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Proposed Bessel Beamformer Is a Better Option for Smart Antenna System for Capacity Improvement

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Abstract: Smart antenna system is still a research area in which a lot of efforts and trials are being conducted to increase capacity and quality in mobile communication networks. In this paper, we propose a new adaptive algorithm namely Bessel beamformer using Bessel function of the first kind employed for spatial filtering i.e. beamforming which is novel in this application. The proposed algorithm is embedded in a smart antenna in coded form which detects desired signal and interferers in such a way that beam is extending towards a desired user and null is placed towards an interferer. Simulation results presented in this paper confirmed that proposed adaptive algorithm is more efficient to optimize the beam and nullify interference which leads to increase capacity and service quality.

Key words: *Adaptive signal processing algorithm · Bessel Algorithm · Bessel function · Smart antenna*

INTRODUCTION

Inspired by spatial filtering i.e. beamforming utilization in mobile communication system [1-21], we give an idea about how the proposed adaptive algorithm i.e. Bessel beamformer using Bessel function of the first kind can improve further smart/adaptive antenna technology for higher throughput. Bessel function are very commonly used in digital signal processing (DSP) applications such as FM synthesis, filters design to suppress the noise frequencies and wave propagation in a waveguide [18, 22-29] but have not been used for spatial filtering i.e. beamforming, therefore using Bessel functions in this sense is unique.

In [22, 24, 29], the various Bessel function techniques are used with Fast Fourier Transform (FFT) for the detection of harmonic signals in the presence of broad noise whereas in our case, the Bessel function of the first the kind is used in order to compute adaptive weights so that it minimizes the cost function and optimum results is obtained in form of beam towards desired direction and to place null towards interferers. The proposed algorithm exploits the spatial structure environment and is the appropriate solution for random noise suppression.

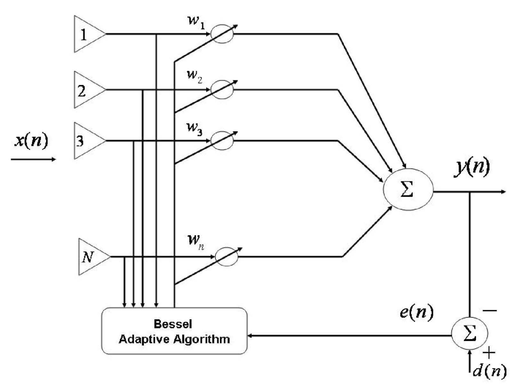

Fig. 1: Bessel Beamformer

The term smart refers to the use of DSP in order to maximize the signal quality. Basically smart means computer control of the antenna performance [6, 7]. Assume smart antenna with array elements equally spaced (d), embedded with an adaptive processor and user's signal arrives from desired direction at an angle Φ_0 as shown in Figure 1.

The proposed beamforming algorithm, used for calculating weights adaptively to optimize signal to noise ratio (SNR) of the desired signal in look direction.

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The next section introduces the smart antenna arrays system model. Section 3 contains mathematical model of proposed algorithm. Section 4 demonstrates simulation results. Discussion and results is presented in section 5. Finally, section 6 contains the conclusions.

SYSTEM MODEL

In signal processing, the Bessel function is a mathematical function being used for linear filter with flat group delay and gives linear phase response. It preserves the wave shape of filtered signals in the passband [18, 26]. Suppose $x(k)$ denotes input sequence consists of desired signal $s(k)$ plus noise vectors $n(k)$ to the smart antenna system model [9, 10] and the corresponding output $y\{(k)\}$ is given by

$$y(k0 = w^H x(k) \quad (1)$$

Let we have a desired sequence $\{d(k)\}$ with which we can compare beamformer output then we have error sequence $\{e(k)\}$ is given by

$$e(k) = d(k) - y(k) \quad (2)$$

putting value of $y(k)$ in (2), we have

$$e(k) = d(k) - w^H x(k) \quad (3)$$

Where w denotes the weights of beamformer and H is the complex conjugate transpose – called Hermitian transpose.

The weight of beamformer is selected adaptively so that sum of mean square error (MSE) is minimized. Thus we have

$$\varepsilon(k) = \sum_{k=0}^{M} e^2(k) \quad (4)$$

Where ε is the MSE with time index k.

putting (3) into (4) and solved simultaneously by squaring & taking expected value over k, we get

$$E[\varepsilon^2(k)] = E[d^2(k)] + w^H E[x(k)x^H(k)]w - 2E[d(k)x^H(k)]w \quad (5)$$

Where $R = E[x(k)x^H(k)]$ and $P = E[d(k)x(k)]$ denotes the input correlation matrix and cross correlation matrix respectively. Therefore, MSE can be written as

$$\varepsilon = E[d^2(k)] + w^H Rw - 2P^H w \quad (6)$$

To obtain minimum MSE, the weight vector is set at its optimal value w^* where the gradient is zero. Differentiating (6) w.r.t. w, we have

$$\frac{\partial \varepsilon}{\partial w} = 0 = 2Rw^* - 2P \quad (7)$$

$$w^* = R^{-1}P \quad (8)$$

This yields the optimum weights of the beamformer which is also known as Weiner Hopf equation.

BESSEL ALGORITHM

The proposed algorithm is based on the Bessel function of first kind of order [18, 26] and provides computationally efficient adaptive weights calculation. This is used for implementation of beamforming, therefore it is named as Bessel beamformer. The proposed algorithm finds the minimum MSE and thus yields the set of optimum weights of the beamformer. The weight of Bessel beamformer is computed by

$$w(k+1) = w(k) - 2\mu e(k) J_v(N) x(k) \quad (9)$$

Where J_v N represents the Bessel function of the first kind and defined by

$$J_v(N) = \left(\frac{N}{2}\right)^v \sum_{k=0}^{\infty} \frac{\left(-\frac{N^2}{4}\right)^k}{k!\,\Gamma(v+k+1)} \quad (10)$$

Where v denotes the order of the Bessel function of the first kind and must be a real number. The number of elements is presented by N and Γ is the gamma function.

The signal array vector is written by

$$x(k) = [x_1(k), x_2(k), \ldots, x_M(k)]^T \quad (11)$$

This signal array vector can also be written as

$$x(k) = s_d(k)a(\theta_d) + \sum_{i=1}^{L} s_i(k)a(\theta_i) + N(k) \quad (12)$$

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 $a(\theta_d)$ are the steering vectors for the desired and interfering signals respectively. The steering vector is described as

$$a(\theta) = [1, e^{-j\phi}, \ldots\ldots, e^{-j(M-1)\phi}] \quad (13)$$

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

$$a(\theta) = [1, e^{-j\frac{2\pi}{\lambda}d\sin(\theta)}, \ldots\ldots, e^{-j\frac{2\pi}{\lambda}d(M-1)\sin(\theta)}] \quad (14)$$

The output of Bessel beamformer is given by

$$y = w^H x \quad (15)$$

The parameter μ is the gain constant which is used to regulate the speed of adaptation and defined by

$$0 < \mu < \frac{1}{\lambda_{\max}} \quad (16)$$

The gain constant also called step size, determines the amount of correction applied as the beamformer adapts from one iteration to the next.

The estimation of error $e(k)$ is computed by (2) and 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} 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 Bessel function of the first kind. The phase modulated signal is given by

$$S(t) = e^{j\sin(\omega t+\phi)} \quad (17)$$

Where ϕ is the phase angle of the applied signal,

Effect of Number of Elements on Array Factor: Uniform linear array is taken with element spacing λ / 2 for simulation purpose with five hundred samples for different number of elements. It is observed that the array directivity increases with the number of elements but at the time number of side lobes and its level increases with the number of elements. The angle of arrival (AOA) for desired user is 0 degree and two interferers are set at 30 and -20 degrees. The array factor for number of elements is shown in Figure 2. The step size in this case is kept as μ = 0.00001. The best array directivity is achieved for N = 14. The beam width is measured between the first two nulls of the array response function [6].

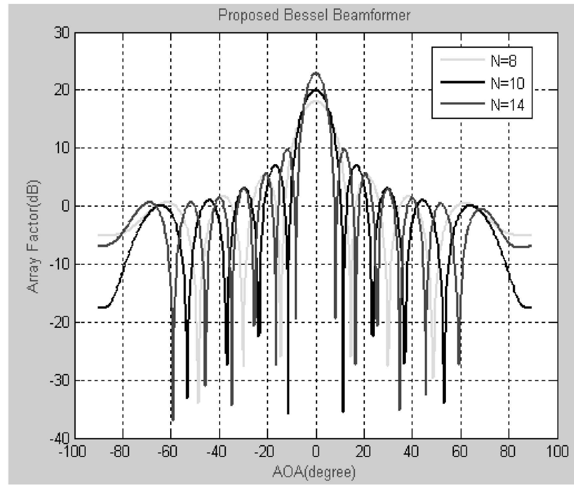

Fig. 2: Array factor plot for Bessel algorithm with AOA for desired user is 0 degree and -20 & 30 degrees for two interferers with constant space of λ / 2 between elements

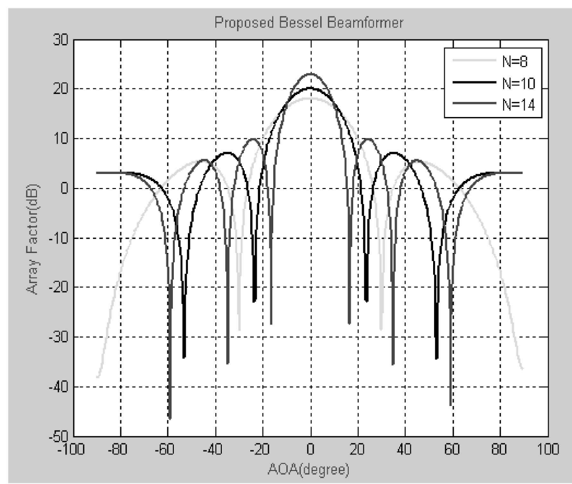

Fig. 3: Array factor plot for Bessel algorithm with AOA for desired user is 0 degree and -20 & 30 degrees for two interferers with constant space of λ / 4 between elements

The results are summarized in Tables 1 when element spacing is kept λ / 2 as shown.

Similarly for same number of elements as shown in Figure 2 if spacing between elements is changed from λ / 2 to λ / 4 and all other parameters kept constant then effect on beamforming can be depicted as shown in Figure 3. The results are summarized in Tables 2 when element spacing is kept λ / 4 as shown.

Table 1: Effect of number of elements on bean width

N	d	Beam width (degree)
8	0.5	36
10	0.5	30
14	0.5	20

Tbale 2: Effect of number of elements on bean width

N	d	Beam width (degree)
8	0.25	60
10	0.25	43
14	0.25	36

Table 3: Effect of element spacing on beam width

N	d	Beam width (degree)
8	0.5	36
8	0.25	60
8	0.125	180

In this case, the beam width is increased but at the same time, reduction in number of side lobes is also observed.

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 shown in Figure 4 for $N = 8$ with two interferers at 30 & – 20 degrees. AOA for desired user is set at 20 degrees. The spacing between the elements is critical, due to sidelobes problems, which causes grating lobes, which are the repetitions of the main beam within the range of real angles. It is shown that the algorithm converges faster and stable for spacing equal to $\lambda / 2$. Increasing the element spacing towards λ results in an increased directivity but the effect of grating lobe is also worth noting.

The results are summarized in Tables 3 when number of elements is kept constant as shown.

Effect of AOA on Array Factor: AOA for desired users is set at 40, 0 and - 40 degrees respectively. In this case also five hundred numbers of samples is taken for simulation purpose. The element spacing is $\lambda / 2$ with $N = 8$ for each user. Simulation result verifies that the proposed algorithm has good response towards beam forming and beam steering as shown in Figure 5.

Effect of Step Size on MSE: It is important to know how the error degrades the array performance. Therefore, five hundred numbers of samples is taken for $N = 8$ to analyze minimum mean square error (MMSE) and compared on the basis of step size as shown in Figure 6.

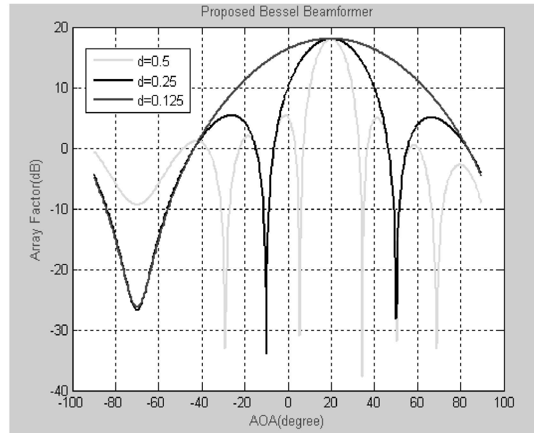

Fig. 4: Array factor plot for Bessel algorithm for $N = 8$ with two interferers at 50 & – 10 degrees.

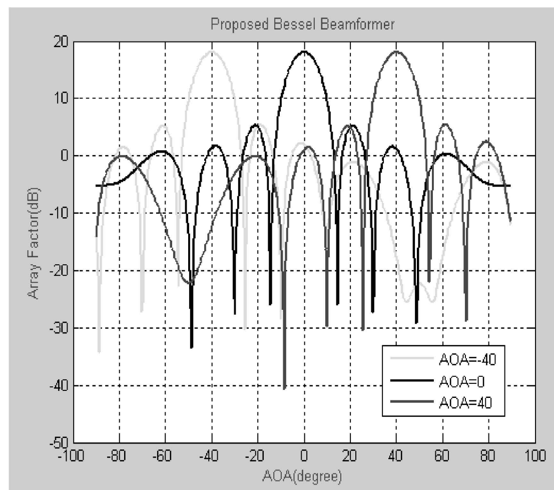

Fig. 5: Array factor plot for Bessel algorithm with AOA for desired users is 40, 0 & - 40 degrees with constant space of $\lambda / 2$ between elements

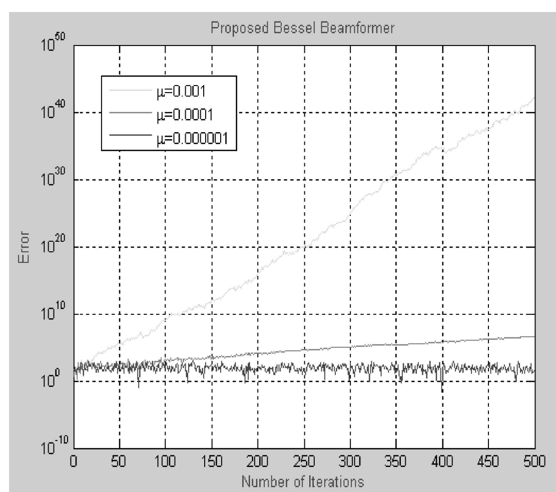

Fig. 6: Mean Square Error plot for Bessel algorithm for $N = 8$

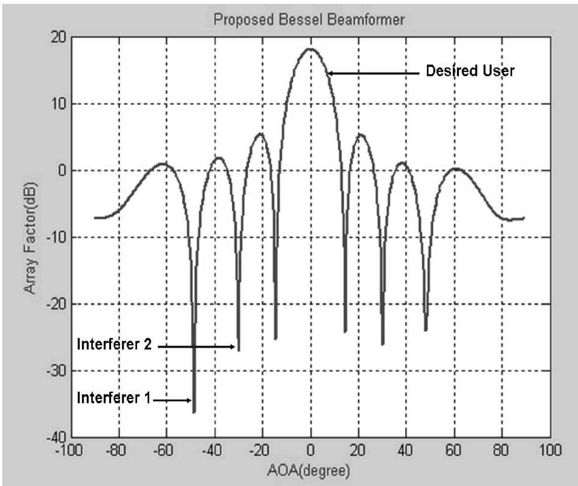

Fig. 7: Null Depth Performance of Bessel algorithm with AOA for desired user is 0 degree and - 30 & - 50 degrees for two interferers with constant space of $\lambda / 2$ between elements

The minimum MSE is achieved for $\mu = 0.000001$ as shown in Figure 6. It is confirmed from the simulation results that step size has great effect on converges and stability of the proposed Beamformer. The step size within bounded range gives marked improvement in reduction of sidelobes and in error minimization.

Null Depth Performance: AOA for desired user is set at 0 degree and two interferers are shown at -30 and -50 degrees for $N = 8$ and $\lambda / 2$. The array factor for number of elements is shown in Figure 7.

DISCUSSION AND RESULTS

In this paper a proposed Bessel adaptive beamforming algorithm for a smart antenna system is discussed. A detailed system model is presented and analyzed, supported by mathematical and analytical model, which is further being utilized to develop simulation results for analysis. The proposed Bessel algorithm is compared on the basis of beam pattern, stability, null depth performance & computation time of optimum weights vector. The findings of simulation and mathematical analysis are:

- The Proposed algorithm has the capability to direct desired beam towards the desired user while suppressing interference. Due to these characteristics, the capacity and quality of network equipped with smart antenna increases.
- The Proposed algorithm is based on space division multiple access (SDMA) technique due to which all users in the network are able to exchange information at the same time using the same channel.
- 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 algorithm uses spatial filtering feature, due to this frequency reuse is efficient and effective in the communication system employing smart antenna.
- 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 estimate that the computation time of Bessel algorithm is 0.0981 second.
- The null depth and steering performance of the proposed algorithm is good as shown in Figure 7.
- The Proposed algorithm is more accurate and stable as it requires pilot signal for synchronization and convergence at the receiver which verifies the required output on the spot by judging against the desired signal.
- The simulation results also capitulate that the proposed algorithm is much more stable and robust so that the degradation in its performance is minimum.
- The convergence property/capability of the proposed adaptive algorithm is good.
- The Proposed algorithm has better capability to obtain minimum MSE by adjusting step size within bounded condition. It is also ascertained from simulation results as shown in Figure 6.

CONCLUSIONS

The performance of the Proposed Bessel algorithm is optimum for beamforming, null steering and for noise cancellation. This algorithm can be employed as one of the better option to implement at base station of mobile communication systems using CDMA environment to reduce system overheading and to increase quality & capacity.

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