CHAPTER 2
BIO - INSPIRED COMPUTING TECHNIQUES IN ANTENNA APPLICATIONS

2.1 BIO - INSPIRED COMPUTING TECHNIQUES

Many bio-inspired computing techniques have been proposed by the researchers in the past two decades that imitate genetic evolution, human brain, or the behavior of the biological individuals in natural world. Bio-inspired computing can tolerate uncertainty, vagueness, partial truth, and approximation. The bio-inspired computing make use of these tolerances to achieve tractability, robustness and low solution cost. A precise analytical model is required in traditional computing and generally, the computation time is very large. Also in most of the cases, the analytical models are applicable for ideal situations and the real world problems exist in non-ideal conditions. Bio-inspired computing techniques are group of methods spanning several areas that come under different categories in artificial intelligence. Despite the fact that some of these algorithms are new, they have been used effectively in many optimization problems with several constraints. The main constituents of bio-inspired computing techniques are ANN, GA, PSO, BFO, and SIMBO etc. At present, these techniques are fundamental to many antenna design solutions and have shown a great promise in tackling the growing requirements of antenna engineering for improved performances, reduced size, and overall cost. The bio-inspired computing techniques have resulted in many useful and non-intuitive antenna design solutions and, in most of the cases, these techniques have outperformed the traditional methods. Another important reason of suitability of the bio-inspired computing techniques is that antenna synthesis and optimization problems frequently involve many parameters and a very large number of possibilities thus making exhaustive search impractical. The use of these techniques for fractal antennas’ design is very suitable because of non-availability of exact mathematical expressions for these antennas.
2.2 ARTIFICIAL NEURAL NETWORK (ANN) APPLICATIONS TO ANTENNAS

The ANNs are computational models inspired by the biological neural networks. The ANNs can process information like human brain to attain, gather and exploit experimental knowledge. ANNs are used to find patterns in data or to model complex relationships between inputs and outputs (Haykin, 1998). The basic computational unit of the ANN is the neuron. The ANNs are massive parallel structures of the neurons arranged in the form of layers having interconnections between them. The neurons are of three types: (i) input neurons which receive inputs from outside world, (ii) hidden neurons which receive inputs from other neurons and whose outputs are inputs for other neurons in the network, and (iii) output neurons whose output is supplied to outside world (Zhang et al., 2003). The connecting branches of the neurons have the associated connection strength parameters which are known as the weights. The design of the ANN involves the training of the network for the specific application. During training, an input-output data set is used to adjust the weights so that the ANN produces correct output for the input applied (Jain and Kumar, 2006). Once the network is successfully trained it can be used for predicting outputs for the unknown inputs.

There exist different types of ANNs which are constructed by using different kinds of interconnections and various types of neurons. The most common type of the ANN is feed-forward neural networks in which the information flows in the forward direction only i.e. there is no feedback connection. The three important forms of feed-forward ANNs are MLPNN, RBFNN, and GRNN (Haykin, 1998). These three forms are very popular in the field of antennas.

The MLPNNs have M layers: one input layer, one output layer and M–2 hidden layers (Shrivastava and Singh, 2011). The number of hidden layers and the number of neurons in the hidden layers are chosen using a trial and error process so that correct output is obtained. The weights between the neurons in subsequent layers are
computed during training using error back propagation algorithm (Zhang et al., 2003). The training process is repeated many times to attain a desired solution.

The RBFNNs are special ANNs with faster performance and have only one hidden layer (Singh and Deo, 2007). The hidden layer neurons use a basis function of the normalized radial distance between the input vector and the weight vector (Sarimveis et al., 2006). The RBFNN training involves two steps. In the first step, the unsupervised training methods determine the parameters of the basis functions. In second step of training, weights of the output layer, which is a linear layer, are determined. The dimensions and number of input-output data sets determine the number of neurons in all layers of RBFNN (Sarimveis et al., 2006).

The GRNNs are memory based networks which converge to underlying linear or non linear regression surface. These are one pass learning algorithm networks with a highly parallel structure (Specht, 1991) based on the non linear regression analysis. The basic structure of GRNN has four layers. The input layer whose neurons act as distribution units: the first hidden layer whose neurons are called pattern units; the second hidden layer whose neurons are known as summation units. This layer has two types of neurons: numerator neurons and denominator neuron. The last layer is output layer which provides the required output (Rutkowski, 2004).

The ANNs have found a number of applications in the field of antennas. The applications include the analysis of antennas, synthesis of antennas, parameter estimation, antenna arrays and many more. The applications presented below are classified into different groups depending upon the functions performed by the ANN model.

2.2.1 Microstrip Antenna Design using ANNs

The design of a rectangular patch antenna using ANN is presented by Mishra and Patnaik (2003). They employed ANN for the accurate estimation of the patch length for the given set of other parameters and for different feeding techniques. The
performance of RBFNN and different MLPNNs are compared for the design of rectangular patch geometry by Turker et al. (2006).

Panda et al. (2003) and Khuntia et al. (2005) presented the coupling of GA and ANN for the design of rectangular patch antenna on thick substrate. A trained ANN is taken as objective function in GA and the optimized dimensions of the antenna are calculated. It is shown that the results obtained by this method are similar to those obtained by experimental and other methods.

A new geometrical methodology based on ANN principles, combined with compact and broadband design principles is presented by Lebbar et al. (2006). Five applications of this methodology resulting in compact size antennas are presented.

The design of an equilateral triangular microstrip antenna using a PSO driven RBFNN is presented by Chintakindi et al. (2009). The neural network weights are replaced by the particle position equation and rate of change of neural network is replaced by the particle velocity equation.

A microstrip circular ring antenna is designed using ANN for specified multi-frequency operation by Siakavara (2009). A multilayered dielectric substrate is used for this probe fed printed slotted ring antenna. A MLPNN model is used to find the width and the position of the slits along with the values of the structural parameters and the feed position of the antenna for desired frequency performance.

The parameter estimation of a multi slotted rectangular microstrip patch antenna using ANN is described in Kumar et al. (2010). Different ANN types have been developed and the results are compared with simulation results.

An ANN model for simultaneous calculation of multiple output design parameters of circular microstrip antennas is presented by Gultekin et al. (2012). Different learning algorithms are used to train the networks and it has been concluded that the extended delta-bar-delta algorithm has best performance.
An ANN based model for the design of a circularly-polarized square microstrip antenna with truncated corners is proposed by Wang et al. (2012). The training data sets are prepared by using the empirical formulas of the resonant frequency and Q-factor. The side length of the square and the size of the truncated corners are taken as outputs of ANN model. The synthesis model used three hidden layered network trained with the Levenberg-Marquardt algorithm.

Bose and Gupta (2012) have presented an ANN model using hybrid neural network for the design of aperture-coupled microstrip antennas by combining radial basis function (RBF) and back-propagation algorithm. The hybrid model determines various output parameters such as dimensions of ground plane, dimensions of aperture, dimensions of radiating element, dimensions of feed, and feed position for desired frequency of operation. The comparison of the results of hybrid model reveals that the hybrid approach is better than the conventional RBF and back-propagation algorithm models in terms of percentage error and the execution time.

An application of ANN for the design of inset fed rectangular microstrip antenna is discussed by Vilovic et al. (2013). In this paper, the PSO is used to find the optimum set of weights of ANN. The values of resonant frequency and substrate parameters have been used as inputs. The width & length of the patch and inset feed distance are outputs of the ANN model.

### 2.2.2 Resonant Frequency Calculation using ANNs

The use of ANNs to calculate the resonant frequency of different rectangular microstrip patch antennas is presented by Devi et al. (2003), Khuntia et al. (2004), and Pattnaik et al. (2005). These papers employ GA for the design of ANN. The GA is used to select the parameters of ANN which leads to decrease in the time required for training of neural network. A fast technique using neuro-fuzzy networks to evaluate the resonant frequency of microstrip antennas is proposed by Angiulli and Versaci (2003).
Pattnaik et al. (2005) presented a simple and accurate method to calculate the resonant frequency of a coaxially-fed single-shorting post tunable rectangular microstrip-patch antenna by using GA and ANN. The GA has been used to optimize the parameters of the ANN to achieve the output. The use of GA reduces the training time for the network.

Guney and Sarikaya (2007) proposed an Adaptive Network based Fuzzy Inference System (ANFIS) to calculate simultaneously the resonant frequencies of various microstrip antennas of various geometries. The results of the proposed hybrid method for the rectangular, circular, and triangular antennas are compared with the experimental results and are found in very good agreement. The application of ANN for the calculation of resonant frequency of electrically thick and thin circular is proposed by Gangwar et al. (2008). The ANN results are sufficiently accurate as compared to theoretical and measured results.

An ANN ensemble is used by Yu-Bo et al. (2011) for modeling the resonant frequency of rectangular microstrip antenna. In ANN ensemble, several ANNs are trained and then the results are combined by following certain rules. This improves the generalization ability of the ANN system. Yu-Bo et al. (2011) used the decimal PSO algorithm and binary PSO algorithm to select ANNs to construct ANN ensemble. The inputs to the ensemble model are antenna dimensions and substrate parameters. The output is corresponding resonant frequency. The ANN ensemble method provided better results than simple ANN methods.

A multilayer ANN structure combined with EM knowledge trained with spectral domain approach responses for the calculation of the resonant frequency of the rectangular microstrip antenna with and without air gap printed on isotropic substrate is proposed by Tighilt et al. (2011). The EM knowledge is used to preprocess the ANN model inputs to reduce the training time and to increase the accuracy.

A multilayer feed-forward ANN model for estimating the dual operating frequencies of a shorting pin-loaded dual-band equilateral triangular microstrip antenna is
proposed by Can et al. (2014). The inputs of the model are the side length, thickness, permittivity, and shorting pin position ratio. The comparison of results with theoretical and measured results has shown the considerable improvement achieved over the recent studies.

2.2.3 ANNs for Other Antenna Parameter Calculations

The calculation of radiation efficiency of a rectangular microstrip patch antenna with the use of ANN trained using back-propagation approach is discussed by Hettak and Delisle (2003). The method proposed by them is valid for substrates with relative permittivities between 1 and 12.8 and for the complete range of thicknesses normally used for antennas.

Neog et al. (2005) presented the use of tunnel based ANN model for the parameter calculation of a wideband microstrip antenna. The proposed tunneling technique used in the traditional gradient descent back-propagation algorithm takes less computational time as compared to the back-propagation model while producing accurate results.

A method based on ANFIS is presented by Guney and Sarikaya (2009) to compute the bandwidth of a rectangular microstrip antenna. They used different optimization algorithms to determine optimally the design parameters of the ANFIS and found that the ANFIS model trained by the least-squares algorithm generates best results.

The use of finite impulse response ANN for speeding up Finite-Difference Time-Domain (FDTD) calculations is presented by Panda et al. (2010). This neuro FDTD technique is applied to calculate the input impedance of a coaxially fed stacked microstrip patch antenna and it has been found that the same result with less number of iterations as compared to convention FDTD can be achieved.

A RBFNN model is proposed by Vilovic and Burum (2012) for the estimation of feed point of a circular microstrip antenna. The radial distances from the center of the
patch are taken as input and corresponding input impedance is taken as the output of the model.

An ANN based synthesis model is presented by Khan et al. (2013) for estimating the slot-size on the radiating patch and air-gap inserted between the ground plane and the dielectric substrate for obtaining the improved performance of a dual band rectangular microstrip antenna. 10-dimensional input consisting of dual resonance frequency, dual-frequency gain, dual-frequency directivity, dual-frequency antenna efficiency, and dual-frequency radiation efficiency parameters is used for the design.

A RBFNN model is proposed by Aneesh et al. (2014) for the bandwidth analysis of a slot-loaded microstrip line feed patch antenna. The slot-loaded antenna has triple band frequency performance and the ANN model estimates the bandwidth in all bands accurately for different slot lengths and widths.

2.2.4 Other Antenna Related Applications of ANNs

An ANN model of a MEMS-switched frequency-reconfigurable antenna is presented by Patnaik et al. (2005). The developed ANN finds the location of the operational frequency bands for any combination of switches connecting different radiating elements. This technique significantly reduces the computational complexities involved in the numerical modeling of reconfigurable antennas.

A review of applications of ANNs for different types of antennas such as microstrip antennas, coplanar waveguide patch antennas, wideband antennas, and multi-band antennas is provided by Patnaik et al. (2004). Some examples of ANN applications in smart antennas, reconfigurable antennas, and antenna arrays are also presented.

A new type of ANN, the Synthesis-ANN, which uses a hetero-associative memory and extends a subspace containing training data to solution subspaces by random variations of inputs and outputs, is proposed by Delgado et al. (2005). The proposed model is applied to the optimization of a printed dipole antenna with an integrated
balun and it is seen that the ANN arrived in the neighborhood of solution subspaces within a few iterations.

The neural-genetic optimization is used by Dubrovka and Vasylenko (2008) for the optimization of a “bow-tie” type planar antenna for UWB performance in the frequency range 3.1–10.6 GHz. The desired operation is achieved by suitably adjusting the radiating contour profile of the conventional triangular taper of the bow-tie antenna.

Mudroch et al. (2009) proposed an approach for the optimization of different UWB dipole antennas using an algorithm tuned using ANN. The optimization process searches for the dipole shape, which meets a good matching and a minimal distortion of radiated impulses.

The synthesis of UWB planar antennas utilizing a model built upon ANN and their inversion by GA is presented by Dubrovka and Vasylenko (2009). A dipole antenna and a slot profile of the Vivaldi antenna are synthesized using the proposed hybrid algorithm which is 5 times faster than GA and 1.5–2 times faster than PSO algorithm.

The design and optimization of an annular ring dielectric resonator antenna using an ANN approach is presented by Lucci et al. (2011). A harmonic tuning technique for a slot-coupled annular dielectric resonator antenna is proposed so that the antenna operates in the C band of frequency spectrum.

The mutual coupling between the radiating elements of a rectangular MIMO antenna for a specified range of separation between the antennas and for various frequencies is studied by Krishna et al. (2012a) using ANNs. The proposed antenna is developed on a flexible substrate, which can be used for wearable applications. Different ANN algorithms are used to train the neural structure and the comparison between them shows that the quasi-Newton and quasi-Newton multi layer perceptron algorithms are better in terms of various performance measures.
Gunes et al. (2013) employed an MLPNN model based on the 3-D CST microwave studio software in both design and analysis of the Minkowski reflectarray antenna. The MLPNN model is also used to observe the effect of the feed movement along the focal length on the gain-bandwidth and the radiation pattern. All steps of designing the MLPNN model and its utilization in design and analysis of a Minkowski reflectarray antenna are explained as a general method, so, the proposed scheme is applicable to different types of antennas.

2.2.5 ANNs in Antenna Arrays

The ANN models are used in antenna arrays for different purposes like fault finding, array synthesis etc. Some of the recent developments in this field are described in this section.

An ANN based approach of locating faulty elements in antenna arrays is proposed by Patnaik et al. (2007). The model takes samples of distorted radiation pattern of the array with faulty elements and maps it to the location of the faulty element in that array.

The optimization of antenna arrays using the application of ANN is proposed by Bashly and Popovskii (2007). The maximization of the energy parameters of antenna array is achieved using an efficient neural network optimization algorithm. The performance of this algorithm is compared to well-known algorithms and an improvement in computational time is observed.

A neural network based automatically converging scheme for the array synthesis for optimum side-lobe reduction is explained by Lee et al. (2009). This scheme automatically converge toward the minimum (or maximum) of system output using the gradient information of system output.

The use of RBFNN and probabilistic neural network for the diagnosis of planar antenna arrays from far field radiation pattern is proposed by Vakula and Sarma
(2009). The ANNs determine the location of the faulty element and error in excitation input using the deviation pattern.

The performance of ANN trained by mutated boolean PSO and minimum variance distortionless response is compared for adaptive beamforming of antenna arrays by Zaharis et al. (2012). The mutated boolean PSO trained ANN has better performance in terms of the steering ability of the main lobe and the nulls as well as the side lobe level.

A new antenna array beamformer based on ANN is presented by Zaharis et al. (2013). The training of ANN used is performed by a variant of invasive weed optimization. The ANN structure constructs an adaptive beamformer, having the ability to properly steer the main lobe toward a desired signal, place respective nulls toward several interference signals, and suppress the side lobe level.

Mishra et al. (2015) presented the use of RBFNN for directivity estimations of arrays of short dipoles. The algorithm is developed for collinear and parallel short dipoles and tested in noisy environment. The proposed algorithm is a fast and accurate method for estimating the directivity of arrays.

### 2.3 BIO-INSPIRED OPTIMIZATION ALGORITHMS

A significant number of applications of three most popular bio-inspired optimization algorithms: GA, PSO and BFO for the optimization of antennas have been proposed in recent years. This section introduces these algorithms.

#### 2.3.1 Genetic Algorithm (GA)

GA belongs to a class of stochastic optimization algorithms which is capable of converging to global optimum through iterations. GA is suitable for electromagnetic optimization due to their inherent parallel nature (Weile and Michielssen, 1997). The genetic operators such as crossover, mutation and reproduction form the basis of
GA’s selection procedure (Panda et al., 2003). These algorithms use a population of finite length strings, called chromosomes, as many initial points while the gradient based optimization algorithms start with only one initial point. Thus, this method searches the whole parameter space in parallel and due to this the chances of achieving the global optimum increases. The fitness of each individual of the population is evaluated (Ozgun et al., 2003) and the members with the higher fitness values are selected to be parents, on which the genetic operators are applied to obtain children. The random mutations are applied to make the population diverse. The parents for the next generation are selected by scoring children and finding the best performers. These steps are iterated until the stopping criterion is met. The commonly used termination criteria are: the maximum iteration number, a target fitness value, and minimum standard deviation criterion (Boeringer and Werner, 2004). The final global best location gives the required optimized solution. The flow chart shown in Fig. 2.1 describes the working of the GA.

2.3.2 Particle Swarm Optimization (PSO) Algorithm

PSO algorithm, a global optimization method, is proposed by Kennedy and Eberhart in 1995 (Kennedy and Eberhart, 1995). This optimization technique is very efficient for solving the problems in which the optimal answer can be represented in an N-dimensional space as a point or surface. The PSO algorithm is motivated by the collective behavior of birds or swarms called particles. The particles have memory and assist each other to reach the global optima (Pérez and Basterrechea, 2007). In the start of optimization process with PSO, the solution space is defined which means the variables to be optimized are initialized. The minimum and maximum value of each variable should also be defined (Robinson and Rahmat-Samii, 2004). In this algorithm, an initial population, which is a group of particles with arbitrary locations in the N-dimensional solution space, is defined. Each particle has an associated velocity with random direction and magnitude. The position of each member of population represents a potential solution to the optimization problem (Boeringer and Werner, 2004). The goodness of these individual locations is evaluated by using a
Fig. 2.1 Flow Chart of GA
cost function which take the position co-ordinates as input and return a single number as fitness score. The cost function is also known as the objective function or the fitness function. The cost function should be chosen critically and accurately because the performance of the PSO algorithm largely depends on it. The functional relationship of the variables to be optimized with the global optima and their relative importance should be demonstrated by the cost function (Robinson and Rahmat-Samii, 2004). The solution space and the cost function are specific to the problem to be optimized; however, all other steps are independent of the optimization problem. In each iteration, PSO lets every particle move from a given position to a new one with a velocity calculated by using the best position of the particle (called pbest), and the best position of the group (called gbest) (Ciuprina et al., 2002). During the optimization process, each particle adjusts its velocity to move toward the best solution. The PSO algorithm employs the following two equations for updating the velocity and the position of the particles (Robinson and Rahmat-Samii, 2004).

\[ v_i(t + 1) = wv_i(t) + c_1r_1[pbest - x_i(t)] + c_2r_2[gbest - x_i(t)] \] \hspace{1cm} \text{…(2.1)}

\[ x_i(t + 1) = x_i(t) + v_i(t + 1) \] \hspace{1cm} \text{…(2.2)}

where \( v_i \) is velocity of the particle, \( x_i \) is position of the particle, \( w \) is inertial weight, \( r_1 \) and \( r_2 \) are two random numbers, \( c_1 \) and \( c_2 \) are parameters which are related to the cognitive and social behavior of the particles. The value of \( c_1 \) influences the exploration of the solution space and that of \( c_2 \) exploitation of the solution space. The algorithm stops either by obtaining an acceptable target solution or after running for maximum number of search iterations or any other predefined criterion (Liu, 2005). The flow chart shown in Fig. 2.2 illustrates the sequence of various steps of PSO algorithm.
Fig. 2.2 Flow Chart of PSO Algorithm
2.3.3 Bacterial Foraging Optimization (BFO) Algorithm

The BFO algorithm is a relatively new algorithm proposed by Passino in 2002. This approach is based on the behavior of E. Coli bacteria, which is present in human intestine, for searching the food (Passino, 2002). This algorithm also, similar to the GA and PSO, starts with a population of bacteria. The operations used to mimic the behavior of the E. Coli bacteria are: chemotaxis (swimming & tumbling), elimination & dispersal, and reproduction (Gollapudi et al., 2008a). During chemotaxis step, the bacteria decide whether they should swim i.e. travel in the current direction or tumble i.e. move in a new direction so that they shift to areas which are rich in nutrients and free of noxious substances. The bacteria interchange between these operations i.e. swim and tumble for the whole lifetime (Datta and Misra, 2009; Coelho et al., 2010). After a specified number of chemotactic steps, the reproduction process is started and achieved in two stages. In first stage, fitness scores are assigned to all bacteria present in the search space and ranking is done on the basis of this fitness value. The second stage involves killing off the one-half least healthy bacteria of the population and splitting of each surviving bacterium into two copies of itself placed at the same location (Okaeme and Zanchetta, 2013). So, the total number of bacteria remains same. The environment where the bacteria exist may undergo certain steady or unexpected changes which affect the lives and the locations of the bacteria. For example, a considerable increase in the value of temperature can happen which will wipe out the nearby groups of bacteria. Similarly there may be changes which cause the shifting of bacteria to new locations. In BFO algorithm, these effects are replicated in the elimination & dispersal step. This step involves two activities, the first is the elimination which means randomly killing off some bacteria within the population and the second is the dispersal which initializes the bacteria (equal to eliminated bacteria) randomly over the search space so that the total population remains constant (Dasgupta et al., 2009). Finally, the algorithm stops when a specified number of iterations of the above operations have occurred. At the point of termination, the algorithm outputs the best fitness value and corresponding design
variables (Gollapudi et al., 2008a). The flow chart shown in Fig. 2.3 describes BFO algorithm in details. The various symbols used in the flow chart are defined as follows:

\[ p: \text{dimension of the search space, } \]

\[ S: \text{total number of bacteria in the population, } \]

\[ N_c: \text{number of chemotactic steps, } \]

\[ N_s: \text{swimming length, } \]

\[ N_{re}: \text{the number of reproduction steps, } \]

\[ N_{ed}: \text{the number of elimination–dispersal events, } \]

\[ P_{ed}: \text{elimination-dispersal probability, } \]

\[ C(i): \text{the size of the step taken in the random direction specified by the tumble, } \]

\[ J: \text{the objective function value. } \]

### 2.4 HYBRID BIO-INSPIRED OPTIMIZATION TECHNIQUES

Many hybrid bio-inspired optimization techniques are proposed in the last decade to enhance the accuracy and computational powers of the conventional bio-inspired algorithms. Another reason for designing the hybrid algorithms is to reduce the computational times of the complex optimization problems. In the field of antennas, the hybrid techniques are used to find more efficient solutions for many problems. Robinson et al. (2002) employed the hybrid of GA and PSO to develop an optimal profiled corrugated horn antenna. Pantoja et al. (2007) presented a hybrid of GA and space-mapping technique for antennas in which the space-mapping stage follows the GA approach and it resulted in improved accuracy and reduced computational cost.
Start

Initialize all variables. Set all loop-counters and bacterium index $i$ equal to 0.

Increase elimination – dispersion loop counter $l = l + 1$

No

$l < N_{ed}$?

Yes

Increase reproduction loop counter $k = k + 1$

No

$k < N_{ed}$?

Yes

Increase chemotactic loop counter $j = j + 1$

No

$j < N_{c}$?

Yes

Perform reproduction (by killing the worse half of the population with higher cumulative health and splitting the better half into two)

Perform elimination-dispersal (For $i = 1, 2, \ldots S$, with probability $P_{ed}$)

Stop

X

Y

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Fig. 2.3 Flow Chart of BFO Algorithm (Dasgupta et al., 2009)
An efficient hybrid of GA and BFO is proposed by Kim et al. (2007a) to solve global optimization problems. Another hybrid algorithm named as the genetical swarm optimization having properties of GA and PSO algorithms is developed by Grimaccia et al. (2007) which is very effective to solve the electromagnetic problems. The PSO and BFO are hybridized by Gollapudi et al. (2008b) to enhance the accuracy of resonant frequency calculation of rectangular microstrip antennas. The accuracy and speed of BFO algorithm is improved by Long et al. (2010) by merging the PSO in chemotaxis step of BFO. The enhancement of global search capabilities of BFO by hybridization with GA is proposed by Okaeme and Zanchetta (2013). All hybrid algorithms have one or more advantages over the individual constituent algorithms so these hybrid techniques along with growing capability of computers result in more acceptable solutions to the optimization problems.

2.5 APPLICATIONS OF OPTIMIZATION TECHNIQUES TO ANTENNAS

The optimization algorithms have found a number of applications in the area of antenna design and optimization in the past two decades. The extracts of some important papers on the use of optimization algorithms in antenna design is presented as follows:

Several applications of GA based methods for antennas have been described by Weile and Michielssen (1997). These include single element antenna applications like optimization of wire antennas, reflector antennas, and Yagi antennas. Also antenna array applications like reducing the side-lobes of an array, reducing the scattering of strip arrays, arrays with specified null locations and a specific pattern shape arrays have been described.

The use of GA to determine the optimized dimensions of microstrip antenna of rectangular shape have been presented in Pattnaik et al. (2003). The GA model inputs are the desired frequency of operation and substrate parameters; and the optimal
length and width values are provided as outputs. The electrically thin antennas are selected for the design.

The design of patch antenna on thick substrate by combining the GA and ANN is described by Panda et al. (2003). A trained ANN is used as cost function in GA for finding optimal results. The optimized values calculated by this approach are nearer to experimental dimensions.

The design of multi-band patch antennas using the cavity-model based simulation tool and the GA is presented by Ozgun et al. (2003). The antennas described in their work have employed a number of slots in the patch or several shorting strips between the ground plane and the patch. In first step, the variation in the input impedance due to the slots and shorting strips are analyzed. Then in second step, GA is used to determine the optimal locations of slots and shorting strips, so that the antennas behave as per the requirements over the selected resonant bands.

The synthesis of a complex phased array to achieve a desired far-field sidelobe value using GA and PSO is described by Boeringer and Werner (2004). The amplitude-only, phase-only and complex weighting arrays are designed with excellent performance using PSO and GA.

Robinson and Rahmat-Samii (2004) presented a comprehensive description of the PSO algorithm and explained its suitability in electromagnetic optimizations. The optimization of a profiled corrugated horn antenna is also described in detail.

Kerkhoff et al. (2004) designed and analyzed planar monopole antennas using GA. The impedance bandwidth of two shapes, the bow-tie and reverse bow-tie are optimized by employing GA. One outcome of this paper is that the bandwidth of the reverse bow-tie is greater than the bow-tie and it has a very small relative size. Then the randomly shaped monopole antennas are designed using GA and these antennas have shown enhanced performances and less sizes in comparison to the reverse bow-tie.
The design of a self-structuring antenna (antenna competent of assembling itself into numerous configurations) using the simulated annealing, ant-colony optimization, and GA is presented by Coleman et al. (2004). The realization of each method is discussed, and the results of all techniques are compared to a random search.

Jin and Rahmat-Samii (2005) presented a methodology based on combination of PSO and FDTD for the design of patch antennas having multiband and wide-band performance. The geometric parameters of antenna which are to be optimized are extracted by PSO and FDTD evaluates a cost function which returns a fitness value which is used to rank the possible designs as per their performance. Two examples, first, the design of rectangular patch antennas and second, the design of E-shaped patch antennas, are investigated in this paper.

The dimensions of a rectangular microstrip antenna are calculated by Khuntia et al. (2005) using a hybrid of ANN and GA. The trained ANN is employed as the cost function of a binary-coded GA.

Pattnaik et al. (2005) presented an easy, low cost, and precise method to compute the resonant frequency of a rectangular microstrip antenna having the coaxial feeding. A GA is employed with a back-propagation algorithm to estimate the resonant frequency of a tunable microstrip antenna having a shorting post.

The comparison of GA and PSO for the multi-objective optimization of wire multi-band antennas is described by Lukeš and Raida (2005). Antennas are optimized to reach the desired matching, to demonstrate the omni-directional constant gain and to have the reasonable polarization purity.

Liu (2005) proposed a PSO based approach to design a multiband monopole antenna having CPW feed. Impedance matching is obtained for multi resonant mode by introducing slits into the feeding line. The design parameters of the antenna for desired multiband performance are obtained by using a PSO algorithm in conjunction with the method of moments.
The application of GA for the optimization of electrically small wire antennas is reported by Choo et al. (2005). A multi-objective GA is implemented to simultaneously optimize bandwidth, efficiency and antenna size. Efficient optimization is achieved by involving three chromosomes with two-point crossover scheme and a geometrical filter.

Soontornpipit et al. (2005) described the use of GA for the designing of a waffle-type antenna appropriate for operation in MICS band (402 – 405 MHz). The design is optimized to get $S_{11}$ less than –15 dB throughout the whole band. This is achieved by simulating the antenna with FDTD and improving the design using a GA.

Misra et al. (2006) used GA to design an asymmetric V-dipole antenna and its three-element array. The directivity is taken as the optimization parameter for the V-dipole and that for the array are input impedance and directivity.

The optimization of antenna for UWB applications using GA is proposed by Telzhensky and Leviatan (2006). The time-domain characteristics are used to optimize a variant of the volcano smoke antenna. The aim of the optimization procedure is to find an antenna with low VSWR and low-dispersion.

Dual-band implantable antennas optimized for MICS and ISM bands using a PSO and HFSS implementation have been described by Hood and Topsakal (2007). The E-shaped patch and many other geometries of antennas are discussed.

A hybrid of GA and space-mapping tool is proposed by Pantoja et al. (2007) for the estimation of optimal lengths and feed locations for an array of microstrip antennas. The GA used coarse models and the space mapping improved the result obtained in the GA step. The computational cost of the hybrid approach is less as compared to the single application of GA with a fine-model simulator.

The design of UWB planar antenna using a hybrid algorithm of two-dimensional GA and FDTD is presented by Ding et al. (2007). The Best-Mate-Worst (BMW) strategy
is used for the mating of chromosomes to avoid the premature convergence. The design of a small UWB antenna which operates over a resonant band from 3.1 GHz to 12 GHz is proposed.

Pérez and Basterrechea (2007) presented a comparison between various optimization algorithms like simulated annealing, GA, PSO and their several modified forms for reconstruction of far-field radiation pattern of antenna from planar near-field data. PSO algorithm in which the swarm is updated asynchronously and having a global topology and the simulated annealing scheme with search step perturbation are concluded as the best algorithms on the basis of accuracy, simplicity and computational load.

PSO has been employed to estimate the resonant frequency and feed location of rectangular microstrip antenna by Chintakindi et al. (2007). The values provided by the PSO algorithm are very near to experimental results and are achieved with a reduced computational time.

Jin and Rahmat-Samii (2007) presented single-objective and multi-objective optimizations of nonuniform and thinned antenna arrays using real number PSO and binary PSO. Real-number PSO achieved a better value of peak side-lobe level by optimizing the positions of the elements in a non uniform array. The ON and OFF state of elements of a thinned array is decided using a binary PSO. Multi-objective cases are considered to find the non dominated solutions on the Pareto front to optimize the other design parameters than the peak side-lobe level.

A hybrid algorithm called genetical swarm optimization combining the properties of PSO and GA is presented by Grimaccia et al. (2007) for the optimization of a linear array. A key characteristic of the proposed optimizer is that the algorithm dynamically sets a driving parameter, called the hybridization coefficient, in order to adapt itself to any specific problem.
Rattan et al. (2008) presented an application of PSO for linear array designing using half wave parallel dipoles. The side-lobes are suppressed and null assignment in desired directions is achieved by arranging the half wave parallel dipoles as non-uniform linear array.

A germ swarm hybrid optimization algorithm is presented by Gollapudi et al. (2008b) to compute the frequency of operation of a rectangular patch antenna. An improvement in the correctness with less processing time is reported.

Dubrovka and Vasylenko (2008) optimized bow-tie type planar antennas with UWB performance using a concept of neural-genetic hybrid algorithm. The optimal result is attained by altering the radiating contour profile of the bow-tie antenna. An optimized antenna with an enhanced gain and impedance matching for the UWB frequency of 3.1–10.6 GHz is proposed.

An improved adaptive BFO algorithm is proposed by Datta et al. (2008) to optimize an array of antenna elements. The objective of the optimization is to maximize the array factor in specific direction and null placements in desired orientations. It is described that the presented method takes less time and increases the accuracy of the optimized solution.

The side-lobe level of a circular antenna arrays having non-uniform configuration is reduced by optimization using PSO by Shihab et al. (2008). The spacing of elements of array and the optimal weights are decided by employing the PSO so that side-lobe level of the radiation pattern is reduced while maintaining a desired major lobe beamwidth.

The synthesis of antenna arrays using GA, memetic algorithm and Tabu search algorithm is discussed by Cengiz and Tokat (2008). Three examples of antenna array design are presented to compare the efficiency of the algorithms. Memetic algorithm finds the most convenient results due to its local search capability but at the cost of increased time of iterations.
Chintakindi et al. (2008) explored the effectiveness of PSO in estimation of frequency of operation of a patch antenna having equilateral triangular shape and it has been found that the PSO can be used for such applications. The optimal values obtained using the PSO are very close to the experimental and GA results.

The use of BFO for the calculation of frequency of operation and the feed location of rectangular patch antenna is explained by Gollapudi et al. (2008a). The accurate results are achieved with reduced computational time.

The PSO has been used to design a multiband microstrip antenna, an antenna array, and an artificial ground plane by Jin and Rahmat-Samii (2008). The simulated and measured results of optimal designs are proposed which confirm the effectiveness of PSO in developing the beneficial and realistic solutions.

The use of PSO for the design of an implantable antenna with dual resonant band is presented by Karacolak et al. (2008). The gels having the electrical properties similar to that of human skin are used for validating the developed antenna and the optimal design of antenna is fabricated and experimented in the presence of the developed gel.

The BFO and PSO algorithms are compared by Datta and Misra (2009) for antenna-array optimization problem. The PSO produced superior solutions for null placement than the BFO, however, BFO performed better in side-lobe suppression.

Panduro et al. (2009) presented a comparison of GA, PSO and the differential evolution (DE) optimization algorithms for developing circular antenna arrays with scannable properties.

An intelligent BFO technique obtained by hybridizing BFO with PSO to reduce the convergence time and enhance the accuracy is proposed by Gollapudi et al. (2009) and this technique has been applied to calculate the frequency of operation of the rectangular microstrip antenna.
A new design model called semi automatic design of antennas using an adaptive improved comprehensive learning PSO is introduced by Wu et al. (2009). This model contains two steps: in first step, a digital configuration of an antenna is obtained and in second step, its dimensions are optimized further according to the current distribution of the digital one. The design of a small multiband printed monopole antenna is presented as an example.

A planar antenna optimization using PSO for ISM band application is explained by Choukiker et al. (2010). An E-shaped patch antenna with inset feeding having excellent radiation properties and sufficient gain in the complete resonant band has been developed.

Mahmoud (2010) optimized a bow-tie antenna for 2.45 GHz band application using a hybrid of PSO and BFO called the bacterial swarm optimization algorithm along with a simple algorithm called Nelder-Mead. The bacterial swarm optimization - Nelder-Mead method has yielded solutions superior than that of BFO, bacterial swarm optimization and BFO - Nelder-Mead algorithms.

Tseng and Han (2010) obtained slot antennas having circular polarization, broad-band and multiband properties using a new genetic local search algorithm. The proposed design technique is validated by developing antennas with various slot geometries: the elliptical, the triangular, and the square.

The use of a hybrid real-binary PSO technique in the design of a non-uniform antenna array and an antenna with dual-band characteristics for handset applications is discussed by Jin and Rahmat-Samii (2010). The usefulness of the hybrid technique in obtaining solutions with enhanced performance is confirmed by simulation and measurement results.

The use of BFO for resonant frequency optimization of a patch antenna of circular shape having air gaps is described in Sharma and Kanaujia (2011). The BFO results
are compared with the experimental results by changing diameter of patch, height of air-gap, mode of resonance and are found to be in good agreement.

Yeung et al. (2012) provided an overview of application of GA, PSO, and space mapping algorithms for antennas and radio frequency circuit designs. Two design examples, the design of a U-slot microstrip patch antenna and design of a microstrip pass-band filter are also discussed.

Anjitha and Kumar (2012) optimized a Zig-Zag antenna using PSO algorithm. The segment length and vertex angle of the Zig-Zag antenna are optimized to maximize the gain. In conventional Zig-Zag design, constant values of segment dimension and vertex angle are used. The simulated results illustrated that the antenna developed by the PSO algorithm produced superior gain values than the conventional Zig-Zag antenna.

Silva et al. (2012) applied a self organizing multi-objective GA to a ring monopole microstrip antenna with a slit in the ground plane for UWB applications. Bandwidth, return loss and central frequency deviation are considered as three objectives simultaneously. These objectives are modeled as dependent of two variables i.e. the slit dimensions and are used in a single weighted objective function. The weights are calculated by an adjuster GA that uses another GA to estimate each combination of possible weights.

Rahmat-Samii et al. (2012) described the main features, terminology, various boundary conditions and engineering constraints of PSO. This paper also discusses implementation of PSO algorithm with real and binary parameters. The application of PSO for two different antenna designs: a multiband handset antenna and an E-shaped patch antenna for circularly polarized applications are presented. The hybrid PSO–Method of Moments (MoM) program implemented for the multiband handset antenna achieved a small size antenna design with dual-band performance. The E-shaped patch design with a low profile antenna with wideband circularly polarized characteristics is achieved by using a PSO – Finite Element Method (FEM) program.
Minasian and Bird (2013) presented a design of microstrip antenna loaded with parasitic patches for WLAN systems. The parasitic patches are electromagnetically coupled with a co-axial probe fed rectangular microstrip antenna. The location and orientations of the patch is optimized by a PSO algorithm so that the antenna resonates over 5 GHz to 6 GHz frequency range. The designed antenna has an omni-directional radiation pattern with sufficient gain for WLAN applications.

Li et al. (2013) improved the performance of traditional PSO algorithm by a neighborhood-redispatch method and named the new improved algorithm as neighborhood-redispatch-PSO algorithm. The efficiency of the proposed neighborhood-redispatch-PSO algorithm is first validated by applying on benchmark functions and then it is used to design a CPW fed microstrip antenna. The optimal values of nine design variables are calculated so that the antenna has a resonant band over UWB frequency range with a stop band from 5.15 GHz – 5.825 GHz to evade possible interferences.

Silva and Martins (2013) described the use of a machine learning approach to optimize a microstrip antenna for UWB applications. Three different objective functions representing bandwidth, return loss, and central frequency deviation are developed using the machine learning approach from the experimental data. This multi-objective optimization problem is converted to a single objective by combing the three objective functions using suitable weights. The design variables are length and width of a slit used in the ground plane to achieve the desired performance.

Cismasu and Gustafsson (2014) presented an approach to compute Q factors of antennas using single frequency simulation data. The method is based on the values of energies stored in electric and magnetic fields excited by the radiating structure. The integration of the proposed method with GA is discussed to optimize the antenna bandwidth with reduced processing time.

The performance comparison of the DE, GA, PSO, and their variants is evaluated by Deb et al. (2014) for the optimization of microstrip antennas over a desired frequency
range. The design objectives are impedance matching for obtaining circular polarization and high gain. Three different feed mechanisms namely co-axial, microstrip-line, and the aperture coupled are evaluated. Four different objective functions are developed and then combined into a single function with dynamic weights allocated using a fuzzy approach. It has been found that the DE based approaches have better performance for the selected antennas.

Manh et al. (2014) described the use of ANN as objective function of a PSO algorithm for antenna optimization. A proximity coupled multilayer dual rectangular ring antenna is optimized by the proposed approach. A new approach of using separated ANNs as surrogate models is used to achieve better time convergence and accuracy.

Koppisetty et al. (2015) designed an adaptive antenna system using GA and PSO techniques. GA is used to find the solutions which are then refined by applying the PSO algorithm. The performance of the method is evaluated by conducting the system level simulations. The improved coverage and system throughput are achieved as compared to the fixed antenna systems. Also the presented method is computationally efficient and simple to implement.

## 2.6 LIMITATIONS OF BIO-INSPIRED COMPUTING TECHNIQUES TO ANTENNA APPLICATIONS

The main limitations of the existing bio-inspired computing techniques are as follows:

- Limited local and global search capabilities
- Large number of iterations required for achieving global optima
- Sequential calculations
- Absence of suitable objective functions to optimize irregular antenna shapes
- Limited generalization leading to need for efficient hybrid algorithm
2.7 BIO-INSPIRED OPTIMIZATION TECHNIQUES IN FRACTAL ANTENNAS

The bio-inspired optimization techniques have found a number of applications for analyzing and designing the fractal antenna. This section discusses the extracts of some important papers.

The initial work in the domain of optimization of fractal antenna is proposed by Werner et al. (2001). An IFS algorithm is employed to generate fractal antenna geometries and the VSWR requirements are satisfied by using two inductive-capacitive loads. GA based approach is employed to design a dual-band fractal antenna by the optimization of the shape of fractal antenna, position of the loads, inductive & capacitive values of loads, and overall length of the antenna element. A sensitivity analysis on the load component values of these antennas suggest that the performance varies with the load component values. Several optimization approaches have been proposed by Werner et al. (2002) which lead to antenna designs with considerably reduced load sensitivity.

Pantoja et al. (2003) developed Koch-like pre-fractal wire antennas using a multi-objective GA by optimizing their efficiency and bandwidth while reducing their frequency of operation. The initial GA population consists of the pre-fractal antenna elements and it is generated using an IFS algorithm. Three different cost functions are used to determine the fitness of individuals in the population and the algorithm uses these fitness scores to reach an optimized solution. The multi-objective GA procedure optimizes all three fitness functions at the same time and provides a number of optimized solutions which is used to choose the antenna elements that meet the specified optimization objectives.

Werner and Werner (2003) demonstrated that antennas can be optimized via GA to achieve superior performance characteristics (e.g., input impedance, VSWR, and gain) when placed in close proximity to a perfect magnetic conductor ground plane.
This technique is used to develop a miniaturized fractal antenna in dipole configuration.

The optimization of a crown square fractal microstrip antenna using GA to get minimum axial ratio is described by Dehkhoda and Tavakoli (2004). The optimization parameters are the ratio of two sides of the antenna and the diagonal feed location.

Fractal tile geometries based patch antennas are introduced by Spence and Werner (2004) to design single-feed microstrip antennas having gain in broadside direction greater than 12 dB. The use of GA has been proposed to optimize the performance of these antennas.

The design of a Koch-like fractal miniaturized monopole antenna for ISM-band application is described by Azaro et al. (2005). The proposed antenna is designed by optimizing the fractal geometry and the segment widths through a PSO algorithm. Same approach is followed by Azaro et al. (2006) for the synthesis of a reduced size pre-fractal monopole antenna suitable for WiMax band frequencies from 3.4 GHz to 3.6 GHz.

The optimization of closed-loop fractal shapes of Sierpinski in the form of Delta wire, Y Wire, and Koch is proposed by Pantoja et al. (2006). A multi-objective GA is used to develop new thin wire antennas which are electrically small and have improved characteristics than various pre-fractal Sierpinski antennas.

Polpasee et al. (2006) described the synthesis method of fractal geometry with maximized directivity by using GA. In this method the position of element is strategically combined with numerical technique. This application has shown that the GA can be used for developing the square-planar fractal array with improved directivity.

Another synthesis procedure for developing compact fractal antennas suitable for various applications using PSO is presented by Franceschini et al. (2006). A
trapezoidal fractal generator is used to reduce the overall length of the design and to obtain the desired VSWR values.

Ghatak et al. (2007) described the optimization of a CPW fed Sierpinski carpet fractal antenna using a real coded GA. The second order Sierpinski carpet antenna is developed with wide impedance bandwidth. The gap between ground plane and middle strip, the distance between ground plane and radiating carpet, and the size of the CPW central conductor are taken as design variables. The real coded GA is combined with IE3D electromagnetic simulation software, to obtain the optimized values. The same approach is followed by Ghatak et al. (2009) for the design of Sierpinski gasket microstrip antenna.

A PSO-based approach for the development of a multi-band fractal antenna has been proposed by Azaro et al. (2007a). The dimensions of a Sierpinski-like fractal shape are optimized using PSO and IE3D electromagnetic simulation software to attain the specifications of the Wi-Fi and GPS frequency bands.

Another example of a triple-band fractal antenna is described by Azaro et al. (2008). The use of this technique for designing a quad-band fractal antenna with similar shape is presented in Rocca et al. (2008).

Vidal and Raida (2008) discussed the synthesis of a self-affined Sierpinski monopole antenna operating at three different frequencies. The self-affined Sierpinski has different scale factor for different directions. Antennas are optimized by GA and PSO separately in order to operate in prescribed frequency bands and it is found that impedance matching is slightly better in case of GA as compared to PSO.

Azaro et al. (2009) described the design of a compact triple band patch antenna. The base antenna shape has been named as hybrid prefractal shape and it is generated by joining two diverse fractal geometries, a Sierpinski-like and a Meander-like structure. The antenna has been optimized using PSO combined with a hybrid pre-fractal geometry generator and IE3D electromagnetic simulator to achieve desired results. It
is observed by analyzing different “intermediate” geometries that the merging of the Meander-like geometry with the Sierpinski-like prefractal shape results in a resonant frequency drifted towards lower end of frequency scale.

Lizzi et al. (2009) proposed a triple band fractal antenna optimized for different frequency bands. The base geometry is a Sierpinski pre-fractal geometry with first three iterations. The ultimate antenna geometry is generated by using an iterative technique which integrates a MoM based electromagnetic simulator and PSO to arrive at a geometry which meets the required specifications in terms of size and the impedance characteristics.

Hazdra et al. (2009) proposed a set of software tools for the design and optimization of fractal patches described by the IFS. The presented approach makes use of fast cavity model and PSO. The optimization objective is to minimize fundamental resonant frequency of the fractal patch while preserving the maximum patch dimension.

Hieu et al. (2010) described the use of PSO to design a triple-band Sierpinski gasket based fractal antenna. The fractal structure of Sierpinski gasket along with a matching line is selected as base shape. The design variables chosen are dimensions of matching line, angle and side dimensions of triangle patch, scale of triangle slot, and width.

Oliveira et al. (2010) described the use of GA for optimization of fractal antennas based on triangular Koch shape. The inset-feed is used and it is optimized to minimize the $S_{11}$ value. The quasi-fractal antennas considered in their paper are designed using Koch curves and excitation of structures is done using a microstrip line.

Capek et al. (2011) described a MATLAB based code for the easy creation of planar IFS fractals. The generated fractal patches are analyzed by the cavity model, or by characteristic modes. The IFS parameters are then optimized using the PSO optimizer in order to minimize the fundamental resonant frequency. The proposed technique is
explained for a second iteration structure called as fractal clover leaf antenna. The L-probe mechanism is used to feed the proposed antenna to achieve broadband operation. Similar design technique for microstrip fractal patch antennas is also proposed by Capek and Hazdra (2010).

Adelpour et al. (2010) presented a modified Koch fractal configuration based dual-frequency microstrip antenna. Some perturbation to the conventional geometry of Koch fractal shape antenna for achieving new configuration with desired performance is investigated using an evolutionary method based on real coded GA.

Anuradha et al. (2011) employed ANN and PSO for the design of fractal antennas for desired frequencies. The ANN is trained to estimate resonant frequencies of the fractal antennas from the given dimensions of the antennas and this trained ANN is used by PSO to design the optimal geometry for the desired resonant frequencies. Two examples i.e. Sierpinski gasket antenna and Koch monopole antenna are developed using this approach. The same approach is proposed by the Ouedraogo et al. (2012) for designing Sierpinski carpet based customized fractal frequency selective surfaces for desired frequency characteristics.

The optimal design of a fractal monopole antenna having dual-band operation appropriate for LTE communications is presented by Lizzi and Massa (2011). The base shape for the proposed fractal antenna is perturbed Sierpinski fractal geometry and PSO is used to determine various geometrical parameters so that the optimized antenna exhibits a excellent matching characteristics for the required bands.

The use of ANFIS for the optimization of impedance bandwidth and radiation pattern of a fractal antenna is proposed by Krishna et al. (2012b). The ANFIS results for a concentric nano-arm fractal are compared with the results of HFSS software and good matching is reported.

Weng and Hung (2014) proposed an H shaped new fractal antenna. The antenna has multiband performance and PSO algorithm is used to optimize the presented antenna
for 2.45 GHz and 5.5 GHz WLAN applications. The performance of the antenna is validated experimentally.

Ghatak et al. (2015) optimized the Haferman carpet antenna array using DE and PSO algorithms. The optimization algorithms are used to find optimal excitations, element spacing, and number of elements. The performance is compared with conventional Sierpinski carpet array and a lower PSLL with reduced radiating element is achieved with Haferman carpet fractal array.

2.8 SUMMARY

This chapter highlights the importance of bio-inspired computing techniques for antennas. The working principles of bio-inspired computing techniques namely ANN, GA, PSO and BFO are described. The applications of feed forward ANNs in microstrip antennas are discussed and it is found that ANNs are used for different parameter estimation applications. A number of papers related to estimation of antenna dimensions using ANNs are reviewed and their extracts are presented. The other ANN applications like resonant frequency calculations, bandwidth estimation and antenna arrays are described to present the suitability of ANNs in antenna design.

Flow-charts of GA, PSO and BFO are shown in this chapter to explain the working of these algorithms. The importance of hybrid optimization techniques are pointed out. Various applications of GA, PSO, BFO and their variants are discussed for antennas. It has been observed from published papers that these algorithms are used for calculating the optimal dimensions of antennas for desired frequencies, computing resonant frequency for given dimensions and to estimate several antenna characteristics like S₁₁, bandwidth, efficiency etc. The size reduction of antennas is also achieved by these optimization algorithms. The use of ANNs as objective function is also reported by some researchers as an effective replacement of mathematical expression relating input and output variables. The performance comparison of different techniques is also discussed for different antenna applications. The applications of bio-inspired optimization techniques for fractal
antennas are reviewed in this chapter and it has been observed that these optimization techniques are very suitable for design optimization of fractal antennas. The fractal geometries are complex geometries as compared to simple Euclidian geometries and have relatively more number of design variables. The optimal values of design variables are required to achieve the design objectives. The optimization techniques have been used by different researchers to solve this type of problems. These techniques are also employed to tune fractal antennas for certain applications like ISM band applications etc. The objective functions of the optimization techniques for fractal antennas are developed empirically or the electromagnetic simulators are used as the objective function. A few applications of using ANN as objective function for fractal antenna optimization are also discussed.

In the following chapters, the applications of these bio-inspired techniques for designing the new fractal antenna are proposed.