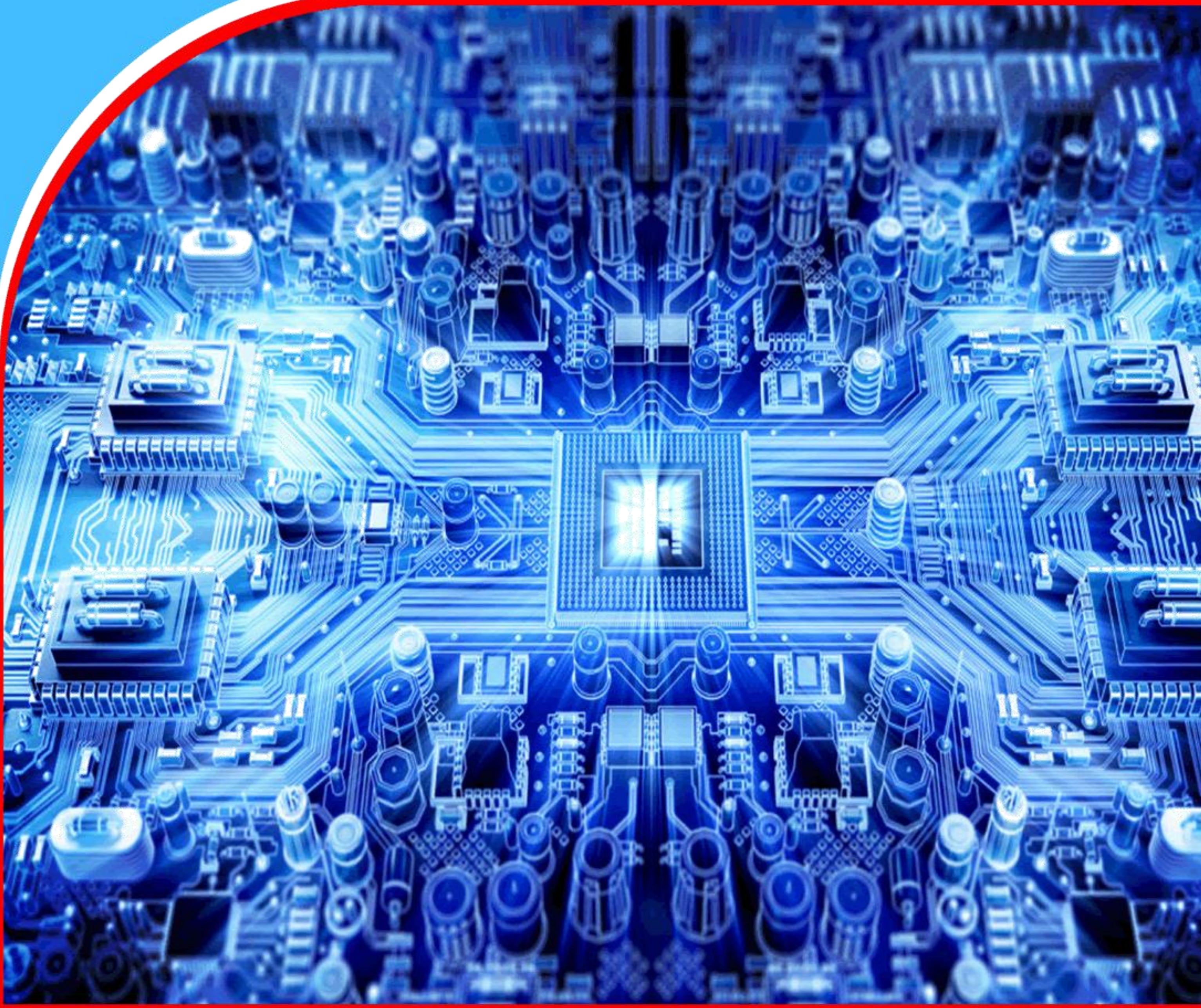
American Journal of
Computing and Engineering
(AJCE)



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American Journal of Computing and Engineering
ISSN 2790-5586 (Online)
Vol.5, Issue 2, pp 39 – 49, 2022
www.ajpojournals.org

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ABSTRACT

Purpose: The performance of smart antenna is affected by antenna array configuration and the direction of arrival estimation (DOA) algorithm used .To have a suitable DOA for an uniform rectangular array (URA),The performance of two dimensional estimation of signal parameters via rotational invariance techniques (2D-SPRIT) that are applied for two different planar dispositions of antenna for URA in Massive Multiple Inputs Multiple Output (Massive MIMO) systems when subjected to the same simulation conditions is comparatively analyzed. The performance of the proposed 2D-ESPRIT algorithm with URA in vertical plane (the case of full-dimensional MIMO) has been compared with that of the existing 2D-ESPRIT algorithm that is applied with URA in horizontal plane.

Methodology: Implementation and simulation of analyzed 2D-ESPRIT algorithms was done in MATLAB and compared considering computational complexity efficiency, DOA estimation precision, estimation failure and variation of Root mean square Error (RMSE) with Signal to Noise Ratio (SNR) and angular spread. MATLAB simulation results got from similar input parameters in a multipath environment are compared to derive a conclusion.

Findings: Simulation results show that the proposed 2D-ESPRIT algorithm applied in vertical plane outperforms the existing 2D-ESPRIT algorithm applied in horizontal plane for all considered performance criteria that include estimation precision, running time and Root mean square error (RMSE).

Recommendation: Other researchers interested in working on 2D-ESPRIT algorithms are recommended to improve the work reported in this paper by further reducing computational complexity observed in 2D-ESPRIT algorithm with URA in vertical plane at large antenna array size to reflect the standard of full-dimension MIMO.

Keywords: *Massive MIMO, Full-Dimension MIMO, DOA estimation, 2D-ESPRIT algorithm.*

1.0 INTRODUCTION

The need of DOA estimation in signal processing of various applications like wireless communications, RADAR communication, SONAR communication, electronic surveillance measure systems, Seismic exploration and in anti-jamming (Gershman et al., 2010). In wireless communication, an antenna array together with a signal processing unit form an important system that is best known as smart antenna. This last one brings several opportunities in wireless communication include increase of network capacity, the security as well as an increased coverage range with reduced interference. The overall performance of Smart antenna system is conditioned by both Array Geometry and the employed DOA estimation algorithm. In application of Multiple input-multiple output (MIMO)Technology in mobile wireless communication, DOA estimation finds much interest because the performance of three dimensional beam-forming of Massive MIMO (Larsson et al., 2014; Hoydis et al., 2011) relies on the accuracy of 2D-DOA estimation of many incident signals received on the antenna array mounted on a base station. Since few years ago, a great work of research is oriented on development of both high-resolution and low-complex DOA estimation algorithms that work well with Massive MIMO array structures in order to enable real-time applications and other various benefits expected from 5G systems.

In DOA estimation literature, various DOA estimation algorithms are studied namely MUSIC (Joshi et al., 2014), ESPRIT (Haardt et al., 2009), Propagator Method (Shu et al., 2008)], Cross-correlation based estimator (Tayem et al., 2016), conjugate symmetry based estimator (Mazlout et al., 2017) are proposed to work in conjugation with various array geometries like uniform linear array (ULA), uniform rectangular array (URA), uniform circular array (UCA), cylindrical array, spherical array and l-shaped arrays. In order to circumvent the computational complexity challenges faced by many high-resolutional DOA estimation algorithm, different solutions have been developed. The use of search-free techniques(Gershman et al., 2010) that skip the step of spectral searching have been proposed. In the study conducted by Ramos in (Haardt et al., 2009), the proposed the use of ESPRIT- based techniques in beam-space and brought the idea of Unitary ESPRIT that estimates DOAs by performing real-valued computation, the solution that reduces significantly the computation load.

This work of research is a review of 2D-ESPRIT algorithm applied URA in horizontal plane and compare its performance with that of proposed 2D-ESPRIT algorithm when applied with URA in vertical plane. Both 2D-ESPRIT Algorithms are simulated in MATLAB and compared their respective performance by observing the variation of RMSE against AOA and EOA. Computational complexities (run time) and the robustness of both method against the variation of SNR and angular spread (AS) are also compared. The study is carried out in the context of Massive MIMO with assumption of the Presence of M antennas on the base station that simultaneously serve K number of User terminals with $M \gg K$ independently identically distributed and the presence of Nk scattered paths from each signal source

1.1 Multiple Input-Multiple Output Overview

In wireless communication, Multiple-Input Multiple-Output (MIMO) is an antenna technology that use many antennas at the transmitter and/or receiver and profit multipath propagation and scale up the capacity of a radio communication link. MIMO techniques has been adopted in modern wireless communication systems among them is HSPA+ (3G), Long Term Evolution (4G), WiMAX (4G), IEEE 802.11n (Wi-Fi) and IEEE 802.11ac (Wi-Fi). Furthermore, the use of MIMO techniques lead to an improvement of symbol rate of systems or performance, without purchasing additional spectrum resources.

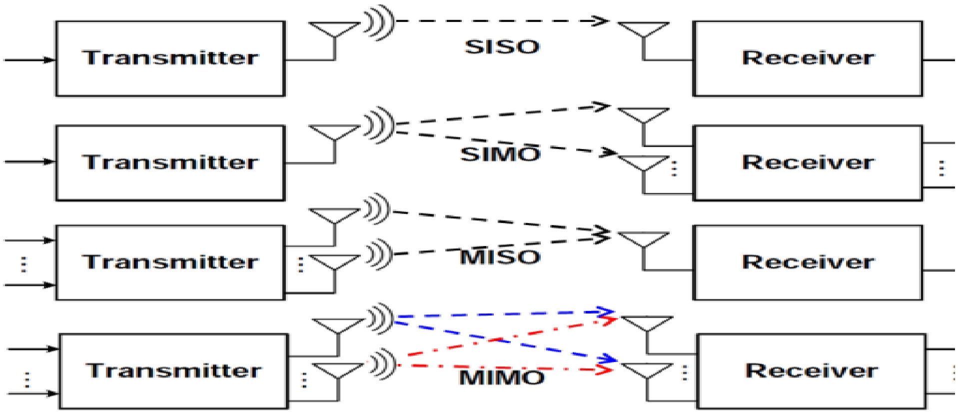

Figure 1: Multiple antenna system configurations

1.2 Massive Multiple Input-Multiple Output

Massive MIMO refer to a system of hundreds of antennas on base station that communicate to tens of user terminals in the same frequency band (Zheng et al., 2014). The rate of data traffic generated by smart phones and tablets, and the qualities of service required by communication based applications that do not cease to increase with time, predicts the need of a thousand times increase in network capacity in the next five years (Hoydis et al., 2011), (Miyim, 2013). Massive Multiple input-Multiple output is proposed as a potential array antenna technology that claims to allow a significant improvement of spectral efficiency (support an increased number of users on the existing frequency band) by limiting the transmission power and maintaining the same bandwidth. In (Marzetta, 2010), Marzetta reported that as the number of antennas at base station tends to infinity; both the effect of additive noise and small fading vanishes. Communication in millimeter waves allows to pack a big number of antenna elements on base station so it is exploited in massive MIMO systems (Shafin et al., 2016).

Another attracting utility of Massive MIMO is the improvement of energy efficiency that leads to the reduction of carbon emission in the environment. emerging digital society infrastructure like internet of things, cloud computing is enabled by Massive MIMO as a solution of processing complexity. Massive MIMO technology is an extension of MIMO technology that came to enable the multiplexing gains for the sake of improved reliability. However, a number of significant challenges came along with this emerging antenna technology namely channel state information acquisition, channel feedback, Hardware impairments, architecture, statistic reciprocity and instantaneous reciprocity (Larsson et al., 2014). Massive MIMO increases 10 times or more the capacity of the system thanks to the spatial multiplexing, and simultaneously improve 100 times the energy efficiency by focusing in a very reduced region of space a well-shaped signal resulting from superposition of many wave fronts (Hoydis et al., 2011).Massive MIMO is built with very cheap components, hundreds low-cost amplifiers that operates in milli-watt range are used in Massive MIMO to replace ultra-linear 50Watt amplifiers employed in conventional systems. Apart from that, Massive MIMO also offers more degree of freedom than its precedent antenna array techniques. On the air interface, Massive MIMO by help of its big number of antenna arrays and it three dimensional beam-forming, offers significant reduction of the latency, a high solicited requirement in future technology (Cox,2012).

1.3 Special Case of FD-MIMO

A full-Dimension MIMO (Ji et al., 2017) can be viewed as a particular implementation of Massive MIMO systems that allows to deploy up to 64 antennas at the base station and operate at recommended frequency. In FD-MIMO system, the considered active antennas are disposed in two dimension configuration and able to process the signal propagation in azimuth and elevation what is not the case in the conventional Massive MIMO system where the active antennas are only considered to process signals in horizontal plane(Ji et al., 2017). This particular antenna array technology that exploit in maximum the capacity of base station antenna allows to handle the Base station form factor constraint and increase the gain in cell capacity at up to 3.5 times and boost the cell edge as well. In a full dimensional MIMO, spatial three dimensional channel model described in equation 1 are considered. FD-MIMO is viewed as the expansion of Massive MIMO antenna technology it will be deployed in next generation of mobile network system(Nam et al., 2013)(Ji et al., 2017). There is a possibility of controlling a radio signal in three dimensional space that is referred to as 3D-beamforming.

$$h_{u,s,n}(t) = \sqrt{\frac{P_n \delta SF}{M}} \sum_{m=1}^{M} \left(\begin{array}{c} \sqrt{G_{BS}(\theta_{n,m,AoD},\beta_{n,m,AoD})} \\ x\, exp(j[kd_s \bar{r}_s . \bar{\emptyset}_{n,m} + \emptyset_{n,m}]) \\ \times \sqrt{G_{MS}(\theta_{n,m,AoD},\beta_{n,m,AoD})} \\ \times\, exp(jKd_u sin(\theta_{n,m,AoD})) \\ \times\, exp\left(\begin{array}{c} jk\|v\| \cos\beta_{n,m,AoA} \\ cos(\theta_{n,m,AoA} - \theta_v)t \end{array} \right) \end{array} \right) \quad (1)$$

For $\bar{r}_s . \bar{\phi}_{n,m} = x_s \cos\beta_{n,m,AoD} \cos\theta_{n,m,AoD} + y_s \cos\beta_{n,m,AoD} \sin\theta_{n,m,AoD} + z_s \sin\beta_{n,m,AoD}$

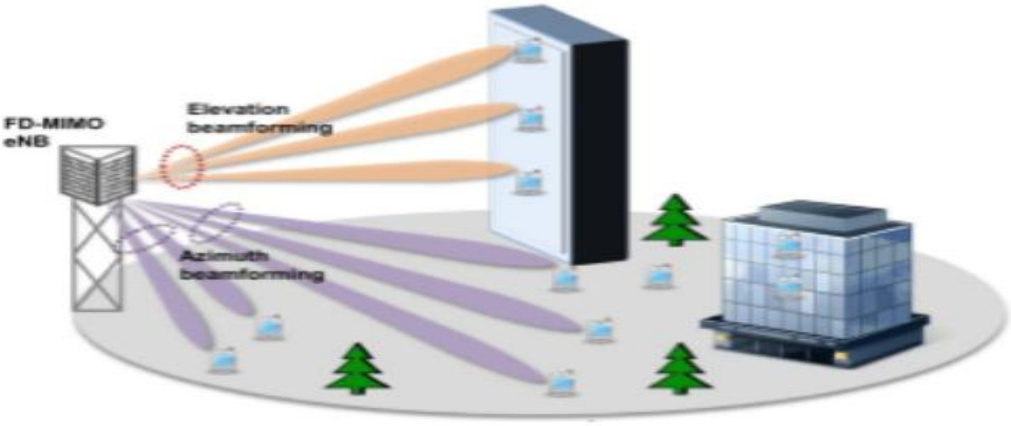

Figure 2: Beam forming in Full dimension MIMO

1.4 Direction of Arrival Estimation Overview

In the past DOA estimation used to be applied in RADAR, SONAR, seismology and in electronics surveillance domain. By the evolution of radio mobile communications, the include of angle and time of arrivals statistics in radio multipath channel modeling made DOA estimation an important area of research (Specc, n.d.). An accurate estimation of DOA helps adaptive antenna to orient the main beam in a specific region of interested target suppress side lobes that would cause interference. Direction of arrival estimation is possible to use a fixed antenna but this approach is very limited and not flexible as the resolution would be constrained by the main lobe of the antenna which varies inversely with the physical size of the antenna. With this traditional approach, we are supposed to increase the accuracy of the angles by varying the size of antenna. Also, this cannot allow the distinction between multiple incident signals. As a solution, DOA are determined by use of array antenna system and application of a suitable signal processing that provide a desired angular resolution. Different array antenna have been presented in literature namely Uniform linear array (ULA),uniform rectangular array (URA),circular arrays and many others (Gershman et al., 2010)(Joshi et al., 2014)(Hu et al., 2014). DOA estimations algorithms are classified in four categories namely Conventional DOA estimation methods, Subspace based DOA estimation methods, Maximum likelihood techniques and Integrated DOA estimation methods. Conventional methods rely on classical beam forming mechanism and they need a great number of antenna elements to reach a high resolution. Subspace methods are sub-optimal but high resolutional that profit from eigen structure of input data matrix. Maximum likelihood methods are optimal and their performance is good even at low SNR, however their computational complexity is prohibitive. Integrated methods separate the multiple incident signals by use of property restoral based techniques and perform the estimation of spatial signature of different incident signals from DOAs are determined by use subspace techniques (Specc, n.d.). To present the problematic of DOA estimation, starting with a very simple case where K signals that impinge on a Uniform Linear array made of M antenna elements as show in figure 2.3 in the next section.

$$\boldsymbol{a}(\phi,\theta) = \begin{bmatrix} 1 \\ e^{ju} \\ \vdots \\ e^{j(M_x-1)}u \end{bmatrix} \otimes \begin{bmatrix} 1 \\ e^{jv} \\ \vdots \\ e^{j(M_y-1)}v \end{bmatrix} \qquad (2)$$

1.5 Channel Models in Massive MIMO

The propagation characteristics of radio waves are modeled by the channel models that are highly affected by antenna array configuration(Larsson et al., 2014). In Massive MIMO, when designer of antenna array must care much on the spacing between adjacent antenna elements as we desire to suppress side lobes that cause directional ambiguity. The number of antenna elements in antenna array is also a very important parameter in design as the increase in number of antenna elements in array lead to a narrower beam so the array gain increases via spatial diversity. However, the number antenna elements in array is constrained by the cost of implementation as well as the physical size limitation (Hoydis et al., 2011).

2.0 PROPOSED 2D-ESPRIT ALGORITHM IN URA VERTICAL PLANE

The proposed 2D-ESPRIT method with URA in Vertical plane that reflect the case of FDMIMO, use the antenna array response define by the expression of equation 3.17 to construct the covariance matrix.

1 Considering T snapshots of the received signal $x(t)(t = 1 \cdots T)$, The covariance matrix denoted by $\widehat{\mathbf{R}_x}$ is estimated according to equation 3.20.

2 Perform eigenvalue decomposition of covariance matrix $\widehat{R_x}$, signal vector E_s whose columns correspond to the K largest eigenvalues of $\widehat{\mathbf{R}_x}$, is extracted from the eigenvector.

3. From the signal vector $\mathbf{E}_s$, derive $\mathbf{E}_1^{(x)}, \mathbf{E}_2^{(x)}, \mathbf{E}_1^{(z)}$ and $\mathbf{E}_2^{(z)}$ that correspond respectively to the sub arrays $1-x, 2-x, 1-z$ and $2-z$ as

$$\begin{cases} \boldsymbol{E}_k^{(x)} = \boldsymbol{J}_k^{(x)}\boldsymbol{E}_s, k = 1,2 \\ \boldsymbol{E}_k^{(z)} = \boldsymbol{J}_k^{(z)}\boldsymbol{E}_s, k = 1,2 \end{cases} \qquad (3)$$

With $\mathbf{J}_k^{(x)}$ and $\mathbf{J}_k^{(z)}(k=1{,}2)$ denote respectively the selection matrices in x-direction and $z-$direction defined as

$$\begin{cases} \boldsymbol{J}_1^{(x)} = \boldsymbol{I}_{Mz} \otimes \boldsymbol{I}_{Mx}(1{:}\,M_x - 1{,}1{:}\,M_x), \\ \boldsymbol{J}_2^{(x)} = \boldsymbol{I}_{Mz} \otimes \boldsymbol{I}_{Mx}(2{:}\,M_x, 1{:}\,M_x) \\ \boldsymbol{J}_1^{(z)} = \boldsymbol{I}_{Mz}(1{:}\,M_z - 1{,}1{:}\,M_z) \otimes \boldsymbol{I}_{Mx}, \\ \boldsymbol{J}_2^{(z)} = \boldsymbol{I}_{Mz}(2{:}\,M_z, 1{:}\,M_z) \otimes \boldsymbol{I}_{Mz} \end{cases} \tag{4}$$

4 Use the Least-square criterion to find Ψ_1 and Ψ_2, matrices that express the invariance property as

$$\begin{cases} \boldsymbol{E}_1^{(x)}\Psi_1 \approx \boldsymbol{E}_2^{(x)} \\ \boldsymbol{E}_1^{(z)}\Psi_1 \approx \boldsymbol{E}_2^{(z)} \end{cases} \tag{5}$$

5 Compute eigenvalues $\xi_{1,k}$ and $\xi_{2,k}(k = 1 \cdots K)$ of Ψ_1 and Ψ_2 respectively.

6 Derive bidirectional DOAs from eigenvalues $\xi_{1,k}$ and $\xi_{2,k}(k = 1 \cdots K)$ as

$$\begin{cases} \hat{\theta}_k = arctan\left(\dfrac{\xi_{2,k}}{\xi_{1,k}}\right) \\ \hat{\phi}_k = \dfrac{\lambda}{2\pi d}\sqrt{\xi_{1,k}^2 + \xi_{2,k}^2} \end{cases} \tag{6}$$

2.1 Performance Analysis of 2D-ESPRIT Algorithms

The performance of the proposed estimator is measured with RMSE of azimuth and elevation by considering the computational complexity (running time), estimation precision (scatter plot) and robustness that measure the frequency of failure at varying input parameters that include RMSE, number of antennas at the base station, number of user terminals, angular spread and SNR.

$$RMSE(\alpha) = \sqrt{\frac{1}{K \cdot N_{MC}} \sum_{k=1}^{K} \sum_{n=1}^{N_{MC}} \left(\hat{\alpha}_{k,n} - \alpha_{k,n}\right)^2}$$

3.0 SIMULATION AND RESULTS

To analyze the impact of antenna configuration, by the use of MATLAB 2013, the implemented 2D-ESPRIT algorithm whose single difference is the planar disposition of antenna elements in the URA. The curve of RMSE variation as it is defined in equation 7 is analyzed and the estimation of elevation DOA in range of [0◦−90◦] is observed by fixing the azimuth angle at 60◦ ,for SNR = 10 dB, AS = 2,number of antenna elements M = 5,and considering the similar experience by keeping elevation angle fixed 30◦ and azimuth varies in range of [0◦−90◦].Then evaluate the DOA estimation performance of the two ESPRIT methods used with URA with different planar dispositions and got the results illustrated in figure 4 and figure 3 respectively when in Elevation and Azimuth by same simulation conditions (M = 5 , L = 200 snapshots, 1000 Monte-carlo trials, Np = 20, K = 1) for both ESPRIT methods.

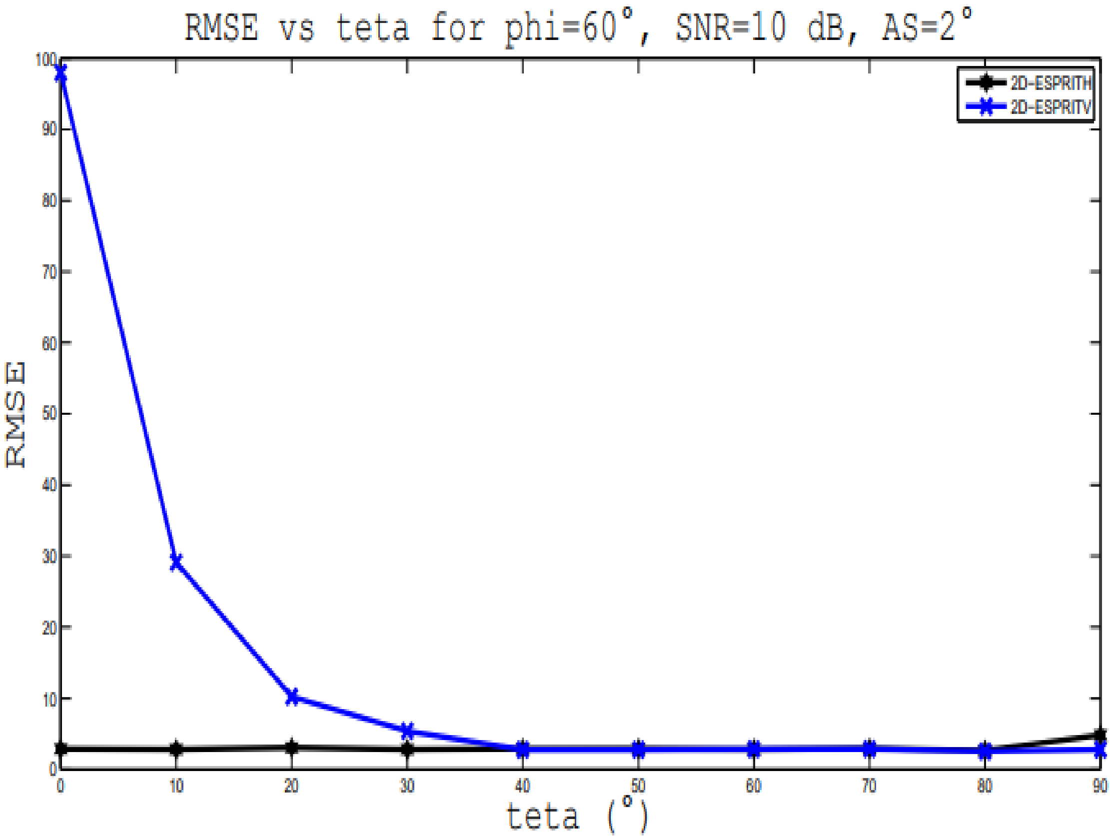

Figure 3: Performance of URA based 2D-ESPRIT algorithms in elevation

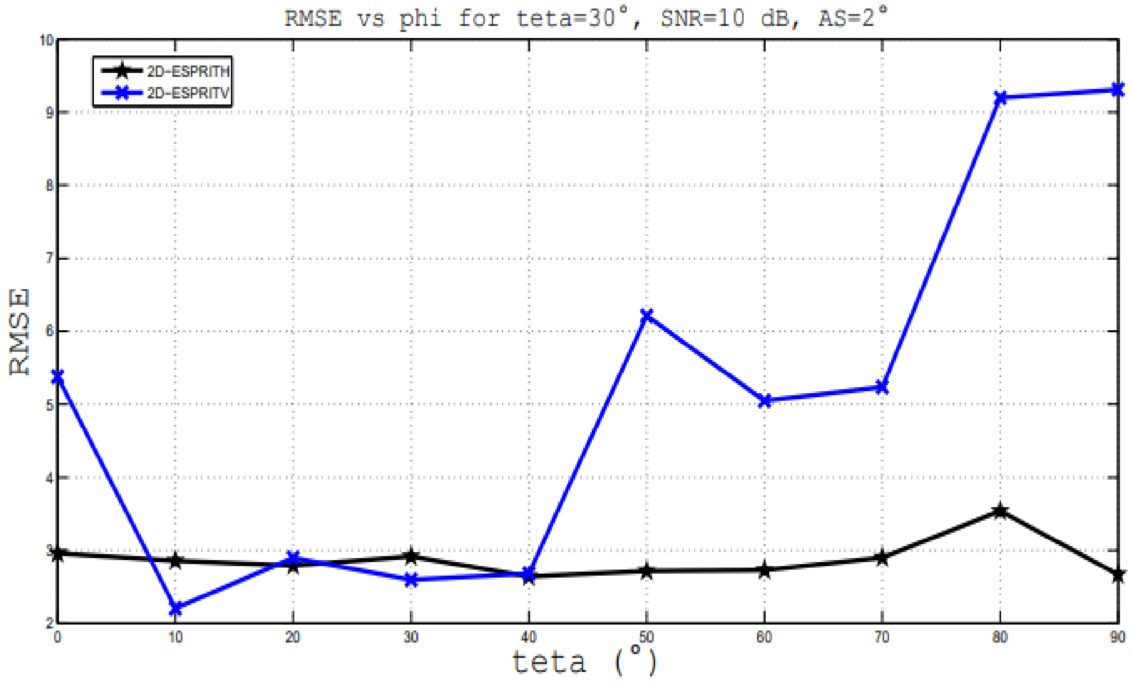

Figure 3: Performance of URA based 2D-ESPRIT algorithms in azimuth

2D-ESPRIT with URA is horizontal plane (applied in convention MIMO system) shows a better performance relatively to the proposed ESPRIT method that use vertical plane URA.

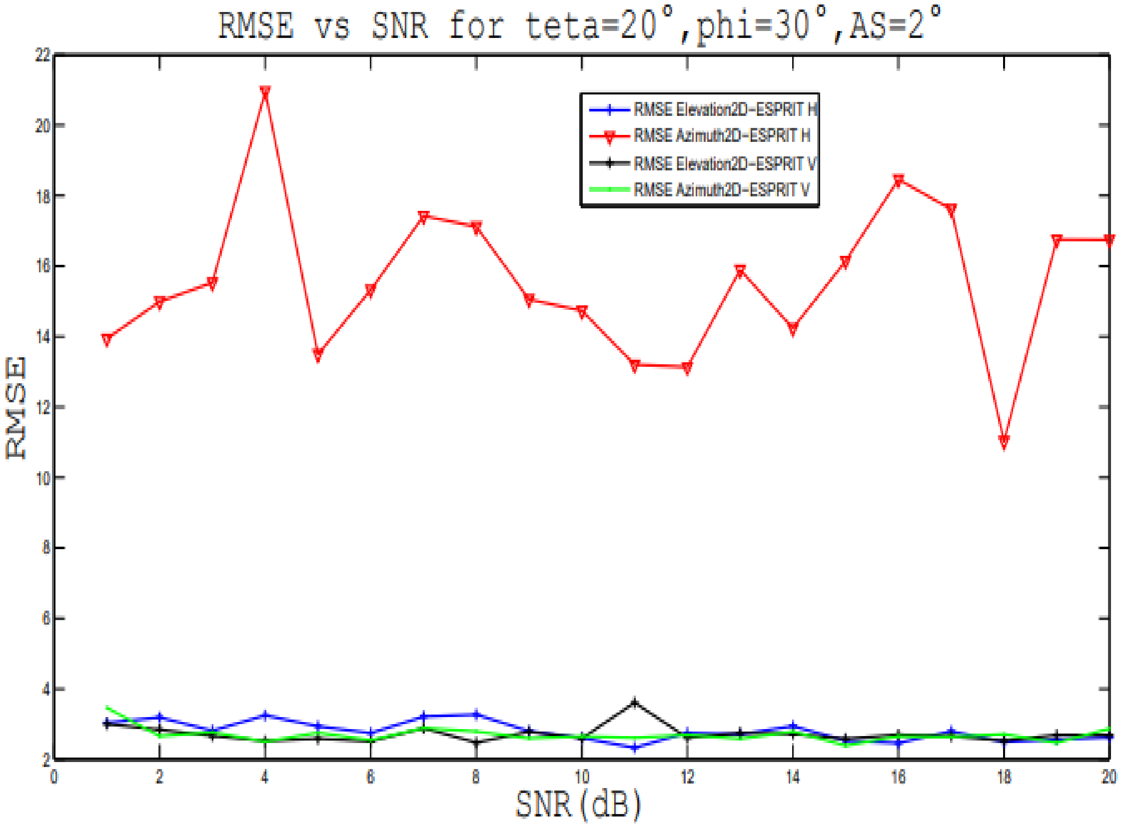

Figure 4: Performance of URA based 2D-ESPRIT algorithms against SNR

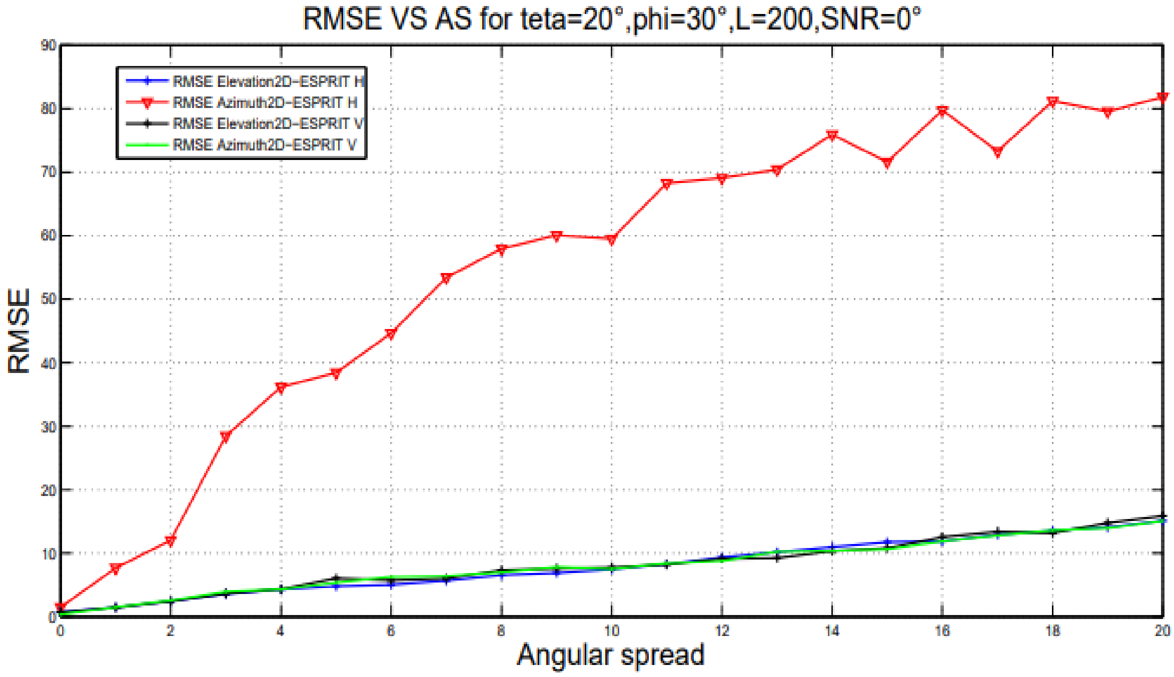

Figure 5: Performance of URA based 2D-ESPRIT algorithms against angular spread

Observing the curves of variation of RMSE for SNR in range of [0−20] AS fixed at 2°, figure 5 and when SNR is kept fix at 10dB, AS in the range of [0−20], figure 6. The red curve represents the performance in azimuth of ESPRIT with URA in horizontal plane shows that that method performs poorly at values of SNR in the considered range and its performance varies in reverse direction of the variation of angular spread. The figure 6 shows the comparison of the two methods on basis of estimation precision. Evaluating the precision estimation for the two methods in estimation elevation angle 20° and azimuth angle 30°.

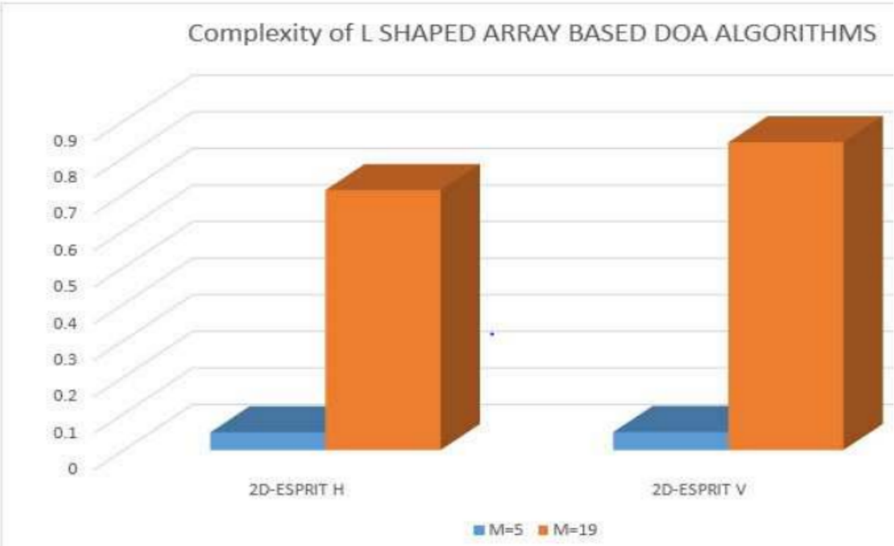

Figure 6: Running time of 2D-ESPRIT algorithms for M=5 and M=19

On basis of estimation precision, 2D-ESPRIT performs better with Horizontal URA than with Vertical URA.

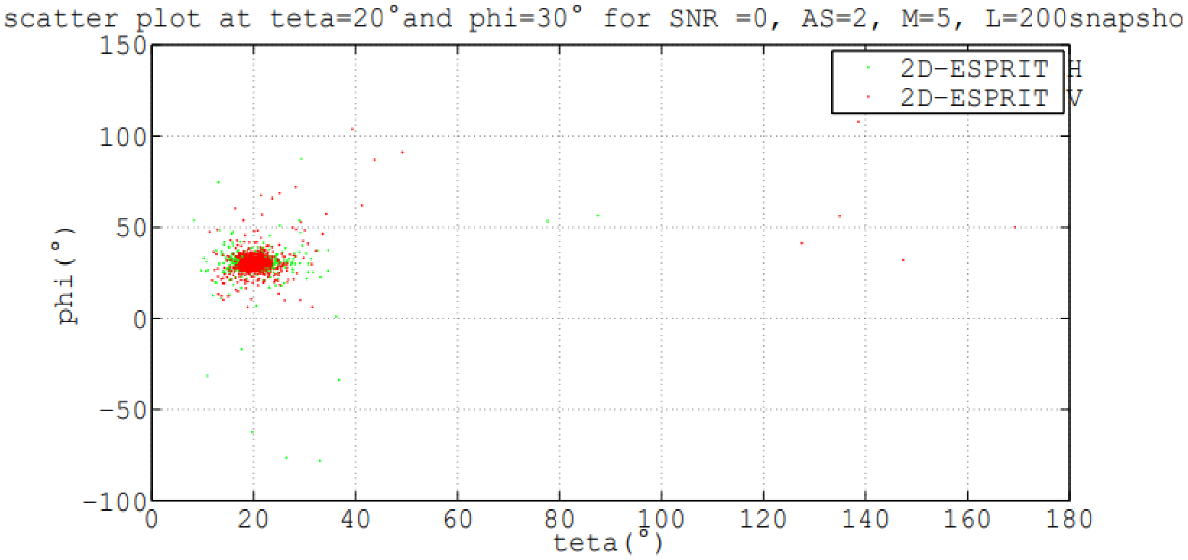

Figure 7: Comparative scatter plot of URA based D-ESPRIT algorithms

Analyzing the performance of both methods setting computational complexity as performance criteria, the running time measured when the two methods are implemented and simulated with the same condition parameter. First, with a reduced size of array antenna (M = 5) where it resulted in running time represented with the blue color, secondary with a larger array antenna size (M = 19) where the running time is shown by the orange color, figure 8. It results in the same running time at M = 5 and a longer time for ESPRIT that use vertical URA.

CONCLUSION

This work of research intended to analyze the performance of 2D-ESPRIT algorithms for URA in horizontal plane and to develop 2D-ESPRIT algorithm applied for URA in vertical plane and make a comparison of respective performance of the two algorithms. According to the results of simulation, proposed algorithm outperforms the existing 2D-ESPRIT algorithm for all considered performance criteria however it still needs some enhancement to meet some full-dimension MIMO standard like less complexity at large antenna array size.

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