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Design and Performance Analysis of Blind Algorithms for Smart Antenna System Using Window Techniques

[1]M. Yasin, [1]Pervez Akhtar and [3]S.H Zaheer Naqvi

[1]Department of Electronics and Power Engineering,
National University of Sciences and Technology, Islamabad, Pakistan
[2]Pakistan Navy Weapon Engineering School, KARSAZ, Karachi, Pakistan

Abstract: Smart antenna system is an area in which a lot of effort and trials are being carried out to increase the capacity and quality of mobile communication networks. This paper focuses on the design of blind adaptive beamforming algorithms i.e. Kaiser-Constant Modulus Algorithm (KCMA), Hann CMA (HCMA) and Hamming CMA (HAMCMA), using window techniques employed for spatial filtering i.e. adaptive beamforming which is novel in this application. These proposed blind adaptive beamforming algorithms are embedded in a smart antenna in code form. We investigate the effect of these proposed blind algorithms on detection of desired signal in the shape of beam form and null generation for interferer in the presence of noise and interference. Performances of these algorithms are analyzed via simulation results. It is confirmed that KCMA is more efficient algorithm to optimize the beam and nullify noise, thus enhancing capacity and service quality as compared to HCMA and HAMCMA.

Key words: Smart Antenna · Constant Modulus Algorithm (CMA) · Kaiser Window · Hann Window · Hamming Window

INTRODUCTION

Beamforming utilization in mobile communication system is the source of inspiration to study [1-14] for capacity and quality improvement employing smart/adaptive array antenna. In article [15], an innovative downlink Multiple-Input Multiple-Output Spatial Division Multiple Access (MIMO-SDMA) optimization technique based on memetic algorithms using phase-amplitude perturbation method for smart antennas is proposed and beamforming along with null suppression is studied. In paper [16], the design and simulation of a smart antenna system for Digital Enhanced Cordless Telecommunication (DECT) radio base stations in wireless local loop (WLL) is discussed using MUltiple SIgnal Classification (MUSIC) and Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) for Direction-of-arrival (DOA) Estimation and Least Mean Square (LMS) algorithm is used for adaptive beamforming. Therefore we give an idea about how the proposed blind adaptive algorithms i.e. Kaiser Constant Modulus Algorithm (KCMA), Hann CMA (HCMA) and Hamming CMA (HAMCMA); using window technique methods can further improve smart/adaptive antenna technology both in beam formation and null generation. In [17-19] Window techniques are used in digital signal processing (DSP) applications such as finite impulse response (FIR) and infinite impulse response (IIR) filters design to suppress the noise frequencies. In paper [20], the author proposes the prototype filters design using Kaiser Windows to optimize the cut off frequency. In [21], the performance of linear switched beam smart antenna (SBSA) has been investigated for various Windowed beam forming functions such as Hamming, Gaussian and Kaiser-Bessel functions and observation is made that the Kaiser-Bessel weights provide one of the lowest array side lobe levels while maintaining nearly the same beam width. Consequently Kaiser-Bessel function can widely be used with SBSA to improve the capacity of 3G cellular system. In our case, we use window techniques for adaptive beamforming, therefore, is novel in this sense.

Corresponding Autor: M. Yasin, Department of Electronics and Power Engineering,
National University of Sciences and Technology, Islamabad, Pakistan. E-mail: myasin@pnec.edu.pk.

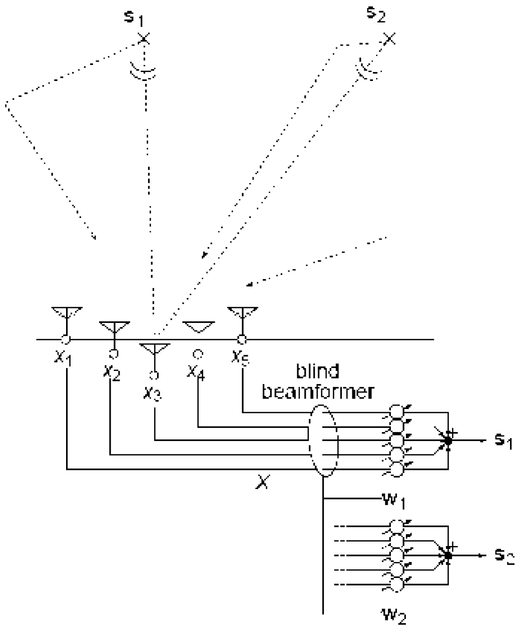

Fig. 1: Smart/adaptive antenna array system

In [22-24], the various windows technique is used with Fast Fourier Transform (FFT) for the detection of harmonic signals in the presence of broad noise whereas in our case, these windows technique are used in order to compute adaptive weights. The proposed adaptive beamforming algorithms provide appropriate solution for random noise suppression exploiting the spatial structure environment such as non-Gaussian and constant modulus and as a result desired beam is achieved in the look direction. The antenna array elements are usually "connected" to an adaptive processor and user's signal arrives from desired direction at an angle Φ_0 as shown in Figure 1 [6].

KCMA, HCMA (also known as a Hanning window) and HAMCMA are the blind beamforming algorithms, used for controlling weights adaptively to optimize signal to noise ratio (SNR) of the desired signal in look direction. The next section introduces the narrowband smart antenna arrays system model. Section 3 contains algorithms description of KCMA, HCMA and HAMCMA. Section 4 illustrates simulation results. Discussion and results is presented in section 5. Finally, section 6 contains the conclusions.

System Model: In signal processing, the window function is a mathematical function which is operated within a bounded interval. Kaiser, Hann and Hamming windows are considered high/moderate resolution windows. They are usually used in narrowband application [19-21] where the input vector $x(k)$ consists of desired signal $s(k)$ plus noise vectors $n(k)$ and is defined by

$$x(k) = s(k) + n(k) \quad (1)$$

Where k denotes the time instant of the input vector and can be dropped for simplification. At each time instant, we obtained array output vector, defined by

$$y(k) = x^T(k)w = w^H x(k) \quad (2)$$

Where T represents the transpose of the input signal vector and H denotes the Hemittian transpose (complex conjugate) operation of the array weight vector which can be expressed as

$$w = [w_1, w_2, \ldots.., w_M]^T \quad (3)$$

The array output is then passed to the signal processor which uses the previous value of the output and current values of the inputs to determine the adjustment to make to the weights. The weights are then adjusted and multiplied with the new input vector to obtain the next output. The output feedback loop allows the weights to be adjusted adaptively, thus accommodating nonstationary environments. Equation (2) is used to find a weight vector that will allow the output y to approximately equal the true target signal.

Algorithms Description

KAISER CMA Algorithm: The proposed algorithm is the unification of CMA [6] and Kaiser Window [20] and provides computationally efficient implementation for beamforming. This proposed algorithm is known as KCMA. The weight of KCMA is computed by.

$$w(k+1) = w(k) - 2\mu e(k) kaiser(N,\beta) x(k) \quad (4)$$

Where μ is the step size. If μ is chosen to be very small, then convergence becomes slow. If μ is kept large, then convergence becomes fast, but stability becomes a problem. Therefore it is better to select μ within bounded conditions as defined by.

$$0 < \mu < \frac{1}{\lambda_{max}} \quad (5)$$

Where λ_{max} is the largest eigen value of autocorrelation matrix of input signal. N is the number of elements and β is the Kaiser window parameter that affects the sidelobes attenuation. It is given by

$$\beta = \begin{cases} 0.1102(\alpha - 8.7), & \alpha > 50 \\ 0.5842(\alpha - 21)^{0.4} + 0.07886(\alpha - 21), & 50 \geq \alpha \geq 21 \\ 0, & \alpha < 21 \end{cases} \quad (6)$$

Where α defines the sidelobes attenuation in dB and x is the signal array vector, written by

$$x(k) = [x_1(k), x_2(k),.....,x_M(k)]^T \quad (7)$$

This signal array vector can also be written as

$$x(k) = s_d(k)a(\theta_d) + \sum_{i=1}^{L} s_i(k)a(\theta_i) + n(k) \quad (8)$$

Where S_d & S_i are the desired and interfering signals arriving at the array at an angle θ_d & θ_i respectively. L is the number of interfering signals and n is the noise at the array elements. $a(\theta_d)$ and $a(\theta_i)$ are the steering vectors for the desired and interfering signals respectively. The steering vector is described as

$$a(\theta) = [1, e^{-j\phi},......, e^{-j(M-1)\phi}] \quad (9)$$

Where $\phi = \frac{2\pi d}{\lambda}\sin\theta$ is the phase shift observed at each sensor due to the angle of arrival of the wavefront and assume d is the uniform distance between array elements. $\lambda = \frac{c}{f}$ where f is in Hertz. Therefore, the steering vector can be written as

$$a(\theta) = [1, e^{-j\frac{2\pi}{\lambda}d\sin(\theta)},......., e^{-j\frac{2\pi}{\lambda}d(M-1)\sin(\theta)}] \quad (10)$$

The output of beamformer is given by

$$y = w^H x \quad (11)$$

The array weight vector can be expressed as

$$w = [w_1, w_2,....., w_M]^T \quad (12)$$

$e(k)$ signifies the estimation of error which is defined by

$$e(k) = y - \frac{y}{|y|} \quad (13)$$

The estimation of error $e(k)$ is taken from CMA algorithm [4]. The weight matrix update approaches its true value, when the number of samples grows i.e. $k \to \infty$ and thus the estimated weights approaches the optimal weights ($w(k+1) \to w$) or w_{MSE}.

HANN CMA Algorithm: The proposed algorithm is designed in order to optimize the performance of spatial filtering using Hann window technique. The Hann and Hamming windows belong to a "raised cosine" windows. The goal of this proposed adaptive beamforming algorithm is to extract desired information (S_d) from signal array vector ($x(n)$) and to place null towards interferers (s_i) of same frequency. This is achieved by adjusting weights of each antennas used in the array adaptively. The weight vector for proposed algorithm to compute optimum weight is given by

$$w(k+1) = w(k) - 2\mu e(k)hann(N)x(k) \quad (14)$$

Where the coefficients of a Hann window are determined from the equation, given by

$$w(k) = 0.5\left(1 - \cos\left(\frac{2\pi n}{N}\right)\right), \quad 0 \leq n \leq N \quad (15)$$

Where x is the input samples arrived on the array system and is given by

$$x(x) = [x_1(k), x_2(k),.....,x_M(k)]^T \quad (16)$$

$e(k)$ is the cost function which can be calculated using (13) and μ is the step size, used for stability of adaptation. The weight vector computed by (14), will allow the output y to approximately equal the true target signal then this weight vector is known as optimum weights ($w(k+1) \to w$) or w_{MSE}.

HAMMING CMA Algorithm: This proposed algorithm is also designed in order to enhance the performance of spatial filtering using Hamming window technique. Hamming window is type of modified Hanning window [20-21]. Again using (1)(2) and (13) for computing optimum weight vectors, which is defined by

$$w(k+1) = w(k) - 2\mu e(k)hamming(N)x(k) \quad (17)$$

Where the coefficients of a Hamming window are worked out from the equation, given by

$$w(k) = 0.54 - 0.46\cos\left(\frac{2\pi n}{N}\right) \qquad 0 \le n \le N \tag{18}$$

u is the step size, used for stability of adaptation as defined in (5) and $e(k)$ is the cost function which is also known as minimum mean square (MSE) can be found using (13).

The array output signal obtained with the sample weights is given by

$$y = w^H x \tag{19}$$

Where x is the input samples arrived on the array system and w is the weight vector, as described in (1) and (3) respectively.

The weight matrix update approaches its true value, when the number of samples grows i.e. $k \to \infty$ and thus the estimated weights approaches the optimal weights $(w(k+1) \to w)$ or w_{MSE}.

Simulation Results: The phase modulated signal is applied for simulation purpose, to illustrate the effect of element spacing, number of elements and beam steering on uniform linear array using window technique methods. The phase modulated signal is given by

$$S(t) = e^{j\sin(\omega t + \phi)} \tag{20}$$

Where ϕ is the phase angle of the applied signal

Simulation for KAISER CMA Algorithm

Effect of Number of Elements on Array Factor: Uniform linear array is taken for simulation purpose with five hundred samples for different number of elements. The spacing between array elements is taken as $\lambda/2$. The angle of arrival (AOA) for desired user is 0 degrees and two interferers are set at 50 and -30 degrees. The normalized array factor for number of elements is shown in Figure 2. It is observed that the array directivity increases with the number of elements but at the time number of side lobes and the side lobe level increase with the number of elements. A comparison of the various results derived from Figure 2 is presented in Table 1.

It is confirmed from Table 1 that half power beam width (HPBW) and beam with of desired user decreases with increase in number of elements.

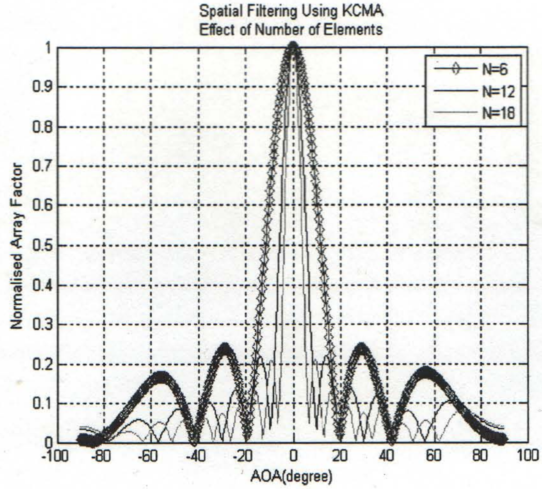

Fig. 2: Normalized array factor plot for KCMA algorithm with AOA for desired user is 0 degree and -30 & 50 degrees for two interferers with constant space of $\lambda/2$ between elements.

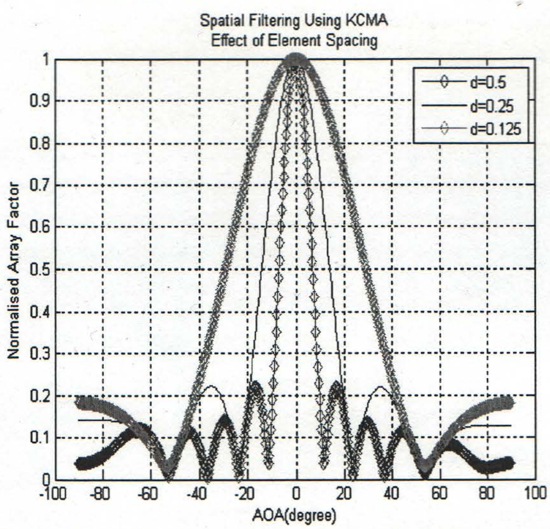

Fig. 3: Normalized array factor plot for KCMA algorithm for N = 10 with two interferers at 50 & – 30 degrees

Effect of Element Spacing on Array Factor: The element spacing has a large influence on the array factor. Larger element spacing results in a higher directivity.

Therefore, the effect of array spacing for $\lambda/2$, $\lambda/4$ and $\lambda/8$ is depicted in Figure 3 for $N = 10$ with two interferers at 50 & – 30 degrees. It is shown that the algorithm converges faster and stable for spacing equal to $\lambda/2$. The results are summarized in Tables 2 when number of elements is kept constant.

Table 1: Effect of number of elements on beam width

Angle of Arrival (degree)	No. of Elements	Element spacing d	Step size μ	HPBW (degree)	Beam width (degree)
0°	6	λ/2	0.001	20	40°
0°	12	λ/2	0.001	16	20°
0°	18	λ/2	0.001	10	16°

Table 2: Effect of element spacing on beam width

Angle of Arrival (degree)	No. of Elements	Element spacing d	Step size μ	HPBW (degree)	Beam width (degree)
0°	10	λ/2	0.001	10	22°
0°	10	λ/4	0.001	20	48°
0°	10	λ/8	0.001	42	108°

Table 3: Effect of number of elements on beam width

Angle of Arrival (degree)	No. of Elements	Element spacing d	Step size μ	HPBW (degree)	Beam width (degree)
20°	6	λ/2	0.001	20	40°
20°	12	λ/2	0.001	16	22°
20°	18	λ/2	0.001	10	16°

Simulation for HANNING CMA Algorithm

Effect of Number of Elements on Array Factor: The spacing between array elements is taken as λ/2 with five hundred samples for different number of elements. AOA for desired user is set at 20 degree and two interferers are taken at an angle 50 and -30 degrees as shown in Figure 4 which provides deep null at 50 and - 30 degrees. It is confirmed that the directivity of array is enhanced when number of elements equal to 18. Table 3 compares the results obtained from Figure 3, when element spacing is kept λ/2 as shown.

Effect of Element Spacing on Array Factor: The effect of array spacing for λ/2, λ/4 and λ/8 is depicted in Figure 5 for $N = 10$ with two interferers at 50 & – 30 degrees. AOA for desired user is set at -10 degrees. The spacing between the elements is critical, due to side lobes problems, which causes grating lobes, which are the repetitions of the main beam within the range of real angles.

Again, it is confirmed that element spacing equal to λ/2 gives best result for narrow beam form and faster convergence. Increasing the element spacing towards λ results in an increased directivity but the effect of grating lobe is also worth noting. An element spacing beyond λ becomes impractical and results in multiple unwanted grating lobes. Various results obtained from Figure 5 are tabulated in Table 4, when element spacing is kept different.

Table 4: Effect of element spacing on beam width

Angle of Arrival (degree)	No. of Elements	Element spacing d	Step size μ	HPBW (degree)	Beam width (degree)
-10°	10	λ/2	0.001	10	24°
-10°	10	λ/4	0.001	20	48°
-10°	10	λ/8	0.001	42	108°

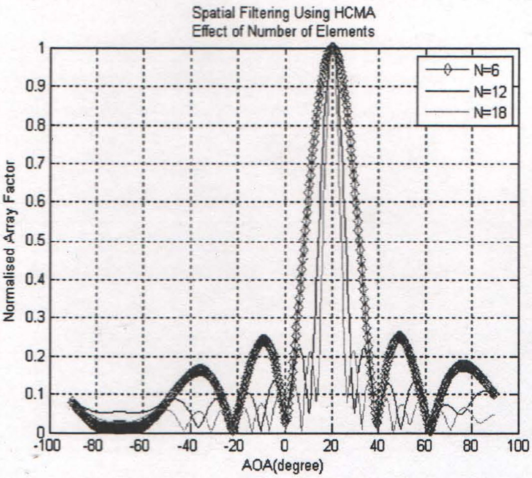

Fig. 4: Normalized array factor plot for HCMA algorithm with AOA for desired user is 20 degree and 50 & -30 degrees for two interferers with constant space of λ/2 between elements.

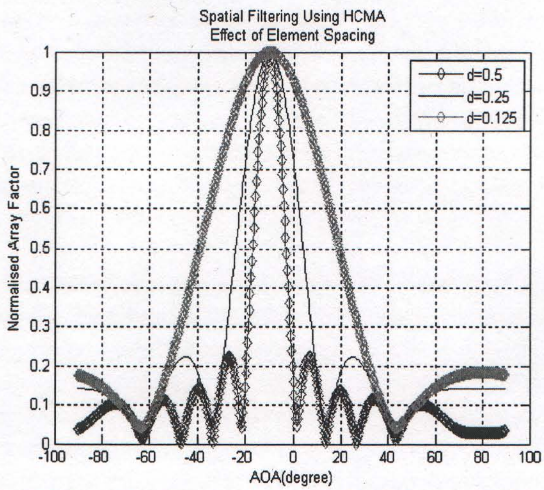

Fig. 5: Normalized array factor plot for HCMA algorithm for $N = 10$ with two interferers at 50 & – 30 degrees

Simulation for HAMMING-CMA Algorithm

Effect of Number of Elements on Array Factor: Normalized array factor is shown in Figure 6 for different number of elements equal to $N = 6,12$ and 18 but it is observed that side lobes also increases with the number of elements. In this case, AOA for desired user is set at 10 degree and two interferers are found at an angle 50

Table 5: Effect of number of elements on beam width

Angle of Arrival (degree)	No. of Elements	Element spacing d	Step size μ	HPBW (degree)	Beam width (degree)
10°	6	$\lambda/2$	0.001	20	40°
10°	12	$\lambda/2$	0.001	16	20°
10°	18	$\lambda/2$	0.001	10	16°

Table 6: Effect of element spacing on beam width

Angle of Arrival (degree)	No. of Elements	Element spacing d	Step size μ	HPBW (degree)	Beam width (degree)
-20°	10	$\lambda/2$	0.001	10	22°
-20°	10	$\lambda/4$	0.001	20	48°
-20°	10	$\lambda/8$	0.001	42	108°

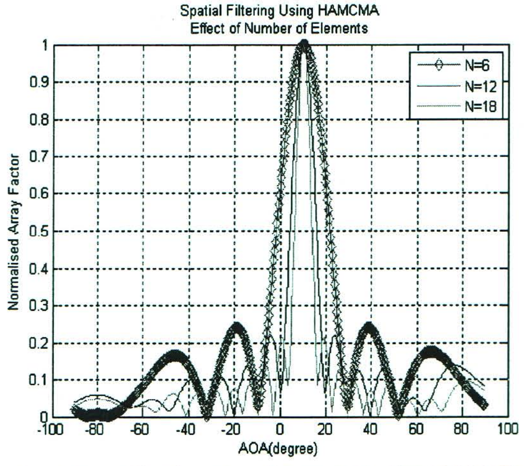

Fig. 6: Normalized array factor plot for HAMCMA algorithm with AOA for desired user is 10 degree and 50 & -50 degrees for two interferers with constant space of $\lambda/2$ between elements

and -50 degrees with element spacing $\lambda/2$. The best array directivity is achieved for $N = 18$.

A comparison of the various results drawn from Figure 6 is given in Table 5 when number of elements is kept constant as shown. It is observed that the array directivity increases with the number of elements.

Effect of Element Spacing on Array Factor: The element spacing has a large influence on the array factor. The effect of array spacing for $\lambda/2$, $\lambda/4$ and $\lambda/8$ is shown in Figure 7 for $N = 10$. AOA is -20 degrees for desired user with two interferers at 50 & – 50 degrees. Deep null is obtained at 50 degrees and at -50 degrees. The results obtained from Figure 7 are provided in Table 6 to demonstrate the effect of array spacing as shown. It is confirmed that half power beam width (HPBW) and beam with of desired user decreases with increase of the element spacing towards λ that results an increase in directivity.

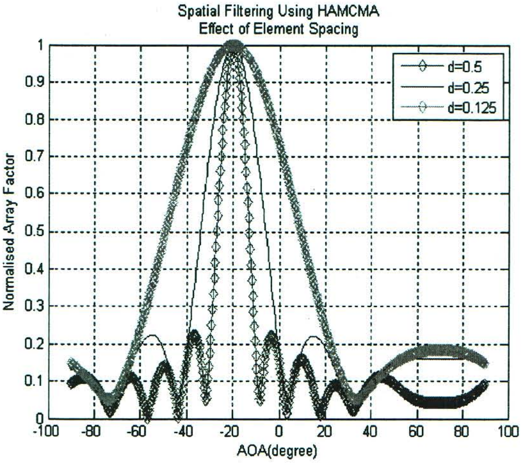

Fig. 7: Normalized array factor plot for HAMCMA algorithm for $N = 10$ with two interferers at - 50 & 50 degrees

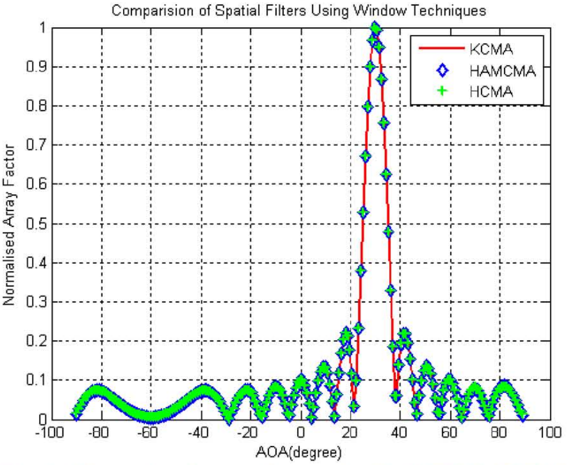

Fig. 8: Normalized array factor plot for KCMA, HCMA and HAMCMA algorithms with AOA for desired user is 30 degree and 50 & -50 degrees for two interferers with constant space of $\lambda/2$ between elements.

Comparison of Windows Algorithms

Effect of AOA on Array Factor: In this case two hundred number of sample is taken for simulation purpose. AOA for desired user is set at 30 degrees for KCMA, HCMA and HAMCMA algorithms, keeping element spacing $\lambda/2$ with $N = 14$. Simulation result verifies that all these three algorithms have good beam forming and beam steering capability as shown in Figure 8.

Effect of Error: It is important to know how the error degrades the array performance. Therefore, two hundred number of sample is taken for $N = 14$ to analyze minimum

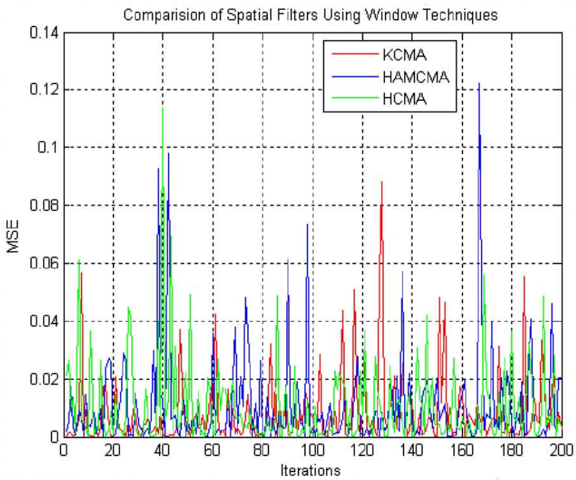

Fig. 9: Mean Square Error plot for KCMA, HCMA and HAMCMA algorithms for $N = 14$.

mean square error (MMSE). The minimum MSE is achieved for KCMA as shown in Figure 9 and same is compared with HCMA and HAMCMA. It is confirmed from the simulation results that KCMA algorithm converges faster as compared to HCMA and HAMCMA. However HCMA is found better than HAMCMA in terms of obtaining minimum MSE.

DISCUSSION AND RESULTS

This paper proposed three in number blind adaptive beamforming algorithms for a smart antenna system. A detailed system model is presented and analyzed, supported by mathematical and analytical model, which is further being utilized to draw simulation results for analysis. The KCMA HCMA and HAMCMA algorithms are compared on the basis of beam pattern, stability, null depth performance & computation time for optimum weights vector.

The findings of simulation and mathematical analysis are:

- The Proposed blind algorithms that uses for beamforming is capable of directing their radiation energy towards the direction of the desired user while suppressing interference. This increases the capacity and quality of network equipped with smart antenna.
- The Proposed blind algorithms which uses spatial filtering i.e. beamforming in smart antenna, due to this frequency reuse is efficient and effective.
- The Communication System equipped with omni antennas keep the adjacent channels on standby during their transmission while System with smart antennas focus only on the desired users and allow the adjacent channels/users to communicate with each other without any interference.
- The Proposed blind algorithms are based on SDMA technique due to which all users in the network are able to communicate at the same time using the same channel.
- The Proposed blind algorithms exploit the spatial structure environment such as non-Gaussian and constant modulus; which is the suitable solution for random noise control.
- The simulations are carried on *Intel(R) Core(TM)2 CPU E7400 @ 2.80 GHz, 1.98 GB of RAM* hardware, using *MATLAB version 7.8.0.347 (R2009a)* software, the simulation results verify that the computation time of KCMA algorithm (0.0973 sec) is more as compared to HCMA (0.0700 sec) and HAMCMA algorithms (0.0459 sec). It also confirms that if more sophisticated signal processor is used for spatial processing then computation time can further be reduced.
- The simulation results also yields that KCMA algorithm is much more stable as compared to HCMA and HAMCMA algorithms.
- The null depth/steering performance of the proposed blind algorithms are good. However, the null depth performance of KCMA is better than that of HCMA and HAMCMA algorithms.
- The Proposed blind algorithms don't require pilot signal for synchronization and convergence at the receiver. Therefore, maximum bandwidth is utilizing to exchange information between transmitters and receivers, thus enhancing capacity.
- The convergence property/capability of the proposed blind adaptive algorithms is approximately same.
- KCMA has better capability to obtain minimum MSE as compared to HCMA and HAMCMA algorithms. However, the noise reduction performance of HCMA is good than that of HAMCMA. It is also ascertained from simulation results as shown in Figure 9.
- This significantly increases the signal quality and mitigates interference on both the uplink and downlink radio channels, resulting in increased coverage and spectral efficiency.

CONCLUSION

The Proposed blind adaptive algorithms are performing very well for beamforming, null steering and for noise cancellation. However the performance of KCMA algorithm is found better as compared to HCMA and HAMCMA algorithms. KCMA is, therefore, a better option to implement at base station of mobile communication systems using either CDMA or TDMA environment to reduce interference in the system, thus to increase quality and capacity.

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