Spacing between elements is assumed to be 0.5λ. Figure 2 shows that the MUSIC spectrum cannot resolve the two closely spaced signals but when the number of snapshots are increased from 20 to 50 keeping the fixed array elements supposed to be 8 elements, then the MUSIC spectrum takes the form of sharper peaks in which angular resolution is improved. While at the same time keeping the restriction that an automotive radars the maximum number of snapshots available is 50.

The number of signal snapshots used to generate realistic signal model is a key factor in the realization of practical antennas. The music spectrum obtained for snapshots equal to 20 and 50. Increased snapshots leads to sharper MUSIC spectrum peaks indicating more accurate detection and better resolution.

4.2 Response for fixed snapshots and varied array elements

Figures 4 and 5 show the MUSIC spectrum for linear array with uniform and fixed number of Snapshots while varying number of array elements. The AOAs are supposed to be 30, 35, 60 degrees. Spacing between elements is assumed to be 0.5λ. Fig.4 shows that the MUSIC spectrum cannot resolve the two closely spaced signals but when the number of array elements are increased from 4 to 8 keeping the fixed no: of snapshots 30, then the MUSIC spectrum takes the form of sharper peaks where angular resolution is enhanced. While at the same time we have kept the maximum condition of snapshots for an automotive radars.

The music spectrum is also obtained for array elements from 4 to 8. Increased array elements leads to sharper MUSIC spectrum peaks which show more accurate detection and better resolution. But increased array elements in a system make it more and more complex because the computation increases in such a way that to identify and measure such system is very difficult.

4.3. For varying no of snapshots and no of array elements

Figures 6 and 7 show the MUSIC spectrum for linear array with varying number of snapshots and array elements. The AOAs are supposed to be 30, 35, 60 degrees. Spacing between elements is assumed to be 0.5λ. Figure 6 shows that the MUSIC spectrum clearly resolve the two closely spaced signals but when the number of array elements and snapshots are increased further from 4 to 8 elements and 30 to 50 simultaneously, then the MUSIC spectrum takes the form of further sharper peaks in which angular resolution is much more improved. While at the same time keeping the restriction that an automotive radars the maximum number of snapshots available is 50.

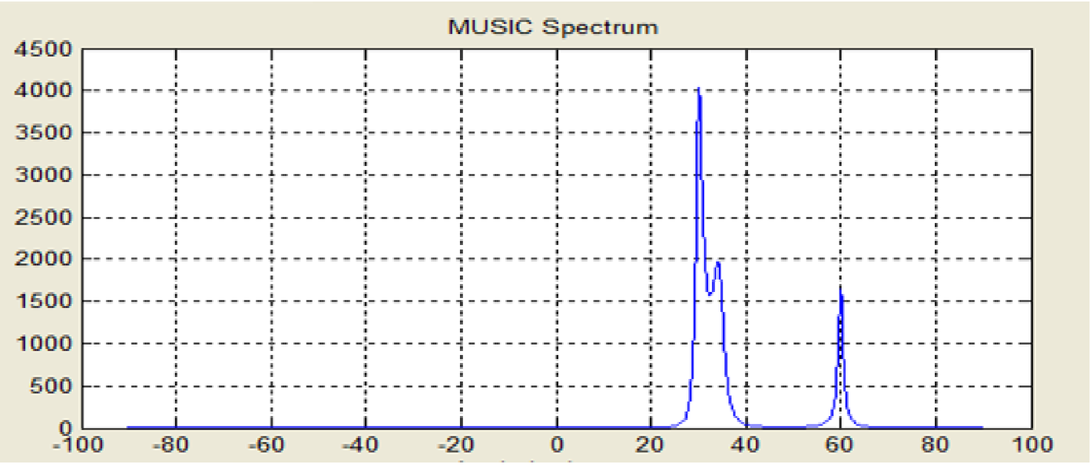


Figure 2. MUSIC Spectrum for varying no: of snapshots

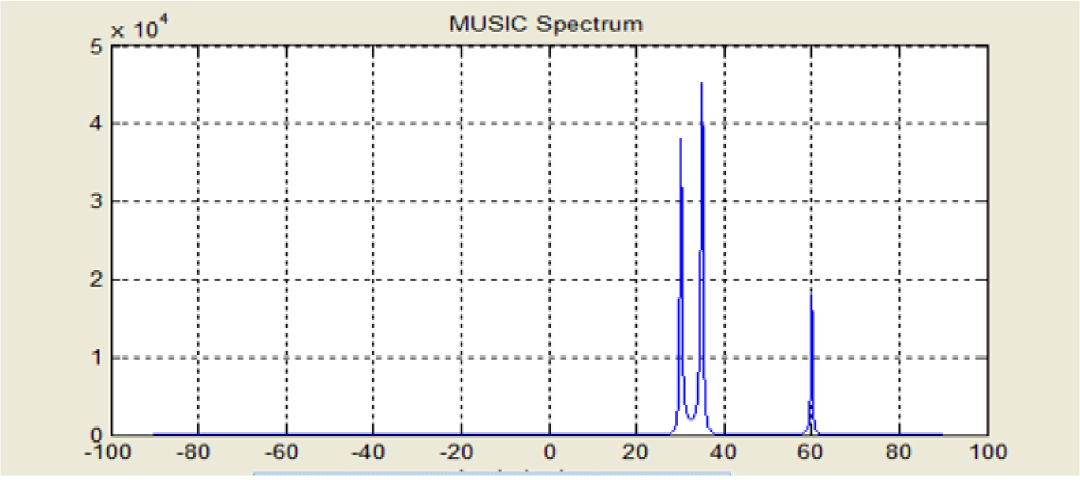


Figure 3. MUSIC Spectrum for varying no: of snapshots

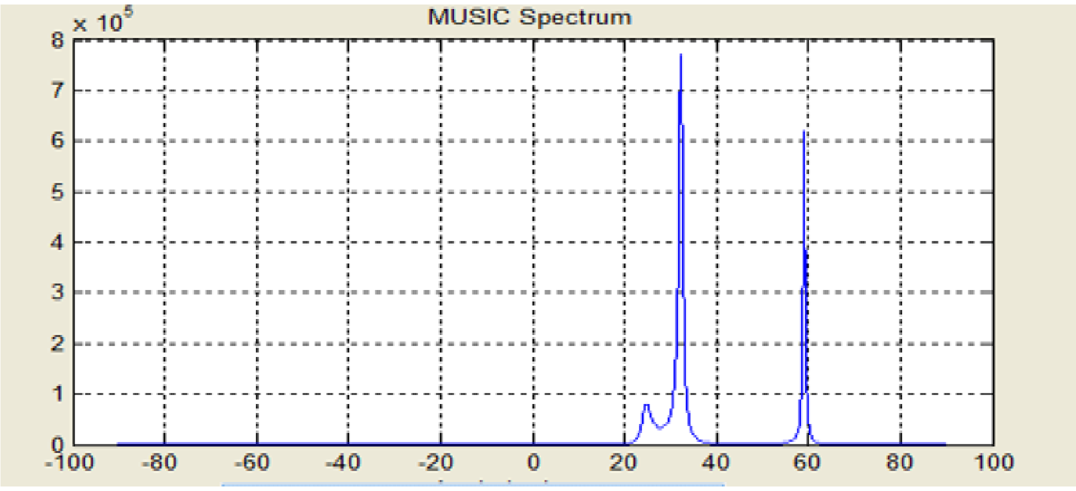


Figure 4. MUSIC spectrum for varying no: of array elements

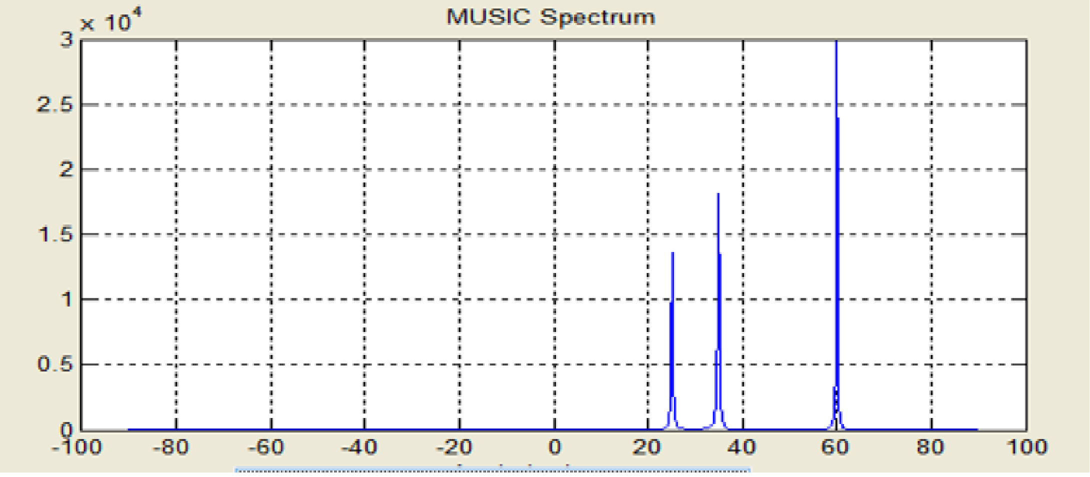


Figure 5. MUSIC spectrum for varying no: of array elements

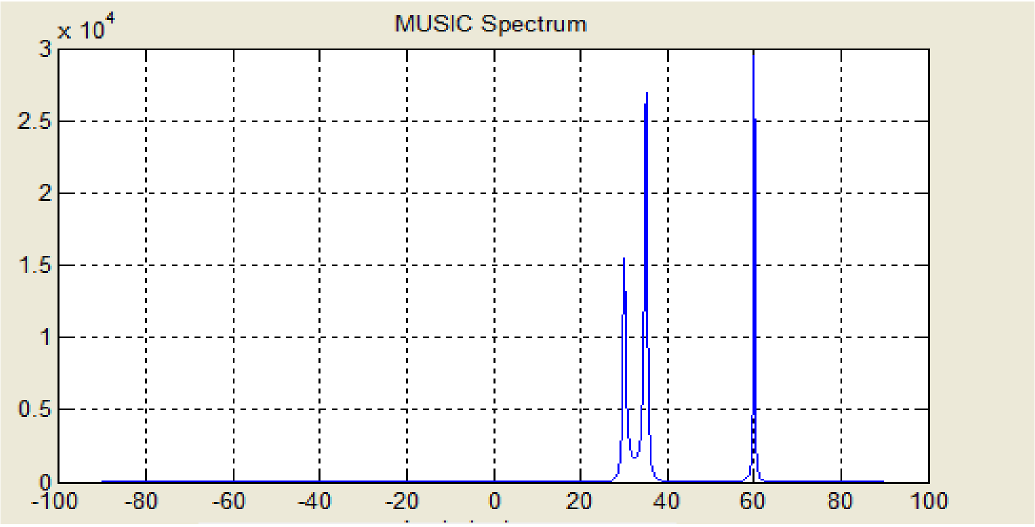


Figure 6. For varying no: of snapshots and no: of array elements

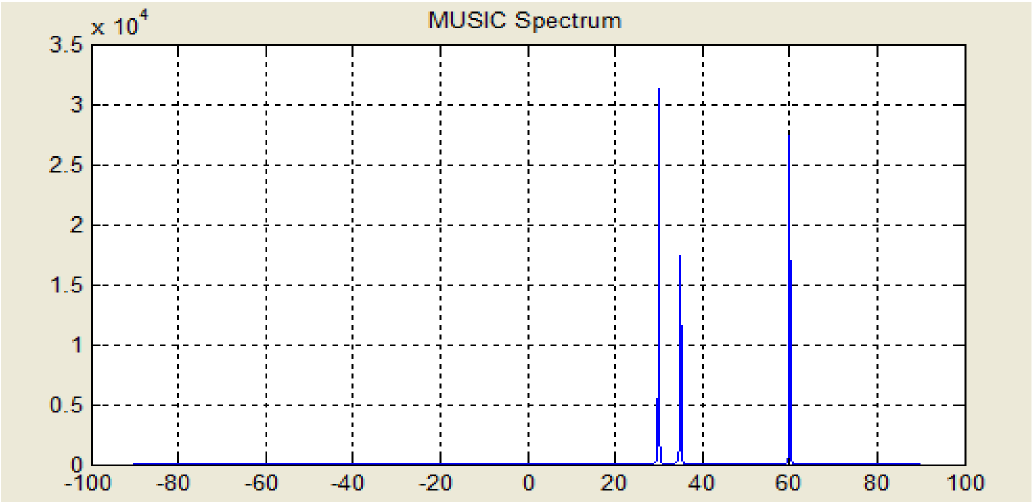


Figure 7. For varying no: of snapshots and no: of array elements

5. Conclusion

The simulations results show that performance of MUSIC enhances with more elements in the array, higher number of snapshots of signals and greater angular separation between the signals. The simulation is performed step by step which shows how the system performance improves while restricting the snapshot parameter. At the same time the array elements is kept smaller for the sake of system simplicity and to make the algorithm much more practical. These improvements are analyzed in the form of sharper peaks in MUSIC spectrum and smaller errors in angle detection. Results indicate that as number of snapshots increases, the MSE decreases, which results in accurate detection of closely spaced signals. This study adds a new possibility of user separation through SDMA and can be widely used in the design of smart antenna system. The above key features indicates the superiority of MUSIC algorithm in such application as compared to other ones. Such algorithm can be used in smaller snapshots application such as Automotive Radars and Sonars.

6. Future work

The implemented Algorithm can be used in SDMA system for the design of smart antenna system. In SDMA, a system may separate a desired user's signal from other signals by its direction of arrival, or spatial characteristics. This is sometimes referred to as "spatial". Thus, even though two users may be transmitting on the same frequency at the same time, the base station may distinguish them because the transmitted signals from the users are arriving from different directions. This concept can be further explored in order to achieve an SDMA SAS. The concept ca be well explained using Figure 8.

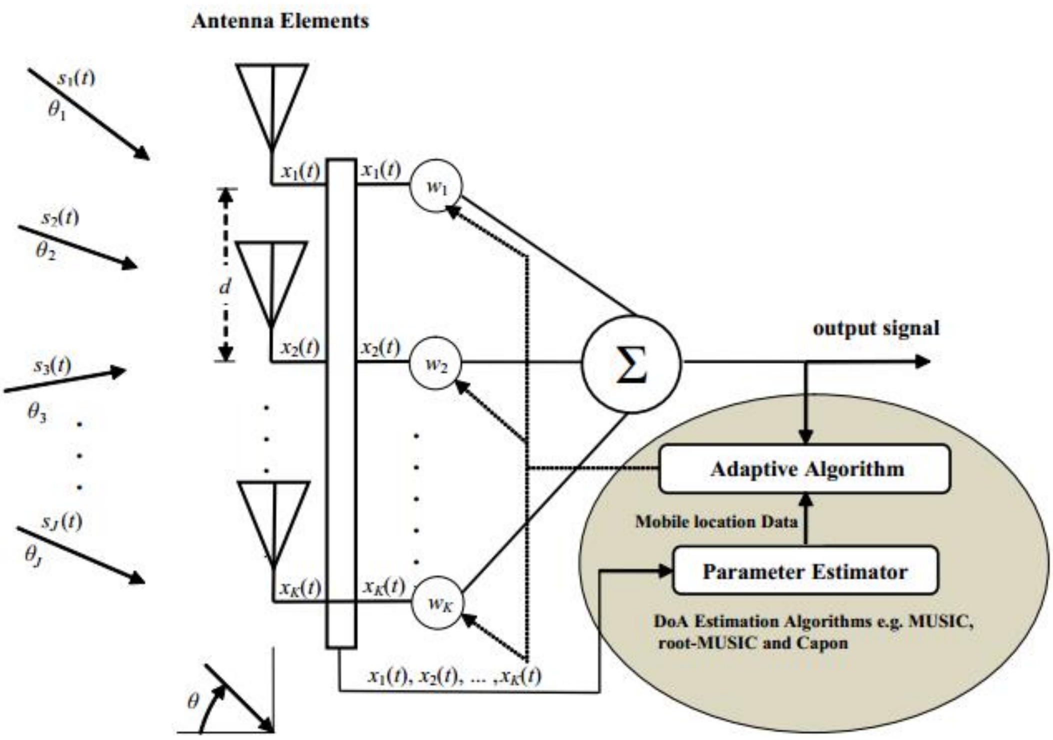


Figure 8. SDMA employing Smart Antenna System (θ_1 to θ_J are DOAs of transmitted signals s_1 to s_J; x_1 to x_K are antenna specific received signals; d = 0.5λ)

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