Performance Trade-Offs Among Optimized Beamforming Techniques for Smart Antenna System

Abdul Rehman, Muhammad Najam-ul-islam, Umar Mujahid

Abstract— **Smart antenna is a promising technology for the efficient utilization of limited Radio Frequency (RF) spectrum, improved system capacities and wireless communications through the implementation of Space Division Multiple Access (SDMA). Smart antenna radiation patterns are controlled via beamforming algorithms exploiting sophisticated spatial processing techniques based upon certain optimum criteria. This paper highlights the implications of optimum beamforming techniques for achieving high data speed rates and coverage area in cellular communication networks. In this paper, optimum beamforming algorithms have been analysed such as Multiple Sidelobe Canceller (MSC), Minimum Variance Distortionless Response (MVDR) and Minimum Mean Square Error (MMSE) respectively. A trade-off analysis of various array performance metrics has also been presented among three beamforming techniques. Simulation results reveal that beamforming minimizes the interference power considerably by selecting optimum weights. The results illustrate that MMSE beamformer is helpful in mitigating Non-Line of Sight (NLOS) fading effects while MVDR beamformer has good performance in Line-of-Sight (LOS) fading environment. Moreover, MMSE beamformer outperforms than other techniques with very narrower Half Power Beamwidth (HPBW) and Null-to-Null Beamwidth (NNBW). Depending on the application, one of the techniques is carefully chosen for deployment in smart base station antenna for cellular communication networks.**

Index Terms—**Optimum Beamforming, Multiple Sidelobe Canceller (MSC), Minimum Variance Distortionless Response (MVDR), Minimum Mean Square Error (MMSE).**

I. Introduction

In recent decades, with a phenomenal increase in mobile service applications there is desperately need of sophisticated technologies to fulfill the ubiquitous user demands and to combat with environmental impairments. Smart antenna is responsible for providing a prime solution to the fundamental requirements of future generation wireless communication systems. Generally, antennas are not smart itself. 'Smart antenna' essentially means an antenna array with a sophisticated signal processor in order to shape the beam pattern towards desired direction. The background of smart antenna system does not encompass to a single discipline [1]. Fig. 1 shows the orderly approach to achieve beamforming goal in smart antenna system.

Abdul Rehman, Muhammad Najam-ul-islam, Umar Mujahid, Department of Electrical Engineering Bahria University Islamabad, Pakistan. Email: najam@bahria.edu.pk. Manuscript received February 13, 2014; revised August 13, 2014 and October 27, 2014

Once the incoming signal direction is estimated [2], the imminent process to perform is beamforming. In smart antenna, beamforming is perceived as a promising technology for improving the capacity of 3G wireless networks by efficiently mitigating multipath and co-channel interference [3]. Beamforming is an array signal processing [2] technique that offers an adaptable form of spatial filtering. Beamforming is a leading technique that ensures highly directional beam pointed towards Signal-of-Interest (SOI) and places null towards Signal-Not-of-Interest (SNOI). Thus enhancing signal to interference-noise ratio (SINR). This spatial selectivity is accomplished via fixed or adaptive transmit/receive beam patterns. The beam is shaped in such a way that it is directed in the interest direction by choosing the complex weights of the antenna elements [4]. The receive beamforming is attained autonomously at each receiver whereas transmitter has to consider all the receivers to optimize beamformer output in transmit beamforming [5,6,7]. The benefits of beamforming antenna are as follows;

1. Gain in SINR minimizes the frequency reuse factor resulting in an increase in capacity. Such as IEEE 802:16m or 3GPP LTE-A are those Emerging Broadband Wireless Systems which will reuse spectrum in every cell (reuse factor = 1) [8, 9].

2. Beamforming may be utilized in satellite communications to make spot beams in the direction of fixed-earth-based locations. Likewise, it can also be employed for mobile base stations to deliver Space Division Multiple Access (SDMA) capabilities [10].

3. Beamforming has the ability to mitigate multipath propagations existing in mobile radio vicinities by practically adding the multipath signal to further strengthen the desired signal [7].

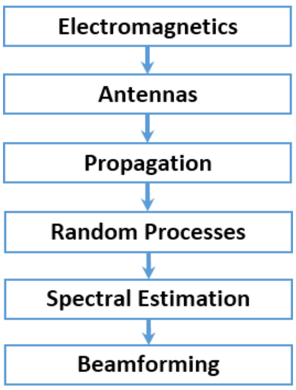

Fig. 1. Orderly approach towards beamforming

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This paper is systematized in the following way. The fundamentals of beamforming design methods are provided in section II. Optimum beamforming techniques and their optimum criteria for producing array weights are briefly narrated in section III. The simulations and results are discussed in section IV. Trade-off analysis is provided in section V. Finally conclusion is provided in section V.

II. BEAMFORMING DESIGN METHODS

In this section, beamforming design methods have been discussed. The main objective is to choose optimum approach so that to increase the desired signal output power. Before discussing beamforming design methods, this section also provide an overview of smart antenna system.

A. Smart Antenna System

A smart antenna system at the base station of cellular mobile system is depicted in fig. 2. A smart antenna system can essentially be divided into three parts. The first part estimates the angle of arrival and figure out number of signals striking the antenna arrays. It consists of a Uniform Linear Array (ULA) for which the current amplitudes are adjusted by a set of complex weights using an optimum beamforming algorithm. The beamforming algorithm optimizes the array output beam pattern such that maximum power is ensured towards desired mobile user. Its objective is to minimize the impact of undesired signals and to control a beam pattern in the desired direction. Prior to beamforming process, the second part which distinguishes between the SOI and SNOI is known as Direction-of-Arrival (DOA) estimation. This is achieved by DOA estimation algorithms. The results are then used to choose the optimum weights required to produce maximum radiated power towards desired users and nulls in the direction of interferers.

B. Methods Material

A successful design of an antenna array depends highly on the choice of DOA algorithm. This forms the basis for optimal beamforming algorithms so that the beamformer can place maximum radiation in the direction of desired source and nulls towards interferers. For a beamformer to work accurately, different signal processing properties necessary for optimum design are exploited in this section. According to fig. 3, a desired signal source and N interferences from $\theta_1\ \theta_2 \ldots \theta_N$ phases are considered which are striking M array elements having M potential weights [10]. Therefore, the array output factor is given as;

$$y(k) = \bar{w}^H . x(k) \quad (1)$$

$$\bar{x}(k) = \bar{a}_0 s(k) + [\,\bar{a}_1\ \bar{a}_2 \ldots \bar{a}_N\,].[i_1(k)\ i_2(k) \ldots i_N(k)]^H + \bar{n}\,(k) \quad (2)$$

$$\bar{x}(k) = \bar{x}_s(k) + \bar{x}_i(k) + \bar{n}(k) \quad (3)$$

The output of the beamforming method can generally be expressed as:

$$y(k) = \bar{w}^H . [\bar{x}_s(k) + \bar{x}_i(k) + \bar{n}(k)] \quad (4)$$

It can also be represented as;

$$y(k) = \bar{w}^H . [x_s(k) + \bar{u}(k)]$$

Where, $\bar{u}(k) = \bar{x}_i(k) + \bar{n}(k)$ is the undesirable signal respectively. Thus, $y(k)$ must follow the following limitations for directing nulls in the path of interferers.

Constraint I

The array gain $\bar{w}^H . \bar{A}_d$ should be unity when desired signals are passed through array elements.

$$y(k) = \bar{w}^H . \bar{A}_d = \bar{u}_1^T = 1 \quad (5)$$

Constraint II

$$y(k) = \bar{w}^H . \bar{A}_i = 0 \quad (6)$$

Accordingly, using constraint I, weights can be calculated by:

$$\bar{w}^H = \bar{u}_1^T . \bar{A}_d^{-1} \quad (7)$$

Where $\bar{u}_1^T = [1\ 0\ 0]^T$ is the Cartesian basis vector and points out that the array weights are selected from the first row of $\bar{A}_d^{-1}$. $\bar{A}_d = [\bar{a}(\theta_1)\ \bar{a}(\theta_2) \ldots \bar{a}(\theta_N)]$ is the array steering vector of each antenna elements. It must be a $N \times N$ matrix. $\bar{A}_i$ is the steering vector for interferers.

C. Assumptions Made

Throughout the simulations, the following assumptions have been assumed.

a) There should be less or equal number of incoming signals as compared to array elements.

b) The impinging signals are reflected to be narrowband and all function at identical carrier frequency.

c) Received signal is assumed to have a zero mean noise, which is Additive White Gaussian Noise (AWGN).

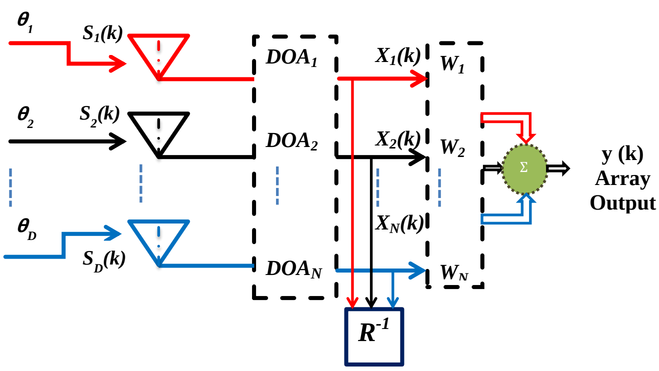

Fig. 2. Functional block diagram of smart antenna system

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III. STATISTICALLY OPTIMUM BEAMFORMING

Several researchers have treated the subject of optimum beamforming systems. Some of them include Applebaum [11], Widrow [12] and Frost [13]. In statistically optimum beamforming [14,15] technique, the weights are selected which are focused around the information received at antenna array. The purpose is to enhance the beamformer response so that the output contains insignificant involvement of SNOI. In this section, a detailed overview of several criteria for obtaining optimum weights is deliberated.

1. Multiple sidelobe canceller beamforming algorithm.
2. Minimum Variance beamforming algorithm.
3. Minimum mean square error beamforming algorithm.

Optimum weight vector solution is implemented by special filters known as wiener filters and therefore termed as wiener solution [10, 16].

A. Multiple Sidelobe Cancellation (MSC) beamforming algorithm

The concept of sidelobe cancellation was first presented by Howells in 1956 [17]. A MSC comprises of a “primary channel” and one or more “secondary channels”. The primary channel forms the mainlobe maximum pointed in the desired signal direction and also minimizes the effect of interferers present in sidelobes. The secondary channel objective is to select weights to cancel the primary channel interference component. Thus overall system requires a zero response to the interferers in primary and secondary channels. Demanding zero response to all interfering signals can generally result into significant white noise gain. Accordingly, weights are typically decided in order to balance interference suppression for white noise gain by reducing the estimated value of the total output power [14]. From (5), (6) and (7) array weights can be calculated by;

$$\overline{w}^H = \overline{u}_1^T.\overline{A}_d^H(\overline{A}_d.\overline{A}_d^H + \sigma_n^2\,\overline{I}\,)^{-1} \tag{8}$$

$\overline{u}_1^T$, is a cartesian basis vector and its length equals the used number of sources.

B. Minimum Variance (MV) beamforming algorithm

The minimum variance solution can also be termed as minimum variance distortionless response (MVDR). The basic idea of MVDR is to enforce a constraint weight on the beamformer output so that SOI with definite gain and phase can be passed [14,15]. The MVDR weights are selected such as to diminish the output noise variance in order to minimize the contribution of signals to the output other than SOI.

However, MVDR beamformer is not suitable in Non-Line of Sight (NLoS) settings as it exploits sensitivity only in one direction. Such settings include an urban area in which there are many scatters adjacent to the desired user and base station [7].

Referring to (5) and (6), MVDR requires the constant beam pattern in the bore sight direction so that;

$$min_{\overline{w}}\{\overline{w}^H.\overline{R}_{xx}.\overline{w}\}\ subject\ to\ \overline{w}^H.\overline{A}_d = 1$$

From (4), the weighted array output is given by;

$$y = \overline{w}^H.[\overline{a}_0 s + \overline{u}]$$

For distortionless response we need to apply the constraint in (5), which gives;

$$y = s + \overline{w}^H.\overline{u}$$

While assuming average zero mean for the undesired signals then estimated array output comes to be;

$$E[y] = s$$

The variance of y is formulated as;

$$\sigma_{MV}^2 = E[|\overline{w}^H.\overline{x}|^2]$$

$$\sigma_{MV}^2 = E[|s + \overline{w}^H\overline{u}|^2] = \overline{w}^H\,\overline{R}_{uu}.\overline{w} \tag{9}$$

The variance in (9) can be minimized by using Lagrange method [18]. So modified performance criteria can be defined by incorporating the constraint in (5) by [10];

$$J(\overline{w}) = \frac{\sigma_{MV}^2}{2} + \lambda(1 - \overline{w}^H\overline{a}_0) \tag{10}$$

Where **λ** is a Lagrange multiplier and $J(\overline{w})$ is the cost function. By setting gradient equal to zero $J(\overline{w})$ can be minimized.

$$\nabla_{\overline{w}} J(\overline{w}) = \overline{R}_{uu}\overline{w}_{MV} - \lambda\overline{a}_0 = 0 \tag{11}$$

By solving (11);

$$\overline{w}_{MV} = \lambda\overline{R}_{xx}^{-1}\overline{a}_0 \tag{12}$$

Where $\lambda = \frac{1}{\overline{a}_0{}^H\,\overline{R}_{uu}^{-1}\,\overline{a}_0}$ is obtained by substituting (5) in (12) respectively.

So, an optimal weight criterion for MVDR is given by;

$$\overline{w}_{MV} = \frac{\overline{R}_{xx}^{-1}\overline{a}_0}{\overline{a}_0{}^H\,\overline{R}_{uu}^{-1}\,\overline{a}_0} \tag{13}$$

C. Minimum Mean Square Error (MMSE) beamforming algorithm

MMSE beamforming is another alternative means of providing optimum array weights by minimizing the mean square error between the array output and the reference signal. Therefore, the reference signal $d(k)$ aids to train the beamformer weights. Sufficient knowledge of desired signal $s(k)$ is necessary such that, it can be correlated with the reference signal $d(k)$ and in the same way, uncorrelated with the interfering signals [10,14,15]. Unlike MVDR, MMSE beamformer gives optimum results in multipath fading environment.

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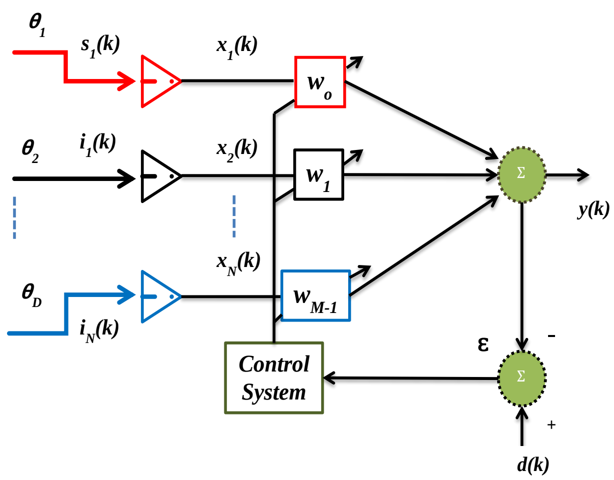

Fig. 3. M-Element array with feedback reference signal

In MMSE beamforming output array is subtracted from the reference signal $d(k)$to produce an error signal $\varepsilon(k) = d(k) - w^H x(k)$, which is used to regulate the weights.

From fig. 3, the error signal is given by [10];

$$\varepsilon(k) = d(k) - \overline{w}^H . \overline{x}(k) \quad (14)$$

Through some simple algebra, MSE is given by (15)

$$|\varepsilon(k)|^2 = |d(k)|^2 - 2\, d(k)\overline{w}^H\, \overline{x}(k) + \overline{w}^H\, \overline{x}(k)\overline{x}^H(k)\overline{w}$$

By suppressing time dependence (k), we get

$$E[|\varepsilon|^2] = E[|d|^2] - 2\, \overline{w}^H \overline{r} + \overline{w}^H \overline{R}_{xx}\overline{w} \quad (16)$$

Where, (16) defines some correlations

$$\overline{r} = E[d *. \overline{x}] = E[d *. (\overline{x}_s + \overline{x}_i + \overline{n})] \quad (17)$$

$$\overline{R}_{xx} = E[\overline{x}^H \overline{x}] = \overline{R}_{ss} + \overline{R}_{uu} \quad (18)$$

The constraint expression in (16) is a quadratic function of $\overline{w}$. This function forms a quadratic surface in M-dimensional space and is also known as performance or cost function [10]. A quadratic surface for MSE is shown in fig. 4 respectively.

MSE can be minimized in (16) by setting the gradient with respect to weight vectors and equating it to zero.

$$\nabla_{\overline{w}}\, E[|\varepsilon|^2] = \overline{R}_{xx}\overline{w} - 2\,\overline{r} = 0 \quad (19)$$

The expression in (19) is known as Wiener-Hopf equation [19]. So, MMSE criterion for optimum weights is given by;

$$\overline{w}_{MSE} = \overline{R}_{xx}^{-1}\overline{r} \quad (20)$$

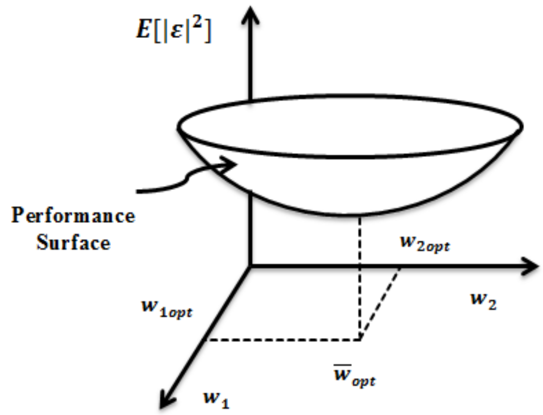

Fig. 4. Quadratic surface for MSE

IV. SIMULATIONS AND RESULTS

Computer simulation is carried out for N-element uniform linear array (ULA) using MATLAB® to demonstrate that how various parameters like number of elements, element spacing, beamforming gain and half power beamwidth influence the beam formation. The simulations are intended to analyse the performance of MSC, MVDR and MMSE beamforming algorithms. A SNR of 10dB is assumed for all incoming signals such that the desired signal strength would remain high as compared to noise level. Thus a copied signal could be easily obtained at the receiver end.

IV. I. Multiple sidelobe canceller beamforming

A. *Effect of Number of Elements on Array Factor*

A single source at $\{0^0\}$ direction is considered. Weights are computed using (8) to create beam in the desired user direction at $\{30^0\}$ and null in the direction of interferers$\{0^0, -30^0\}$. The spacing between the elements $\{Ne = 12, 10, 8\}$ is $\lambda/2$. Optimum weight vectors are computed for each antenna element and then plotted against angle of arrival.

Fig. 5, 6, 7 and 8 shows the array factor and polar plot for MSC beamforming.

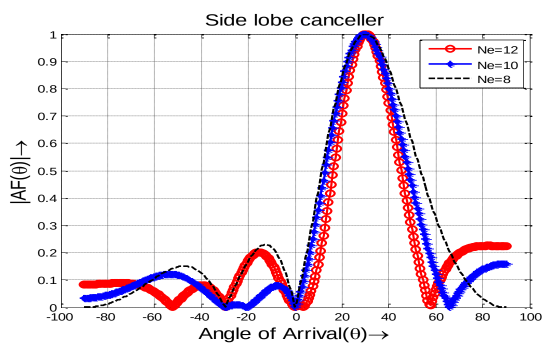

Fig. 5. Array factor plot for MSC beamforming for desired source at $\mathbf{30^0}$, interferers at $\mathbf{0^0}$& $\mathbf{-30^0}$ with element spacing of $\boldsymbol{\lambda/2}$.

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From fig. 5 it is evident that angle of arrival for desired user is set at $\{30^0\}$ and for interferers deep nulls are formed towards $\{0^0 \& -30^0\}$. At the same time narrow beam is produced as the number of elements is increased. In fig. 6, 7 and 8, it is interpreted that the main beam gets narrower with the increase in elements number. The deep nulls at $\{0^0 \& -30^0\}$ are clearly formed for $Ne = 12$ as compared to $Ne = 10$ & 8 respectively.

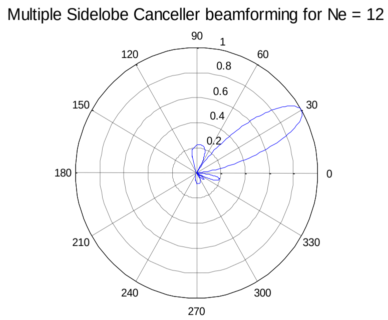

Fig. 6. Polar Plot for MSC beamforming with desired source at $\mathbf{30^0}$, interferers at $\mathbf{0^0}$& $\mathbf{-30^0}$ and element spacing of $\boldsymbol{\lambda/2}$.

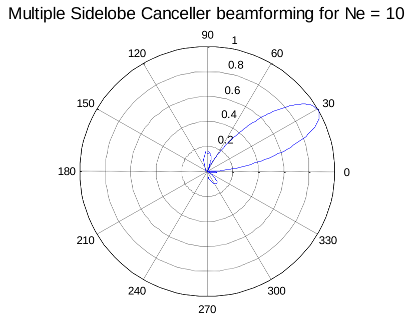

Fig. 7. Polar Plot for MSC beamforming with desired source at $\mathbf{30^0}$, interferers at $\mathbf{0^0}$& $\mathbf{-30^0}$ and element spacing of $\boldsymbol{\lambda/2}$.

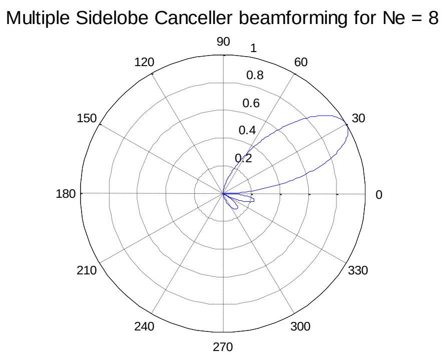

Fig. 8. Polar Plot for MSC beamforming with desired source at $\mathbf{30^0}$, interferers at $\mathbf{0^0}$& $\mathbf{-30^0}$ and element spacing of $\boldsymbol{\lambda/2}$.

B. *Effect of Element spacing on Array Factor*

The effect of element spacing $\{\lambda/2, \lambda/4 \; and \; \lambda/8\}$ is presented in fig. 9 for $Ne = 12$. In the formation of array pattern, the element spacing is critical. This is because of sidelobes problem which can cause spurious echoes, diffraction secondaries and can create repetitions of the main beam within the range of real angles.

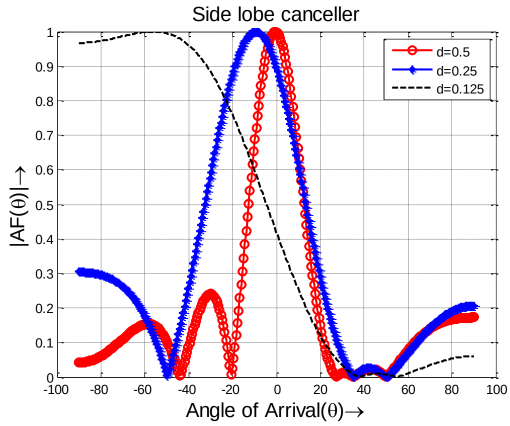

Fig. 9. Array factor plot for MSC beamforming with desired user at $\mathbf{0^0}$for $\boldsymbol{Ne = 12}$ and constant spacing of $\{\boldsymbol{\lambda/2}, \boldsymbol{\lambda/4}$ & $\boldsymbol{\lambda/8}\}$.

The case of $Ne = 12$ is shown in fig. 9. It is observed that decreasing element spacing has produced broad beam at the cost of less sidelobes. On the other hand, increasing element spacing has produced narrow beam at the expense of increase number of sidelobes. Therefore, it is further observed that narrow beam is produced when the element spacing is $\boldsymbol{d = \lambda/2}$.

The impact of element spacing for $Ne = 8$ is shown in fig. 10. Yet again narrower beam width is achieved at $\boldsymbol{d = \lambda/2}$. Reducing element spacing has increased the mutual coupling between the elements and as a result shift in maximum lobes happened to move the main beam away from desired direction.

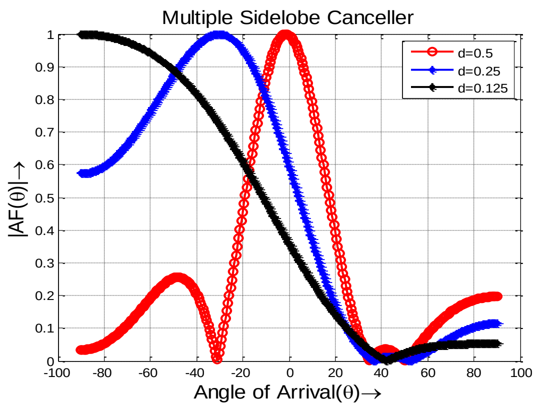

Fig. 10. Array factor plot for MSC beamforming with desired user at $\mathbf{0^0}$ for $\boldsymbol{Ne = 8}$ and constant spacing of $\{\boldsymbol{\lambda/2}, \boldsymbol{\lambda/4}$ & $\boldsymbol{\lambda/8}\}$.

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A single source at $\{30^0\}$ direction is considered. Weights are computed using (13) so that unity gain is obtained in the desired user direction at $\{30^0\}$ and null in the direction of interferers$\{0^0, 15^0, 60^0\}$. The spacing between the elements $\{Ne = 12, 10, 8\}$ is $\lambda/2$. Optimum weight vectors are computed for each antenna element and then plotted against angle of arrival. Fig. 11, 12, 13 and 14 shows the array factor and polar plot for MVDR beamforming respectively.

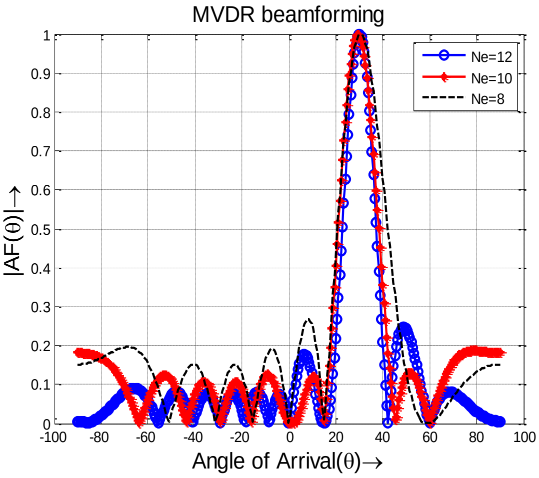

Fig. 11**.** Array factor plot for MVDR beamforming with desired user at $\{\mathbf{30^0}\}$**,** interferers at $\{\mathbf{0^0, 15^0, 60^0}\}$with element spacing of $\boldsymbol{\lambda/2}$.

From fig. 11, it is evident that angle of arrival for desired user is set at $\{30^0\}$ and deep nulls are formed towards $\{0^0, 15^0 \& 60^0\}$. As compared to MSC, MVDR forms narrower beam pattern as the number of elements increases. Fig. 12, 13 and 14 illustrates that main beam is formed in the direction of desired user at $\{30^0\}$ and nulls in the direction of interferers at $\{0^0, 15^0, 60^0\}$. Therefore, main beam becomes sharp with the increase in elements number. The corresponding polar plots represents that the number of sidelobes also increases with decrease in elements number.

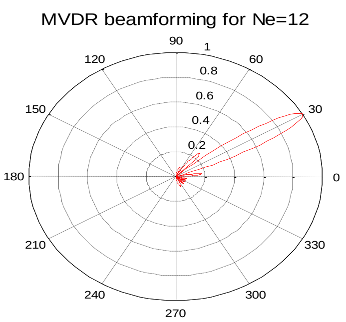

Fig. 12. Polar Plot for MVDR beamforming with desired user at $\{\mathbf{30^0}\}$ and interferers at $\{\mathbf{0^0, 15^0, 60^0}\}$**.**

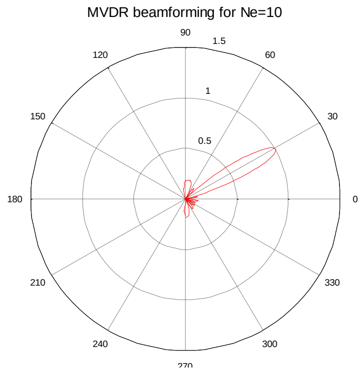

Fig. 13. Polar Plot for MVDR beamforming with desired user at $\{\mathbf{30^0}\}$ and interferers at $\{\mathbf{0^0, 15^0, 60^0}\}$.

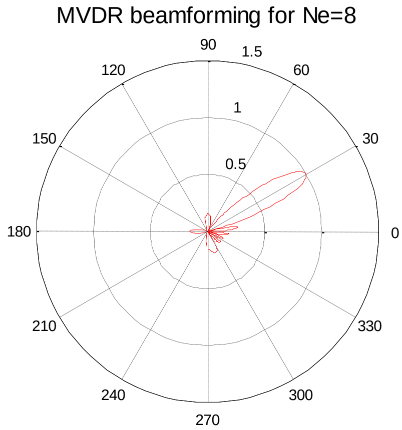

Fig. 14. Polar Plot for MVDR beamforming with desired user at $\{\mathbf{30^0}\}$and interferers at $\{\mathbf{0^0, 15^0, 60^0}\}$**.**

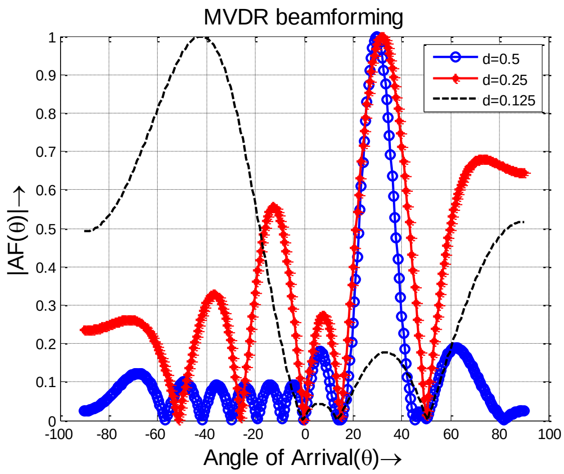

Fig. 15. Array factor plot for MVDR beamforming with $\boldsymbol{Ne = 12}$ and constant spacing of $\{\boldsymbol{\lambda/2, \lambda/4}$ & $\boldsymbol{\lambda/8}\}$.

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B. *Effect of Element Spacing on Array Factor*

The effect of element spacing {**λ**/2, **λ**/4 and **λ**/8} is shown in fig. 15 for $Ne = 12$. Meanwhile the element spacing is critical because of sidelobes problems, there occurs an inverse relation between number of sidelobes and array elements. Again optimum beam width is achieved with an element spacing of $d = \lambda/2$ respectively.

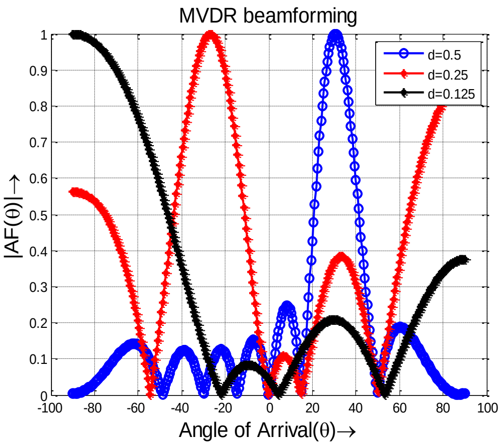

Fig. 16. Array factor plot for MVDR beamforming with $\boldsymbol{Ne = 8}$ and constant spacing of $\{\boldsymbol{\lambda/2}, \boldsymbol{\lambda/4}$ & $\boldsymbol{\lambda/8}\}$.

The effect of element spacing for $Ne = 8$ is shown in fig. 16. It is observed that if correct number of array elements is not selected against reduced element spacing then a shift between maximum and nulls occur.

IV. III. MMSE beamforming

A. *Effect of Number of Elements on Array factor*

For this simulation, both non-multipath and multipath environments are discussed. For non-multipath environment, a single source at $\{30^0\}$ direction is considered. Weights are computed using (20) such that optimum beam is produced in the direction of desired user at $\{30^0\}$ and null in the direction of interferers $\{20^0, 0^0, -30^0\}$. The spacing between the elements $\{Ne = 12, 10$ & $8\}$ is $\lambda/2$. Optimum weight vectors are computed for each antenna element and then plotted against angle of arrival. Fig. 17 shows the array factor plot for MMSE beamforming.

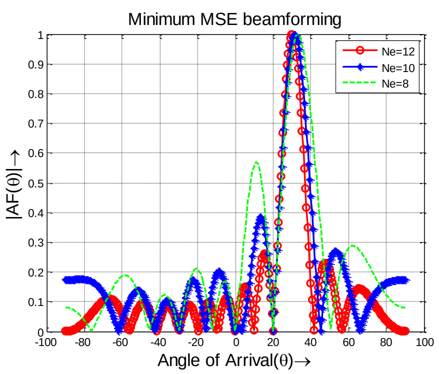

Fig. 17. Array factor plot for MMSE beamforming for desired source at$\{\boldsymbol{30^0}\}$,interferers at $\{\boldsymbol{0^0}, \boldsymbol{20^0}$& $\boldsymbol{-30^0}\}$and element spacing of $\boldsymbol{\lambda/2}$.

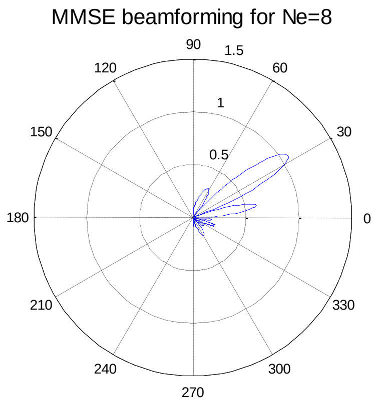

Fig. 18. Polar Plot for MMSE beamforming with desired source at$\{\boldsymbol{30^0}\}$and interferers at $\{\boldsymbol{0^0}, \boldsymbol{20^0}$& $\boldsymbol{-30^0}\}$.

Fig. 17 illustrates that main beam is formed in the direction of desired user at $\{30^0\}$ and null in the direction of interferers $\{-20^0, 0^0, 30^0\}$. In fig. 18 for $Ne = 8$, main beam is slightly away from the desired signal

For multipath environment, a desired source from a direct path of 40^0 with $SNR = 15dB$ and from a reflected path of 0^0 with $SNR = 10dB$ is considered. Interferers for this purpose are $\{-40^0, 25^0$& $80^0\}$ respectively. Weights are calculated using (20) to create beam patterns towards direct and reflected path and nulls in the direction of interferers. Fig. 19 and fig. 20 shows array factor and polar plot for MMSE beamforming respectively.

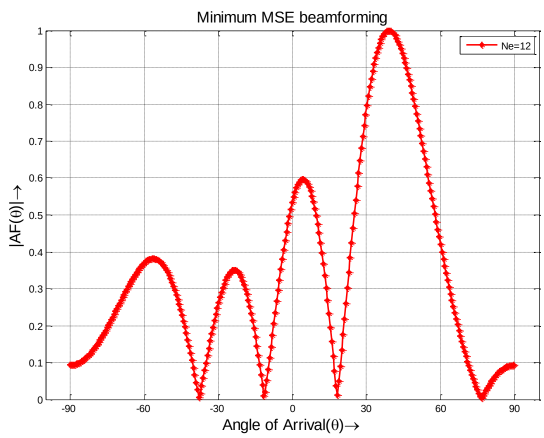

Fig. 19. Array factor plot for MMSE beamforming for desired source from a direct path of $\{\boldsymbol{40^0}\}$& a reflected path of $\boldsymbol{0^0}$, interferers at $\{\boldsymbol{-40^0}, \boldsymbol{25^0}$& $\boldsymbol{80^0}\}$.

From fig. 19 it is evident that MMSE is helpful in mitigating multipath fading effects. It is observed that a desired source from direct path of 40^0 follows the reference signal respectively.

Hence multipath arrival added the strength in desired signal. Fig. 20 demonstrates the polar plot representation of multipath environment for MMSE beamforming.

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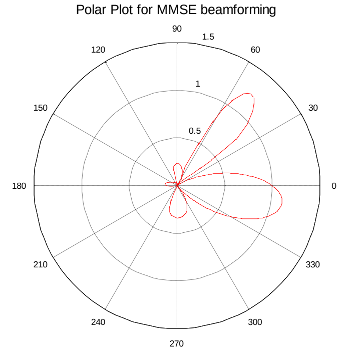

Fig. 20. Polar Plot for MMSE beamforming with desired source from a direct path of $\{\mathbf{40^0}\}$ & a reflected path of $\mathbf{0^0}$, interferers at $\{\mathbf{-40^0}, \mathbf{25^0} \& \mathbf{80^0}\}$.

B. *Effect of Element Spacing on Array Factor*

The effect of element spacing is shown in fig. 21 for $Ne = 12$ array elements. Just like MSC and MVDR algorithms, the same result is achieved for $d = \lambda/2, \lambda/4$ & $\lambda/8$ spacing respectively.

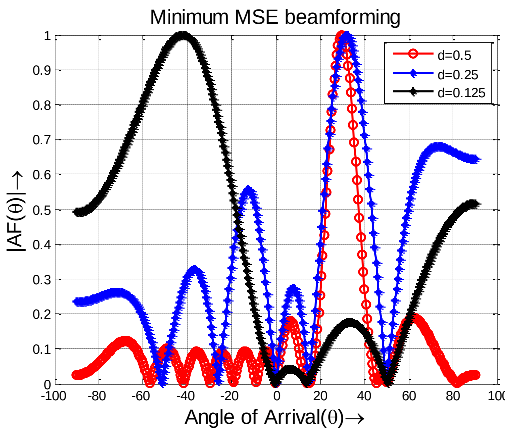

Fig. 21. Array factor plot for MMSE beamforming with $\boldsymbol{Ne = 12}$ and constant spacing of $\{\boldsymbol{\lambda/2}, \boldsymbol{\lambda/4} \& \boldsymbol{\lambda/8}\}$.

V. TRADE-OFF ANALYSIS

In this section, performance trade-offs among different array parameters is discussed. These certain parameters are essential in forming narrow beams for optimized beamforming approaches investigated in this paper. Simulations are performed to examine the trade-offs to study the effect of number of elements 'Ne', element spacing 'd' and scanning angle versus *NNBW* and *HPBW*. Table 1 provides the performance analysis of MSC, MVDR and MMSE beamformer approaches.

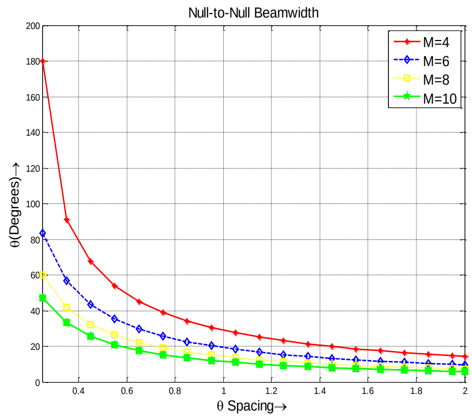

Fig. 22. NNBW as function of element spacing d

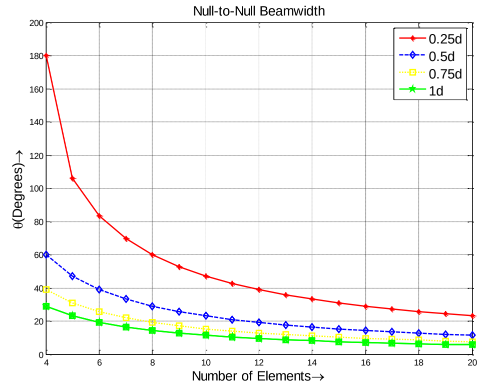

Fig.23. NNBW as a function of elements M

The behaviour of *NNBW* is shown in fig. 22 and fig. 23 as a function of element spacing and number of elements, respectively. It is observed that larger the array size, the smaller the *NNBW* becomes and narrower the main lobe gets.

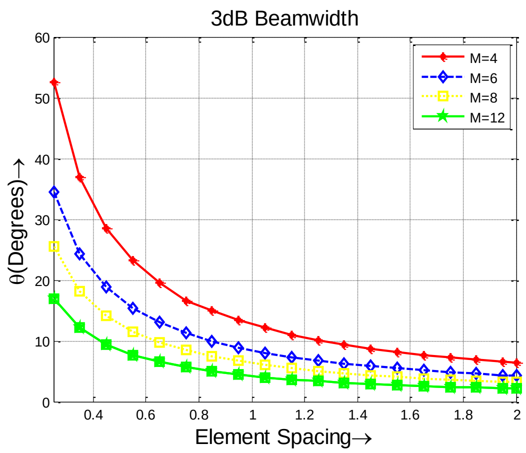

Fig. 24. HPBW as a function of element spacing d

Same behaviour is observed for *HPBW* or *3dB* beamwidth as with *NNBW* shown in fig. 24 and fig. 25 respectively.

Fig. 26 demonstrates the effect of scanning angle on *HPBW*. It is investigated that *3dB* beamwidth is not constant

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for $M = 8, 10 \; \& \; 12$, respectively but rather it depends on the scanning angle.

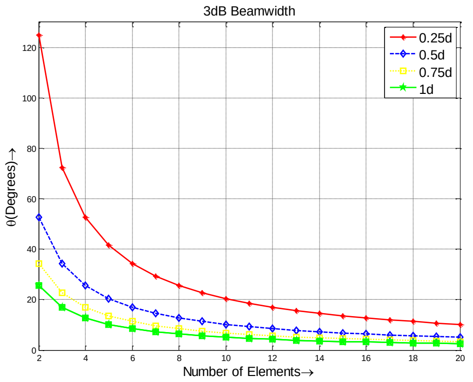

Fig. 25. HPBW as a function of number of elements M

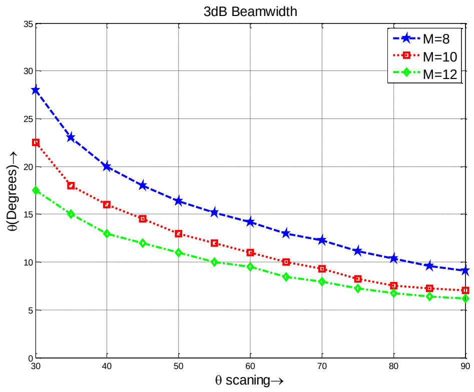

Fig. 26. Effect of scanning angle on HPBW

1. *Number of Elements, M*

Increasing number of elements; reduces sidelobe levels, produces more deep nulls and forms a narrow beam with high gain. In contrary to, cost increases due to large number of elements. Moreover, the number of sidelobe increases despite of lower sidelobe levels. Overall, narrow beam improves the interference cancellation capability and optimizes power consumption.

2. *Element Spacing, d*

Increasing element spacing produces the narrow beam. Due to sidelobe problems, element spacing must be such that to avoid mutual coupling between the elements. If element spacing is reduced, number of elements must increase and vice versa. But increasing d produces narrow beam at the cost of increasing grating lobe. Overall, grating lobes have a negative impact on interference nulling.

3. *Null-to-Null & Beamwidth & Half Power Beamwidth*

The null-to-null beamwidth (NNBW) and half power beamwidth (HPBW) have a significant impact on beamforming in smart antenna system. NNBW and HPBW are inversely proportional to the power dissipated in unwanted direction in sidelobes. Increasing the number of elements, the smaller the NNBW as well as HPBW becomes and the narrower the main lobe gets. Moreover, increasing element spacing also makes NNBW and HPBW smaller. Overall, system performance improves because of narrow beam.

VI. CONCLUSION

This paper delineates beamforming technique, which has secured remarkable significance in wireless communication system owing to its capability to reject interference and increase in SINR. For cost efficient deployment, highly directional beams are required to increase the capacity so that the number of base stations can be reduced.

In this paper, performance trade-offs among three beamforming algorithms i.e. MSC, MVDR and MMSE beamformers are compared. Sidelobe cancellation beamforming produces beam in the desired direction and also forms nulls in the direction of interferers. But choosing optimum weights can cause cancellation of desired signals while minimizing output power. Therefore, it is effective in low SNR environments. This problem is overcome by MVDR beamformer. MVDR directs main beam in only one direction with unity gain and does not consider desired signals arriving from other directions. Hence, it provides best performance in Rician (line-of-sight) fading environment such as rural areas where no multipath occurs. MMSE beamformer overcomes this drawback in MVDR by performing well in mitigating the Rayleigh (non-line-of-sight) fading effects. Upon comparing the parameters such as number of elements, element spacing, HPBW and NNBW, we proved that for producing optimized narrower beams, there exists a trade-off among these parameters for smart antenna system performance.

Thus, beamforming has demonstrated its benefits for future cellular communication system and has played an influential role in delivering cutting-edge mobile networks. Beamforming is a good challenger which achieves ubiquitous user demands with efficient spectrum utilization.

REFERENCES

[1] Anees, A. and Mujahid,U. “A systematic approach to understand Smart antenna system”, APTEC Proceedings, pp. 1, 19th April, 2011.

[2] Mujahid,U., Mudassir Mukhtar,J.A., Rehman,A., Abbas, M. & Shahid,U. ”Spectral Estimation for Smart Antenna System”, 2013 3rd International Conference on Computer, Control and Communication (IC4), pp. 1-5, 25-26 Sep, 2013.

[3] Susmita Das, “Smart antenna design for wireless communication using adaptive beamforming approach”, 2009.

[4] Compton R. ,”Adaptive antennas concept and performance”, Prentice Hall, 2011.

[5] Constantine A. Balanis, “Introduction to Smart Antenna”, 1st Edition, Morgon and Claypool Publications (2007), pp. 87-93

[6] Dahrouj H, Yu W. ,”Coordinated Beamforming for the Multicell Multi-Antenna Wireless System”, IEEE Transactions on Wireless Communications, Vol. 9, No. 5, May 2010.

[7] R. Gaokar,Dr. A. Cheeran, “Performance analysis of beamforming algorithms”, IJECT, Vol. 2, No. 1, pp. 43-47, March 2011.

[8] Wimax forum (2010), [Online] Available: http://www.wimaxforum.org/

[9] LTE forum (2010), [Online] Available: http://www.alcatel-lucent.com

[10] Frank Gross, "Smart Antennas for Wireless Communication with MATLAB,"*Mc-Graw Hill*, 2006, pp. 93, 211-226

[11] Applebaum, S. P. and Chapman, D. J., "Adaptive arrays with main beam constraints", IEEE Transactions on AP, Vol. AP-24, pp. 650-662, Sep 1976.

[12] Widrow, B. ,Mantey, P. E, Griffiths, L.J. and Goode, B. B., "Adaptive antenna systems," Proceedings of IEEE, Vol. 55, pp. 2143-2159, Dec. 1967.

[13] Frost III, O. L. , "An algorithm for linearly constrained adaptive array processing ," Proceedings of IEEE, Vol. 60, pp. 926-935, August 1972.

[14] Van Veen,B. D. and Buckley, K. M. ,"Beamformer: A versatile approach to spatial filtering," IEEE ASSP Magzine, pp. 11-15, April 1988.

[15] Lal C. Godara, "Applications of Antenna Arrays in Mobile Communications, Part II:Beamforming and direction-of-arrival considerations," IEEE Proceedings, Vol. 85, No. 8, pp. 1195-1234, August 1997.

[16] Constantine A. Balanis, "Antenna Theory Analysis and Design," John Wiley and Sons Inc. 2005,3rd Edition, pp. 971-972.

[17] Howells, P. W. , "Intermediate Frequency Sidelobe Canceller," U. S. Patent 3202990, 24 Aug, 1965.

[18] Cohen, H. , "Mathematics for Scientists and Engineers", Prentice Hall, New York, 1992.

[19] Madisetti, V. ,"Digital Signal Processing Handbook", Second Edition, CRC Press.

TABLE I. Performance Analysis of Beamforming Algorithms

Beamforming Algorithms	Gain (dB)	HPBW for AOA of 30^0 (Degrees) Array Elements(Ne)			NNBW for AOA of 30^0(Degrees) Array Elements(Ne)			Comments
		8	10	12	8	10	12	
SLC	15	28.77^0	24.36^0	19.86^0	85^0	65^0	55^0	This method cancels out strong interference in a communication system. But it requires absence of desired signal when computing optimum weights.
MVDR	1	24.23^0	20.62^0	17.25^0	40^0	30^0	25^0	This method maintains a unity gain in desired direction. However, computation of constrained weights is required. It does not support multipath environments.
MMSE	< than unity in desired direction	20.52^0	18.77^0	15.38^0	35^0	25^0	20^0	This method is suitable for multipath environment. But it requires the generation of reference signal. Although the gain is less than unity but this method provides a stronger interference rejection than MVDR and SLC beamformers.

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