A Comparative Study of RBF and MLP Neural Model for Seven Element Dynamic Phased Array Smart Antenna

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Abstract—**In this paper we present the neural Modelling techniques for dynamic phased array smart antenna. Neural networks are mathematical and computation models that are used to optimize the smart antenna system, which are very much suitable for real time applications. Here we are optimizing the seven element dynamic phased array smart antenna using Radial basis function neural network (RBFNN) and Multilayer Perceptron neural network (MLPNN). The beam ship prediction of seven element DPA is done up to 60 deg scan angle and results of RBF and MLP are compared to find out the better neural network approach for smart antenna optimization.**

Index Terms—**neural network, smart antenna, dynamic phased array, radial basis function (RBF), multi layer perceptron (MLP), neural modelling.**

I. INTRODUCTION

Wireless communication has come a long way since the invention of the wireless concepts; the extensive growth in number of wireless users in past few years has triggered an enormous demand, not only for the capacity but also high quality of service and good enough coverage. Number of new technologies are explored and deployed to make good use of limited resources and provide better services. Unlike wireless systems in the past which used fixed antenna systems, SDMA based system uses smart antennas or adaptive arrays that are dynamically able to adopt as per the changing traffic requirements.

Smart antennas [1] are one of the most promising technologies that will enable higher capacity in wireless networks by effectively reducing the multipath fading, co-channel interference [2],[3] These are the technology based intelligent antennas that use a fix set of radiating elements in the form of an array as shown in Fig. 1.

The signals from these antenna elements are combined to form a movable beam pattern that can be steered to the direction of the desired user. This feature of makes the antenna smart and minimizes the various signal quality degradation factors like noise, interference etc. The adoption of smart antenna techniques in future wireless systems is expected to have a significant impact on the efficient use of the spectrum, the minimization of the cost of establishing new wireless networks, the optimization of service quality, and realization of transparent operation across multi technology wireless networks [1].

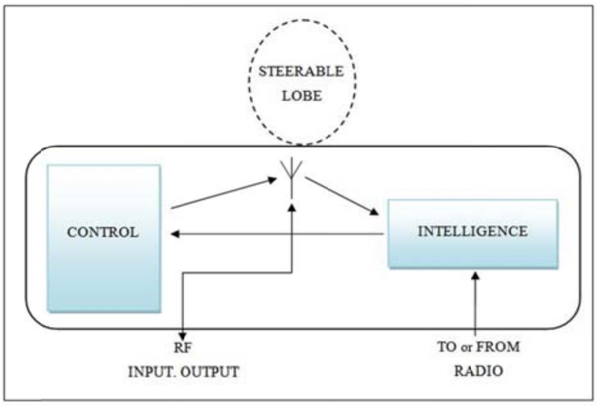

Figure 1 Basic principle of smart antenna

The use of smart antennas will lead to a much more efficient use of the [4] power and spectrum, increasing the useful received power as well as reducing interference. Smart antenna system technologies include intelligent antennas, dynamic phased array (DPA), digital beam forming, adaptive antenna systems [5], [13] and others. The phased array antenna consists of multiple stationary antenna elements, which are fed coherently and use variable phase or time delay control at each element to scan a beam to given angle in space. Array can be used in place of fix aperture antennas (reflectors, lenses), because the multiplicity of elements allows more precise control of radiation pattern, thus resulting in lower side band and careful pattern shaping [14] . However the primary reason for using array is to produce a directive beam that can be repositioned (scanned) electronically.

As the goal of smart antenna is to improve the system performance and give better coverage to the users, there is good amount of research and development is going on in this area, in the same process of development there are basically three types of Smart Antennas.

1) Switched Lobe Smart antenna (SLSA)

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2) Adaptive Array Smart Antenna
3) DPA Smart Antenna

A. Switched Lobe Smart Antenna (SLSA):

The SLSA are conventional directional antennas deployed at base stations of a cell in mobile or wireless communication systems as shown in Fig. 2. They have only switching function between separate directive antennas or predefined beams of an antenna array. The arrangement that gives the best performance, usually in terms of received power, is chosen. The outputs of the various elements are sampled periodically to ascertain which has the best reception beam. Because of the higher directivity compared to a conventional antenna, some gain is achieved. Such an antenna is easier to implement in existing cell structures than the more sophisticated adaptive arrays, but it gives a limited improvement in the quality of received signals [6].

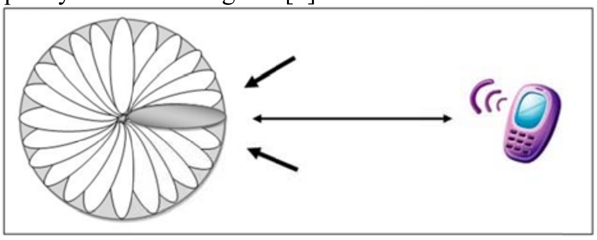

Figure 2 Switched Lobe Smart Antenna

B. Adaptive Array Smart Antenna

An Adaptive Antenna Array is a set of antenna elements that can adapt their antenna pattern to changes in their environment. An adaptive array is similar to a dynamically phased array however it is more intelligent taking into account a greater number of factors. An adaptive array adapts to its environment by taking into account other interfering devices and multiple signal paths as shown in Fig. 3.

The Interfering devices can be 'blocked' by reducing the signal received from the antenna elements in that direction and increasing it in others. Multiple signal paths can be utilized by forming beams in the directions of signal paths, meaning a combined signal can be formed from multiple beams. This provides a much better signal to noise power ratio giving better communication to a device. Each antenna of the array is associated with a weight that is adaptively updated so that its gain in a particular direction is maximized, while that in a direction corresponding to interfering signals is blocked by putting null in that place.

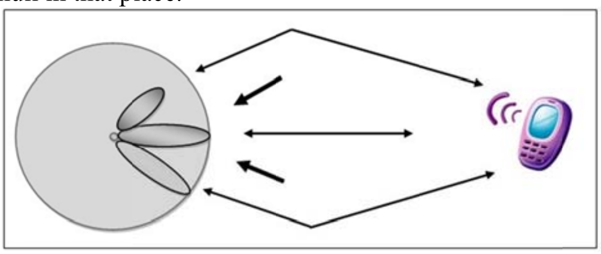

Figure 3 Adaptive Array Smart Antenna

In other words, they change their antenna radiation or reception pattern dynamically to adjust the variations in channel noise and interference, in order to improve the SNR of a desired signal. This procedure is also known as adaptive beam forming or digital beam forming. Conventional mobile systems usually employ some sort of antenna diversity (e.g. space, polarization or angle diversity). Adaptive antennas can be regarded as an extended diversity scheme, having more than two diversity branches.

C. DPA Smart Antenna

The DPA smart antenna [7] achieves optimum gain while the interference is not suppressed completely but up to certain extent where its effect is almost negligible. In this approach smart antennas communicate directionally by forming specific antenna beam patterns as shown in Fig.. 4. They direct their main lobe with increased gain in the direction of the user, and they direct nulls or very small side lobe in directions of interference.

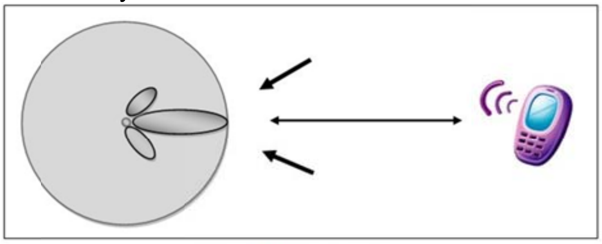

Figure 4 DPA Smart Antenna

In DPA smart antenna, a direction of arrival (DOA) algorithm tracks the user's signal as he roams within the range of the beam that is tracking him. So even when the intra cell handoff occurs, the user's signal is received with an optimal gain. It can be viewed as a generalization of the switched lobe and adaptive array concept where the received power is maximized. The Table I [8], [12] compares these three types of smart antennas. DPA smart antennas have the following advantages as compared to its counterpart adaptive array and adaptive array as applied to mobile or wireless applications.

D. Comparison between all three Smart Antennas

We discussed all three basic types of the antenna systems; let us compare all of them on the basis of their performance, type of setup and the pattern. In Fig. 5 three basic types of smart antennas are shown, as previous sections discussed in detail about the DPA, adaptive array and switched lobe smart antennas here is the comparison.

TABLE I
COMPARISON BETWEEN BASIC THREE SMART ANTENNAS.

S. No	SWITCHED LOBE	DYNAMICALLY PHASED ARRAY	ADAPTIVE ARRAY
	A finite number of fixed, predefined patterns or combining strategies (sectors)	It has fixed number of array which can be electronically steered in a particular direction.	An infinite number of patterns (scenario-based) that are adjusted in real time
	This kind of antenna will be easier to implement in existing cell	Easy to move electronically. In this case, the received power is maximized.	Complex in nature at the time of installment and best

	structures than the more sophisticated adaptive arrays, which also means low cost.		performance in the three types of smart antennas.
	The signal strength can degrade rapidly during the beam switching.	It does not null the interference.	Excellent performance in interference.

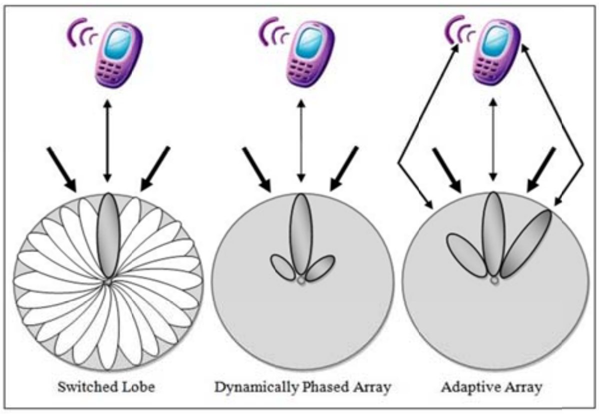

Figure 5 Comparative diagrams of three basic Smart antennas

DPA smart antennas can't suppress interference completely but reduce interference up to significant level and therefore design is less complex and cheaper.

1. DPA smart antenna can improve shape and size of radiation pattern as well as reject interference up to significant level.
2. Less complex system in comparison of adaptive system.
3. Predict feeding details for particular pattern shape.

This paper presents the optimization of dynamic phased array smart antenna using neural network modelling. Development of radial basis neural network and multi layer perceptron based algorithm to compute the approximate beamwidth of dynamically phased array antenna. This new approach shows that dynamically phased array [9] can detect and estimate beamwidth in a particular direction. The present work is restricted only for 0 to 60 deg.

II. RBFNN Used For Dynamic Phased Array Antennas

Radial basis function and Hopfield type neural networks are commonly used in various applications of phased arrays. RBFNN's [10] are a member of a class of general purpose method for approximating nonlinear mappings since the DOA problem and Beamforming is of nonlinear nature. Unlike the back propagation networks which can be viewed as an application of an optimization problem, RBFNN can be considered as designing neural networks as a curve fitting (or interpolation) problem in a high-dimensional space. Radial basis function (RBF) neural networks consist of neurons which are locally tuned.

An RBF network can be regarded as a feed forward neural network with a single layer of hidden units, whose responses are the outputs of radial basis functions. The input of each function of a RBF neural network is the distance between the input vector (activation) and its center (location). Since the radial basis neural networks are excellent candidates for selecting relevant features in pattern recognition problems, we are using modelling of radial basis neural network in seven element phased array and trained it.

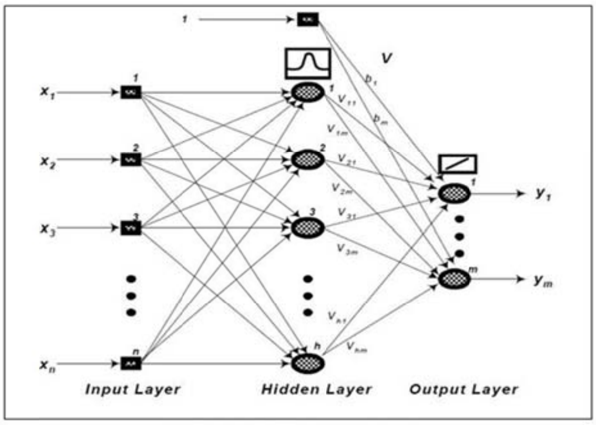

Figure 6 Typical RBFNN Architecture

A typical RBF network [3] Fig. 6 is having input layer of the dimension of training patterns, hidden Layer of up to p locally tuned neurons centered over receptive fields for non-linear, local mapping and output layer that provides the response of the network. Each hidden unit output y is obtained by calculating the "closeness" of the input x to an n-dimensional parameter vector n associated with the m^{th} hidden unit. Receptive fields center on areas of the input space where input vectors lie, and serve to cluster similar input vectors. If an input vector (x) lies near the center of a receptive field (), then that hidden node will be activated. The output layer is a layer of standard linear neurons and performs a linear transformation of the hidden node outputs. This layer is equivalent to a linear output layer in a MLP, but the weights are usually solved for using a least square algorithm rather trained for using back propagation. The output layer may, or may not, contain biases.

III. MLPNN Used For Dynamic Phased Array Antenna

One of the most common neural networks is multi layer perceptron neural network (MLPNN). The architecture of MLPNN [3] as shown in Fig.. 7 may contain two or more layers. Input layers are the first layer in which the numbers of neurons are equal to the number of selected specific features. The output layer is the last layer which determines the desired output classes. The intermediate layer collected hidden layer increases the ability of MLPNN for nonlinear system. A MLP neural network trained in the back propagation mode can be used to locate the fault elements in an antenna array from its distorted radiation pattern, and to estimate direction of arrival.

Here the neurons are interconnected by weight matrices, $\boldsymbol{W}$ and $\boldsymbol{V}$. The MLPN transforms n inputs to m outputs (also called input-output mapping) through some nonlinear function.

$\hat{f} : \mathbf{R}^n \rightarrow \mathbf{R}^m$.

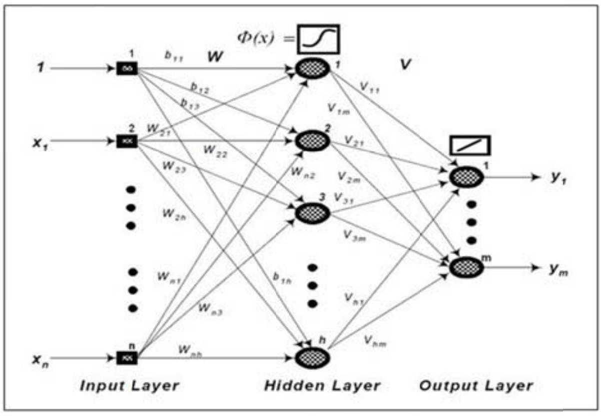

Figure 7 Typical MLPNN Architecture

The weights of the MLPN are adjusted/trained using the gradient descent based backpropagation algorithm. The activation function for neurons in the hidden layer is given by the following sigmoid function.

$$\emptyset(x) = \frac{1}{1+\exp(-x)}$$

The output layer neurons are formed by the inner products between the nonlinear regression vector from the hidden layer and the output weight matrix, $\boldsymbol{V}$. The MLPN requires no offline training. During on-line training, the MLPN starts with random initial values for its weights, and then computes a one-pass backpropagation algorithm at each time step k, which consists of a forward pass propagating the input vector through the network layer by layer, and a backward pass to update the weights by the gradient descent rule.

IV. Antenna Synthesis by Fourier Method

Array factor is actually a function of Fourier series design [5] method is identical to the same method used for designing the FIR digital filters in DSP. In equation (1) to (5) calculating the inverse discrete Fourier transforms if the array factor is the base of this approach. The one-dimensional equally spaced arrays are usually considered symmetrical with respect to the origin of the array axis and require a slight reduction in the cases of even number of the array elements.

Let an array of N elements at location X_m along the X-axis having element spacing d.

The array factor will be:

$$A(\varphi) = \sum_m \left[a_m e^{jk_x x_m} \right] = \sum_m \left[a_m e^{jkx_m \cos\varphi} \right] \qquad (1)$$

where $k_x = k \cos\varphi$, $x_m = md$:

$$A(\varphi) = a_0 + \sum_{m=1}^{\infty} \left[a_m e^{jm\varphi} + a_{-m} e^{-jm\varphi} \right] \qquad (2)$$

Then the corresponding inverse function will be:

$$a_m = \frac{1}{2\pi} \int_{-\pi}^{\pi} A(\varphi) e^{-jm\varphi} d\varphi \qquad (3)$$

Generally, desired array factors require an infinite number of coefficients and require exact representation. Only using finite number of coefficient in the Fourier series introduces undesired ripples in the response which is known as Gibbs Phenomenon.

For minimizing these ripples we can use an appropriate window with the expense of wider transition regions. So now the Fourier series may be summarized as a desired response, say $A_d(\varphi)$, pick an odd or even window length

For example $N= 2M+1$, and calculate the N ideal weights by evaluating the inverse transform.

$$a_d(m) = \frac{1}{2\pi} \int_{-\pi}^{\pi} A(\varphi) e^{-jm\varphi} d\varphi \qquad m = 0, \pm 1, \ldots, \pm M \qquad (4)$$

So, the final weights are obtained by windowing with a length-N window $w(m)$:

$$a(m) = w(m)\ a_d(m) \qquad (5)$$

The only point to remember in this method is convenient only when the required integral can be done exactly. The details for desired interference signal for seven dipole leg are given in the Table II and the relative correspondent feeding detail are given in Table III.

TABLE II.
Details Of Desired And Interference Signal

Angle	Power(dB)
-90	-50
-80	-50
-70	-50
-60	-50
-50	-50
-40	-50
-30	-50
-20	-50
-10	-50
-5	0
0	0
5	0
10	-50
15	-50
20	-50
25	-50
30	-50
35	-50
40	-50
45	-50
50	-50

55	-50
60	-50
65	-50
70	-50
80	-50
90	-50

TABLE III.
DETAILS OF APPLIED AMPLITUDE AND PHASE ANGLE

Position	Linear Applies Voltage	Phase in radian
1.	0.817373	-4.54E-11
2.	0.900246	-3.07E-11
3.	0.952458	-1.55E-11
4.	1	0
5.	0.952458	1.55E-11
6.	0.900246	3.07E-11
7.	0.817373	4.54E-11

The corresponding radiation pattern is shown in Fig. 3 and Fig. 4. Since the most of the beam shape need for mobile towers are not so complicated so this could used successfully for DPA smart antenna design.

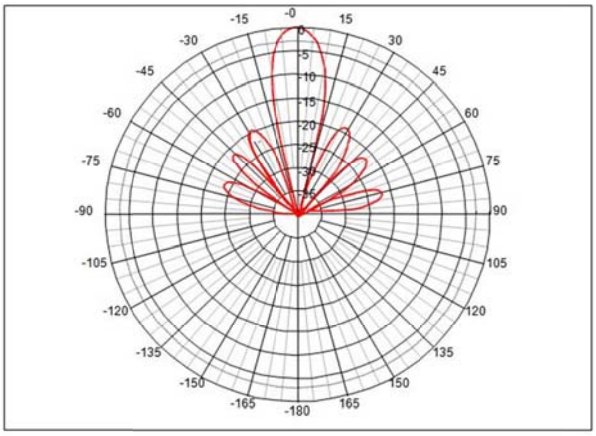

Figure 8 Polar plot of radiation pattern.

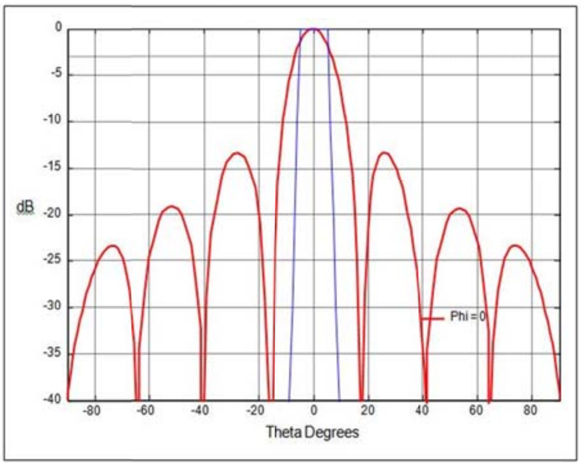

Figure 9 Linear plot of radiation pattern.

V. PROBLEM FORMULATION AND SIMULATION RESULTS

In the given proposed method we used seven dipole leg at the spacing of 860 MHz in MATLAB simulink environment [9]-[10] and collected data for 0 to 60 degree locations of major lobe. These data are then used for designing, training of both radial basis neural network and multi layer perceptron and after it testing of other set of data. The efficiency of the training is dependent on the training parameters. So for achieving desired accuracy the parameters are adjusted. The value of the training parameters taken for the training of the present network are as mentioned in Table IV.

Fig. 10 shows the networks of RBF and MLP respectively. Fig. 11 is depicting the training performance of the RBFNN in which 75 epochs are reached to goal. Fig. 12 show shows the same performance for MLP. Regression plot for the RBFNN is shown in Fig. 13. Comparative regression plot of MLP is shown in Fig. 14.

TABLE IV.
TRAINING PARAMETER

S. No.	Parameters	Specifications
1	Array Element	Dipole Leg
2	Applied Frequency	860 MHz
3	Number of Elements	7
4	Spacing between Elements	0.5
5	Radius for summation of field contributions	999 meter

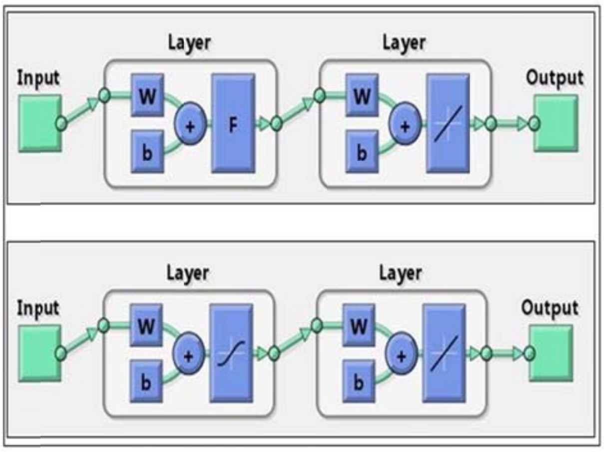

Figure 10 RBF and MLP network view respectively.

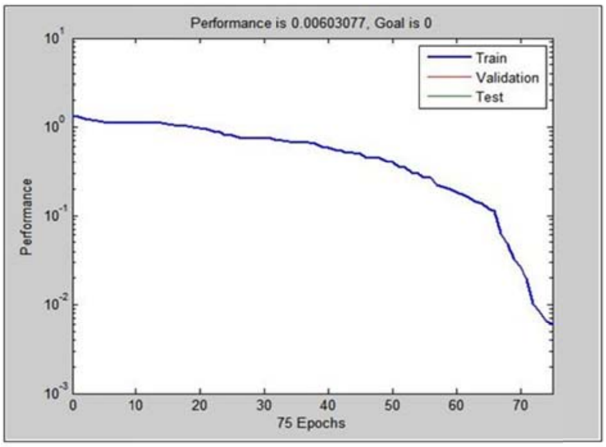

Figure 11 Training performance for RBFNN

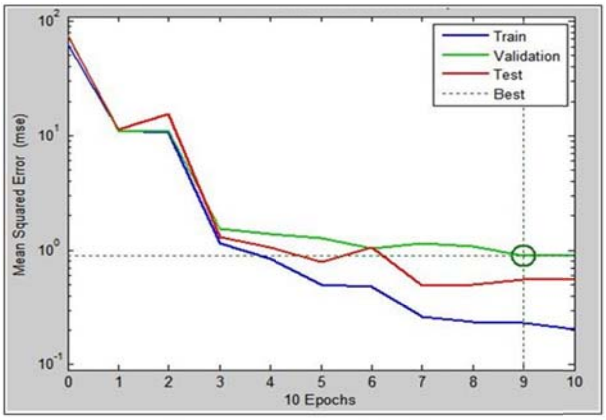

Figure 12 Training performance for MLPNN

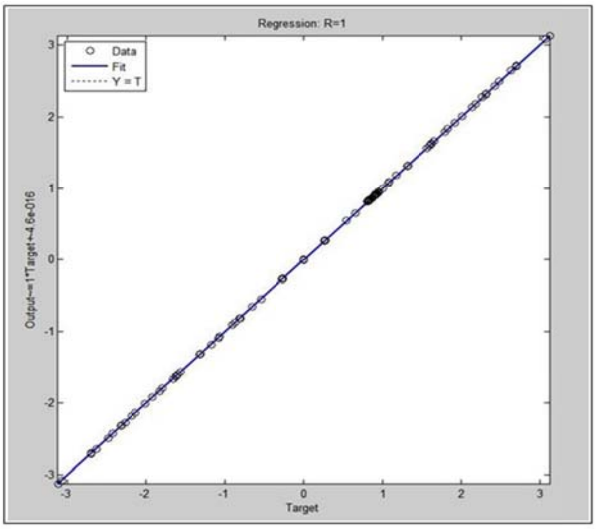

Figure 13 Training regression plot for RBFNN.

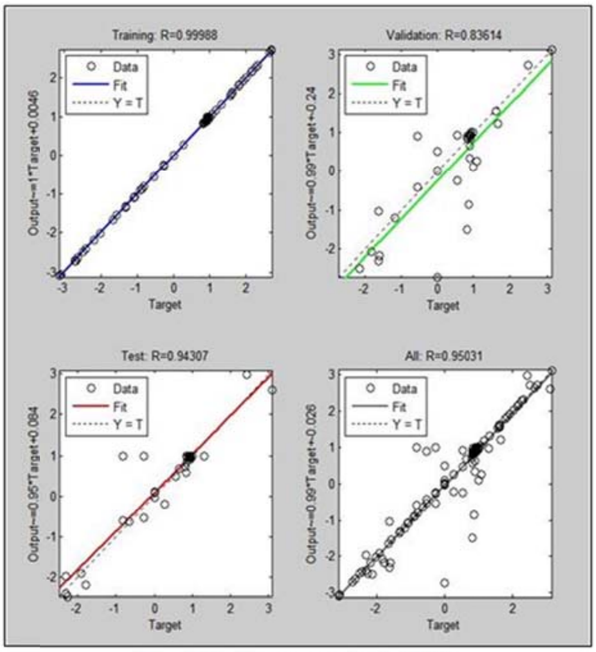

Figure 14 Complete regression plots for MLPNN.

VI CONCLUSION

In this paper neural network based 2 approaches radial basis neural network(RBFNN) and multi layer perceptron (MLPNN) are applied on seven element dynamic phased array smart antenna to determine the more suitable approach for beamforming. As per the results shown specially the regression plots suggest that the RBFNN is much suitable and faster method to make the antenna smart. Performance and training pattern is good at MLPNN but overall performance and validation and testing results are not suitable for real time application. So this Fourier based RBF method is capable enough to decrease the level of interference up to a good range -50dB in this case. The results shown in the RBNN modelling are in excellent agreement with the simulation results. The developed network can be used at the base stations to move radiation pattern in a particular direction using best combination.

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