KIET IJCE

KIET International Journal of Communications & Electronics
Volume. No. 1, Issue No. 3, Sep – Dec 2013, ISSN: 2320 - 8996

# Beamforming Algorithm for Smart Antenna in WCDMA Network

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***Abstract*— The capacity of cellular system is limited by two different phenomena namely, multipath fading and multi-access interference. The Third Generation based Wide Band Code Division Multiple Access (W-CDMA) Networks use smart antenna techniques that include Direction of Arrival (DOA) approach and adaptive beamforming algorithm to remove multipath fading, multi-access interference and to increase the Signal to Interference Noise Ratio (SINR), and system capacity to improve the communication quality. In this paper, DOA is estimated using Multiple Signal Classification (MUSIC) method which makes use of the Eigen structure. Subsequently, the adaptive beam forming algorithm is employed which comprises of complex weightings, time delays and the summer. Here, we improve on the Minimum Variance Distortion less Response (MVDR) method in order to assign the weightings. We have proposed a new method to compute the complex weighting coefficients based on certain data-dependent criteria known as constraints. Instead of using a single linear equality constraint, as in MVDR, multiple constraints that broaden the null area of interferers have been used to calculate the optimum weights. Simulations have been carried out in the presence of noise to compute BER for the conventional MVDR method and proposed method by varying (i) the number of antenna elements, and (ii) the spacing between the antenna elements. For both the cases, the performance of the proposed method is better than MVDR method.**

***Index Terms*— W-CDMA, Smart antennas, Antenna Array, Direction of Arrival estimation, Adaptive Beam forming.**

## I. INTRODUCTION

The Third generation cellular networks are being designed to provide high data rate services, multimedia traffic as well as voice signals. The 3G system utilizes Wide Band Code Division Multiple Access (WCDMA) as the radio access technology that has many advantages such as highly efficient spectrum utilization and variable user data rates services [1-3]. These advantages of WCDMA are limited by multipath fading and multi-access interferences, which create problems such as high bit error rate, low capacity and poor signal to interference noise ratio for the high data rate services offered by 3rd generation cellular networks [4]. Researchers have done a lot of work to solve these problems. However, it is most important to configure receiver and transmitter flexibly in response to signal environment. Several techniques such as phased array antenna and diversity antenna have been studied in many applications that use active array configuration to adapt the antenna pattern according to change of mobile communication environment. This can noticeably increase the performance characteristics such as capacity and quality of communication network [5].

A higher performance in WCDMA network can be facilitated with the help of smart antennas by efficiently minimizing multipath fading and co-channel interference. This can be accomplished by focusing the radiation only in the preferred direction and regulating it to varying traffic conditions or signal environments [6]. Smart antennas utilize a set of radiating elements arranged in the form of an array connected to digital signal processor. The signals provided by the antenna elements are joined to make a movable or switchable beam pattern that would track the desired user [7]. Conventional antennas give out energy in every direction leading to wastage of power. Comparing with the conventional systems, the smart antennas radiate energy in the desired user path only [8].
Smart antennas mainly consist of two parts; namely DOA approach and the Beamforming. The DOA approach determines the number of source signals, direction of arrival of each signal, signals from the desired user and signals from the interferers. The DOA evaluation performance of an array relies on the number and locations of the array elements. A great deal of DOA evaluation algorithms have been developed and analyzed [9-11]. Some of the DOA algorithms are maximum likelihood method, linear-prediction method, multiple signal classification (MUSIC) method and Estimation of signal parameters via Rotational Invariance Techniques (ESPRIT) method [12-13].

The another part of smart antenna is beamforming network which forms an antenna pattern with a main beam steered in the direction of desired user while placing nulls in the direction of interfering users direction by constantly updating the complex weights. Based on angle information, the beamforming network computes the complex weights required for beam steering. There are two beamforming processes; one is switched beamforming and another is adaptive beamforming. Switched beam systems have several available fixed beam patterns. A decision is made as to which beam to access, at any given point in time, based upon the requirements of the system. Adaptive beamforming allows the antenna array to steer the beam to any direction of interest while simultaneously nulling the interfering signals. This can be done by updating the complex weights of the filter adaptively in response to changing environment and/or as the desired user and interference user moves.

There are many adaptive beamforming algorithms (Blind or Non Blind) to update the complex weight vectors, each with its speed of convergence for optimum solution and required processing time [14]. Least Mean Square (LMS), Recursive Least Square (RLS) and Sample Matrix Inversion (SMI) are characterized as Non Blind adaptive algorithm as they require the training sequence to update the complex weights [15]. A typical method of forming the adaptive weights without the knowledge of training sequence is via the MVDR algorithm [16], which uses a single linear constraint to maintain a unit gain in the boresight direction. The dedicated pilot channel of WCDMA frame structure supports the use of weight vector in each slot. Here, the weight vector of MVDR Beamforming method to be applied in that slot is updated by the use of constraint method. Instead of using a single constraint for calculating the weight vector i.e. for setting the antenna gain in desired direction unity (which may not always be true), variable constraints that set the different antenna gain in desired direction is used. The result of which is that the optimum weights are dependent on that constraint. These updated weights reduce the error between the desired and actual beam pattern formed and produce the optimal beam forming. The Direction of arrival at which the signal is received is estimated by using MUSIC method which makes use of the Eigen structure. In this algorithm, initially the covariance matrix is calculated and from this matrix the normalized angular MUSIC spectrum is derived. We also consider the fading effect which occurs during the propagation of high data rate signals.

The rest of the paper is organized as follows: In section II, MUSIC algorithm for DOA estimation and MVDR Beamforming algorithm is presented. In section III, we describe the proposed method i.e. Modified MVDR in order to assign the weightings using constraint criteria. The detailed experimental results and discussions are given in section IV. Finally, the conclusions are summed up in section V.

## II. DOA ESTIMATION MODULES

DOA estimation algorithms can be classified as:

1. Conventional Techniques
2. Subspace Techniques
3. Maximum Likelihood Techniques
4. Integrated Techniques

Each of these methods varies in computational complexity, resolution power and accuracy. The first two methods are spectral based that calculate the spatial spectrum of the received signal and find the direction of arrival from the location of peak in the spectrum. The next two approaches utilize parametric array processing method that directly estimates the direction of arrival without calculating the spectrum first. Due to higher computational complexity of parametric method, spectral based MUSIC algorithm is used for DOA estimation and MVDR for beamforming.

### A. *MUSIC Algorithm*

MUSIC algorithm is a high resolution Multiple Signal Classification sub-space based technique that exploits the Eigen structure of the input covariance matrix. The Eigen structure of the covariance matrix belongs to either of two orthogonal signal or noise subspaces. It gives information about the number of incident signals, Direction of Arrival of each signal (DOA estimation), strengths and cross correlation between incident signals, noise power, etc.

Suppose, there are K users arriving at angles $\theta_1, \theta_2, \ldots\ldots, \theta_K$ on the antenna array of length N. The received input data vector at the antenna array can be given as linear combination of signals from K users and noise as

$$U(t) = \sum_{i=1}^{K} a(\theta_i) E_i(t) + n \; = AE + n \qquad (1)$$

Where A is the steering vector matrix which consists of vectors a ($\theta_1$), a ($\theta_2$), a ($\theta_3$)….a ($\theta_K$), E is the signal vector matrix and n is the noise vector matrix with variance $\sigma_n^2$.

The received vector U and the steering vector A can be combined to form N-dimensional vector space. The Covariance Matrix can be given as

$$M = \; E(UU^H) \; = \; AM_S A^H + {\sigma_n}^2 \qquad (2)$$

Where $M_S$ is the signal correlation matrix. Subsequently, the Eigen decomposition of the covariance matrix is done to obtain the eigenvalues and eigenvectors of the covariance matrix M. The eigenvectors of the covariance matrix M belong to either of the two orthogonal subspaces i.e. the signal subspace and the noise subspace [17]. The dimension of the signal subspace is K, while the dimension of the noise subspace is N-K. This can be expressed as:

$$Ei_S = [e_1, e_2, \ldots, e_K] \qquad (3)$$

$$Ei_N = [e_{K+1}, e_{K+2}, \ldots, e_N] \qquad (4)$$

Where $Ei_S$ is the Eigen vector for the signal, having the signal Eigen values $[e_1, e_2, \ldots, e_K]$ that spans the signal subspace and $Ei_N$ is the Eigen vector for the noise, having the noise Eigen values $[e_{K+1}, e_{K+2}, \ldots, e_N]$ . The N-K smallest eigenvalues of M are equal to $\sigma_n^2$, and the eigenvectors $Ei_N$ corresponding to these eigenvalues span the noise subspace.

As the K steering vectors make up steering matrix A that lies in the signal subspace and are orthogonal to the noise subspace, so by searching through all possible array steering vectors to find those which are orthogonal to the space spanned by the noise eigenvectors $Ei_N$, the DOA's $\theta_1, \theta_2, \theta_3, \ldots \; \theta_K$ can be determined. After the Eigen decomposition, the normalized angular MUSIC spectrum is calculated [18-19];

$$G(\theta) = \frac{A^H . A}{A^H . V_n . V_n{}^H . A} \qquad (5)$$

By inspecting the denominator part in equation (5), it is clear that peaks in the MUSIC angular spectrum occur at angles θ for which steering vector matrix A is orthogonal to the noise subspace matrix $V_n$ containing the noise eigenvectors $Ei_N$. Those angles θ define the desired directions-of-arrival of the signals impinging on the antenna array.

### *B. MVDR Algorithm*

Let a uniform linear array consists of N equispaced sensors and the antenna array receives a number of signals from L users arriving at different angles $\theta_1, \theta_2, \ldots\ldots, \theta_L$ as shown in figure 1. The received signal be denoted by $S_i(t)$. At a particular instant of time t=1, 2,…, k, where k is the total number of instances considered, the array output will consist of the signal plus noise components. The received signal vector can be defined as

$$C(t) = \sum_{i=1}^{L} a(\theta_i) S_i(t) \tag{6}$$

Where *S (t)* is an L×1 vector of user waveforms, and for a particular user at direction θ from the array boresight; *a (θ)* is an *N*×1 vector referred to as the array response to that user or array steering vector representing the array steering response at θ direction. This vector is defined by:

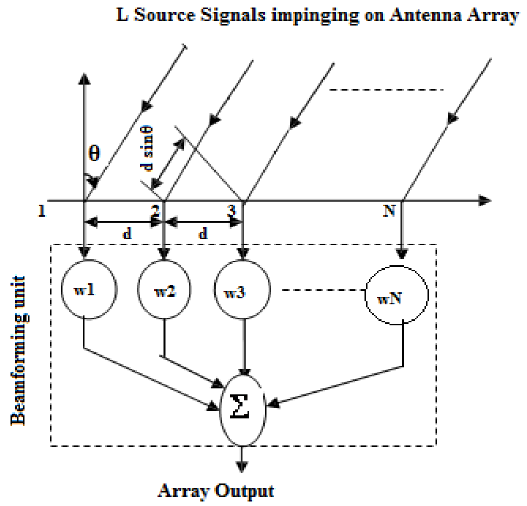


Fig. 1: Structure of Uniform Antenna Array with Beamforming Network.

$$a(\theta) = \exp[-j(N-1)\phi]^T$$

or

$$a(\theta) = [1 \quad e^{-j\phi} \quad \ldots\ldots e^{-j(N-1)\phi}]^T \tag{7}$$

Where T is the transposition operator and $\phi$ is the electrical phase shift from element to element along the array, given by:

$$\phi = 2\pi\left(\frac{d}{\lambda}\right)\sin\theta \tag{8}$$

Where d is the spacing between the antenna elements and λ is the wavelength of the received signal.

The user signal vector C (t) of equation (6) having size N×1 can be written as

$$C(t) = A_L . S(t) \tag{9}$$

Where $A_L$ is $N \times L$ matrix of user signal direction vector and is given by

$$A_L = [a(\theta_1),\ a(\theta_2),\ a(\theta_3) \ldots\ldots a(\theta_L)] \tag{10}$$

And S(t) is the $L \times 1$ user source waveform vector defined as

$$S(t) = [S_1(t) \quad S_2(t) \ \ldots \ S_L(t)]^T \tag{11}$$

The array output consists of the signal component plus noise components and it can be given as:

$$R(t) = C(t) + n(t)\} \tag{12}$$

Here, the noise signal n (t) consists of white Gaussian noise $n_1$ (t), noise considering the deep fading channels such as Rayleigh fading $n_2$ (t) and Ricean fading $n_3$ (t). Hence the noise signal can be expanded as:

$$n(t) = n_1(t) + n_2(t) + n_3(t) \tag{13}$$

The spatial correlation matrix M of the received signal vector R (t) can be given as:

$$M = E\{R(t)R^H(t)\} \tag{14}$$

Where E {.} is the ensemble average or expectation operator and H is the conjugate transpose operator. The spatial correlation matrix M can now be expressed as:

$$M = E\{C(t)C(t)^H\} + n(t)n(t)^H \tag{15}$$

Applying the value of C (t) from equation (9), we get:

$$M = A_L(t)E\{S(t)S^H(t)\}A_L{}^H(t)\} + n(t)n(t)^H \tag{16}$$

This equation can be approximated by applying temporal averaging over *P* samples taken from the signals incident on the antenna/sensor array. This averaging process leads to forming a covariance matrix *M* given as:

$$M = \frac{1}{P}\sum_{p=1}^{P} A_L(p)[S(p)S^H(p)]A_L{}^H(p) + \sigma_n{}^2 I \tag{17}$$

Where $\sigma_n$ is the noise variance and *I* is the identity matrix.

The MVDR technique minimizes the contribution of the undesired interferences by minimizing the output power while maintaining the gain along the desired direction to be constant, usually unity i.e. min E $[y(\theta)^2]$ = min $w^H M w$ , $w^H A_L = 1$. Here y(θ) is the output, *W* is the weight vector, H is the conjugate transpose operator, M is the correlation matrix, $A_L$ is the user signal direction vector. Using Lagrange multiplier, the weight vector is given by,

$$W = \frac{M^{-1}A}{A^H M^{-1} A} \tag{18}$$

Where $A_L = A$ for simplicity.

## III. PROPOSED MVDR METHOD

Beamforming is a signal processing method, which is employed in antenna arrays for the directional signal reception. Beamforming unit mainly consists of complex weightings, time delays and the summer. Here the elements are used to combine the signals in a particular way so as to form radiation pattern with maximum towards the signal of interest and nulls towards other signals. Signals arriving at particular angle experience constructive interference while the others experience destructive interference. The beam pattern consists of a main lobe together with nulls and side lobes. An adaptive beamformer automatically adapts its response to various conditions.

The output response of the linear antenna array with weight vector $w = [w_0, w_1, \ldots, w_{K-1}]$ and signal vector C is given by:

$$z = \sum_{n=0}^{N} w_n{}^* c_n = w^H.C \tag{19}$$

In optimal beamforming, the noise is effectively suppressed by reducing the output energy. This is achieved by the fact that gain of the signal is maintained constant and hence, the only way to achieve the reduction of total output energy is by reducing the noise. This can be written as

$$w_{OBF} = \arg\min\{E|z|^2\} \quad (20)$$

Substituting equation (19) in equation (20) yields:

$$w_{OBF} = \arg\min\{E|w^H.C|^2\} \quad (21)$$

For calculating the optimized minima of a given function subject to a constraint, the method of Lagrange multipliers is an effective solution. Suppose the optimization problem is to minimize the function $l(y)$ subject to the constraint $g(y) = \lambda$. Using Lagrange variable $\gamma$, we can mathematically represent the above optimization as:

$$\chi(y,\gamma) = l(y) + \gamma(g(y) - c) \quad (22)$$

Our aim is to minimize the function $E|w^H.C|^2$ subject to the constraint $w^H \mu_0 = \lambda$ where $\lambda$ is a constant and $\mu_0$ is the spatial signature matrix. Here $C \in C.Ei$ where $Ei$ is the Eigen value matrix. Using Lagrange multiplier as in equation (22), we obtain:

$$\chi(w,\gamma) = E\{|w^H.C|^2\} + \gamma[w^H \mu_0 - \lambda] \quad (23)$$

Expanding the square term in equation (23), we obtain:

$$\chi(w,\gamma) = E\{|wCC^H w^H\} + \gamma[w^H \mu_0 - \lambda] \quad (24)$$

$$= wE\{CC^H\}w^H + \gamma[w^H \mu_0 - \lambda] \quad (25)$$

As $E\{CC^H\} = M$, where $M$ is the covariance matrix, we can simplify the equation as:

$$\chi(w,\gamma) = wMw^H + \gamma[w^H \mu_0 - \lambda] \quad (26)$$

$$= wMw^H + \gamma w^H \mu_0 - \gamma\lambda \quad (27)$$

On differentiating and equating equation (27) to zero, we get:

$$\frac{d}{dw^H}(\chi) = w_{new}M + \gamma\mu_0 = 0 \quad (28)$$

$$w_{new}M = -\gamma\mu_0 \quad (29)$$

Multiplying both sides of the equation (29) with non-singular Eigen value matrix $Ei$, we get:

$$Ei(w_{new}M) = -\gamma Ei\mu_0 \quad (30)$$

Simplifying equation (30) for finding out the optimum weight, we get:

$$w_{new} = \frac{-\gamma M^{-1} Ei\mu_0}{Ei} \quad (31)$$

Substituting the value of $\gamma$ which is found by using the constraint on the weight vector i.e. $w^H \mu_0 = \lambda$ in equation (31) and then solving the gain constraint, we can set the final weights to be:

$$w_{new} = \frac{\lambda M^{-1} Ei\mu_0}{\mu_0^H M^{-1} Ei\mu_0} \quad (32)$$

These final weights $w_{new}$, depends upon the gain constant $\lambda$ and when set with different value, gives the minimize energy (variance) of the output signal in the undesired direction and the desired signal is not distorted.

## IV. SIMULATION AND RESULTS

In this section, we have a detailed analysis of the method and make comparisons with the existing methods to prove the validity of the proposed method. We also have a detailed discussion of the method by varying various parameters and plotting the graphs accordingly. We make use of the Bit Error Rate graphs for analysis.

Here, angle value of output signal that comes with new weights is calculated and if angle value comes greater than zero then output is taken as one otherwise minus one. This output is compared with transmitted data bits to find the number of bits in error. We plot BER vs. $E_b/N_0$ graphs from which we can infer the performance of the system. Here $E_b/N_0$ is the energy per bit ($E_b$) to noise power spectral density ($N_o$) ratio of the received signal. $E_b/N_0$ is basically a normalized signal-to-noise ratio (SNR) measure of the signal.

The proposed method for analysis is implemented in MATLAB. For evaluation of the proposed method, we make use of randomly generated signals.

For the detailed analysis by the use of the BER curve, we consider two cases:

- By varying the distance between the antennas.
- By varying the number of elements in the antenna array.

Both the above mentioned cases are plotted for single desired user having direction of arrival (DOA) 120 degree.

In the figure 2, graph is plotted for N=10 number of antenna elements and d=0.2 spacing between the elements. In the plot, the proposed method shows significant improvement. For the $E_b/N_0$ of 10dB, the proposed method has BER of 7.1e-005 while the existing method has BER of 0.00478.

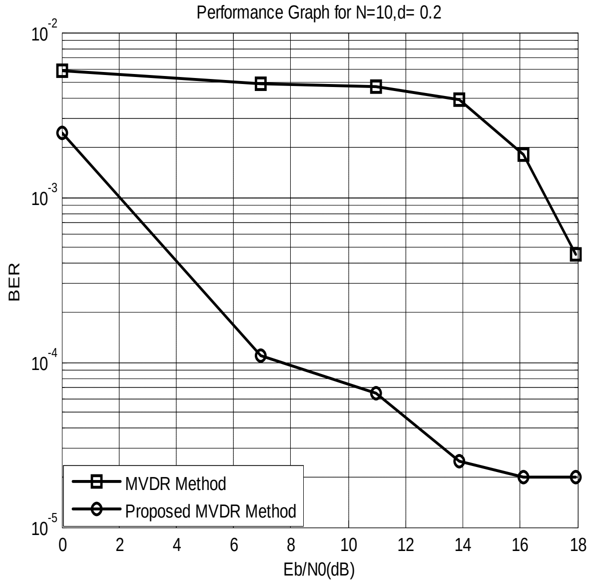


Fig. 2: BER Performance Graph for N= 10 and d =0.2.

Figure 3 is plotted for same number of elements i.e. N =10, but the spacing between element is changed to 0.5. This also shows the less BER with proposed method. For the target $E_b/N_0$ of 10dB, the proposed method has BER of 0.00383 while the existing method has BER of 0.00622.

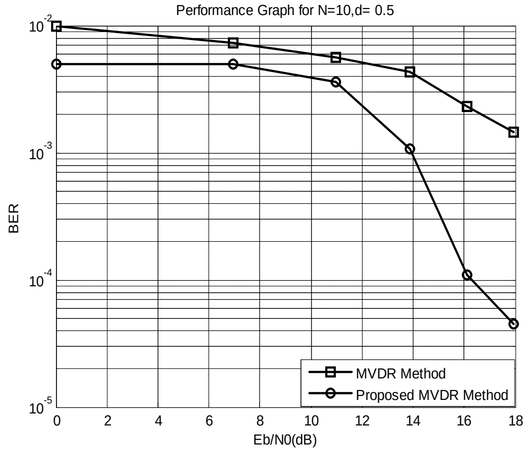


Fig. 3: BER Performance Graph for N= 10 and d =0.5.

A table has been shown from above figures for comparing the performance by varying the distance between the elements without changing the number of elements.

| N=10 | BER | | | |
|---|---|---|---|---|
| | d=0.2 | | d=0.5 | |
| $E_b/N_o$(dB) | MVDR | Proposed MVDR | MVDR | Proposed MVDR |
| 6.93 | 0.00487 | 0.00110 | 0.00735 | 0.00498 |
| 10.99 | 0.00465 | 6.5e-005 | 0.00557 | 0.00360 |
| 13.86 | 0.00392 | 2.5e-005 | 0.00429 | 0.00107 |
| 16.09 | 0.00181 | 2e-005 | 0.00230 | 0.00011 |

Table 1: BER Performances of Proposed method for N=10, with d= 0.2 & d= 0.5.

From the Table 1, it is clear that proposed method shows less BER for both values of d = 0.2 and d = 0.5. From the table 1, figure 2 and 3, it is observed that performance improves when spacing between the antenna elements changes from d = 0.5 to d = 0.2. This is due to fact that at less spacing, the power spectrum is more concentrated, produces sharper peaks and lower noise floor towards the desired user and produce deep null towards interfering user.

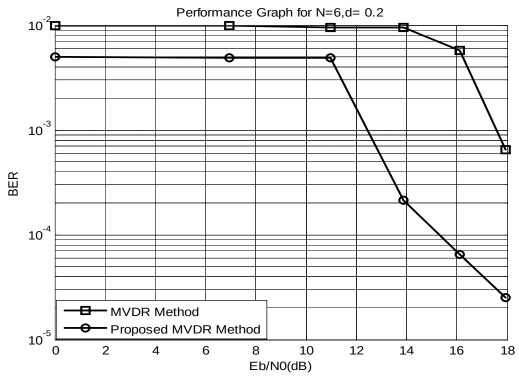


Fig. 4: BER Performance Graph for N= 6 and d =0.2.

Figure 4 shows the graph when number of antenna elements are taken 6 and spacing between the elements is 0.2. In the figure, the proposed method shows good performance. For the $E_b/N_0$ of 10dB, the proposed method has BER of 0.00484 while the existing method has BER of 0.00954.

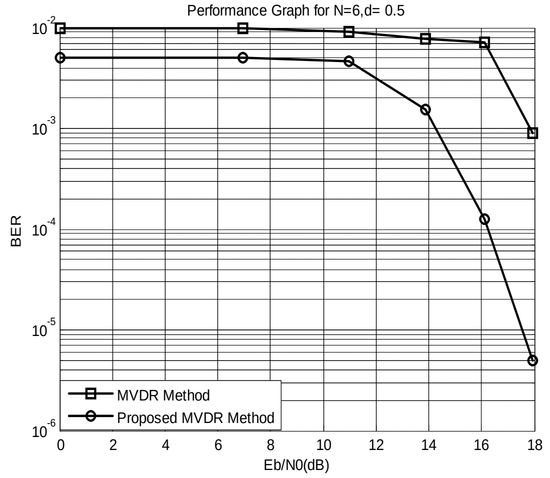


Fig. 5: BER Performance Graph for N= 6 and d =0.5.

Figure 5 shows the graph when number of antenna elements are taken 6 and spacing between the elements is 0.5. In the figure, the proposed method shows less number of bits in error. For the $E_b/N_0$ of 10dB, the proposed method has BER of 0.00484 while the existing method has BER of 0.00960. The Plot of figure 4 and 5 is almost flat for 2≈< $E_b/N_o$≈<10 and there is a fall in the curve for $E_b/N_o$≈>11dB but both figures shows the effectiveness of proposed method.

| d=0.2 | BER | | | |
|---|---|---|---|---|
| | N=6 | | N=10 | |
| $E_b/N_o$(dB) | MVDR | Proposed MVDR | MVDR | Proposed MVDR |
| 6.93 | 0.00990 | 0.00489 | 0.00487 | 0.00110 |
| 10.99 | 0.00960 | 0.00486 | 0.00465 | 6.5e-005 |
| 13.86 | 0.00960 | 0.00021 | 0.00392 | 2.5e-005 |
| 16.09 | 0.00576 | 6.5e-005 | 0.00181 | 2e-005 |

Table 2: BER Performances of Proposed method for d= 0.2, with N=6 & N= 10.

| d=0.5 | BER | | | |
|---|---|---|---|---|
| | N=6 | | N=10 | |
| $E_b/N_o$(dB) | MVDR | Proposed MVDR | MVDR | Proposed MVDR |
| 6.93 | 0.00990 | 0.00499 | 0.00735 | 0.00498 |
| 10.99 | 0.00958 | 0.00483 | 0.00557 | 0.00360 |
| 13.86 | 0.00773 | 0.00152 | 0.00429 | 0.00107 |
| 16.09 | 0.00713 | 0.00012 | 0.00230 | 0.00011 |

Table 3: BER Performances of Proposed method for d= 0.5, with N=6 & N= 10.

The table no. 2 and 3 show the performance comparison by varying the number of elements without changing the distance between the elements. From the tables it is clear that BER values decrease drastically as we go on increasing the number of antenna elements from 6 to 10. Therefore, the six antenna system does not have sufficient degree of freedom for nulling the interference user or the part of array gain has been spared to suppress the interferences leading to reduced performance.

## V. CONCLUSION

In this paper, we modified the MVDR Beamforming method in order to assign the weights. These optimum modified weights produce less error signal as compared to conventional MVDR and result into minimum energy (variance) of the output signal in the undesired direction and the desired signal is not distorted. The Direction of arrival of the signal received at the antenna array is estimated using MUSIC method. For analyzing the effectiveness of the method, we compared it with the MVDR method and plotted Bit Error Rate graphs. An in-depth analysis was done by varying the number of elements and the spacing between the antenna elements. It is shown that when the spacing between the elements is less and number of antenna elements is more, the bit error rate falls drastically which shows the effectiveness of the proposed method.

## VI. REFERENCES

[1] W. Oliphant and Malcolm, "The Mobile Phone Meets the Internet," IEEE Spectrum, vol. 36, Issue 8, pp. 20-28, August 1999.
[2] UMTS, "Spreading and Modulation," 3G TS 25.213 V3.2.0 (2000-03).
[3] UMTS, "Physical Channels and Mapping of Transport Channels onto Physical Channels (FDD)", 3G TS 25.211V3.2.0 (2000-03).
[4] R. Prasad, W. Mohr and W. Konhauser, Third Generation Mobile Communication Systems, Artech House, Boston / London, 2000.
[5] Parveen Singla and Jyoti Saxena, "Enhanced Capacity Analysis in WCDMA System", International Journal of Electronics & Communication Engineering, Vol. 4, No.1, pp.69-82, 2011.
[6] S. Bellofiore, J. Foutz, R. Govindarajula, I. Baheci, C. A. Balanis, A. S. Spanias, J. M. Capone and T. M. Duman, "Smart antenna system analysis, integration and performance for Mobile Ad-hoc networks (MANETs)" , IEEE Transactions on Antennas and Propagation, Vol.50, No. 5, pp. 571-581, May 2002.
[7] J. Lu and T. Ohira, "Smart antennas at wireless mobile computer terminals and mobile stations," In IEEE APS International Symposium, USNC/URSI National radio Science Meeting , July 2001.
[8] A.J.Paulraj, D.Gesbert and C.Papadias, "Smart Antennas for Mobile Communications", Encyclopedia for Electrical Engineering, John Wiley Publishing Co. pp 1-15, 2000.
[9] F. Harabi, H. Changuel and A. Gharsallah, "Estimation of 2-D Direction of Arrival with an Extended Correlation Matrix ", IAENG International Journal of Computer Science, Vol. 33, Issue 2, p25, May 2007.
[10] L.C. Godara, "Application of Antenna Arrays to Mobile Communications.II. Beamforming and Direction-of-Arrival Considerations", Proceedings of IEEE, Vol. 85, Issue 8, pp.1195-1245, August 1997.
[11] A. Kuchar, M. Tangemann and E. Bonek, "A Real-Time DOA-Based Smart Antenna Processor", IEEE Transactions on Vehicular Technology, Vol. 51, Issue 6, pp. 1279-1293, November 2002.
[12] S.Ravishankar, H.V. Kumaraswamy and B.D.Satish, " Comparative Analysis of Direction of Arrival Estimation and Beamforming Techniques in Smart Antennas", obcom: Mobile , Ubiquitous & Pervasive Computing, Vellore institute of Technology, Vellore, Tamil Nadu, 19 Dec, 2006.
[13] M. A. Akbar, H. B. Tila, M. Z. Khalid and M. A. Ajaz, "Bit Error Rate Improvement using ESPRIT based Beamforming and RAKE receiver", IEEE 13th International Multitopic conference –INMIC 2009, pp.1-6, Dec. 2009.
[14] H. Li and T. Liu, "Comparison of Beamforming Techniques for WCDMA Communication Systems", IEEE Transactions on Vehicular Technology, Vol. 52, Issue 4, pp. 752-760, July, 2003.
[15] T.B. Lavate, V.K. Kokate and G.S. Mani, "Non Blind and Blind Adaptive Array Smart Antenna Beam forming Algorithms for W-CDMA Mobile Communication Systems", Second International Conference on Computer Engineering and Applications, Bali Island, Indonesia, vol. 2, pp.200-203, March 2010.
[16] R. Lorenz and S. Boyd , "Robust Minimum Variance Beamforming", IEEE Transactions on Signal Processing, vol.53, No. 5, pp.1684-1696, May 2005.
[17] E.M. Al Ardi, R.M. Shubair and M.E. Al Mualla, "Direction of Arrival Estimation in a Multipath Environment: An Overview and a New Contribution," Applied Computational Electromagnetic Society Journal: Special Issue on Phased and Adaptive Array Antennas, vol. 21, Issue 3, pp. 226-239, Nov. 2006.
[18] S. Haykin, Adaptive Filter Theory. Prentice-Hall, 4th Ed., 2002.
[19] H.L. Van Trees, "Detection, Estimation, and Modulation Theory, Part IV: Optimum Array Processing", John Wiley & Sons, 2002.