CHAPTER 2

BACKGROUND AND RELATED WORKS
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Background and Related Works

2.1 Introduction

The literature survey presents significant information about the past and the present state of the art technology in the field of the single antenna, antenna arrays, and metaheuristic optimization techniques, and therefore stretches an idea for the future of antenna array and metaheuristic algorithms. The purpose of this chapter is to find out the common impression in various approaches to optimize the non-linear MOMP synthesis, its analysis, and comparison among different directional arrays. This survey also sets up our study in a proper framework with one-point perspective and provides an appropriate direction to our research. By examining the results of other studies, we can access our failure, our success, and our contribution by and large to human beings or society by large. Design, optimization and optimal design of arrays have attracted a considerable amount of research attention in the past. Analysis and code preparation becomes simpler when we analyze and use numerical methods [159-161]. There are many numerical methods available at present to study and examine array structures; out of which we selected array factor method in few cases and moment method in most cases for our design problems as stated earlier in the introduction chapter for some specific reasons.

This chapter presents some of the critical literatures on evolutionary and non-evolutionary algorithms, Yagi-Uda arrays, log-periodic arrays, linear arrays, planar arrays, and circular arrays to fulfill our multi-objective design synthesis problem. There are so many optimization algorithms, and antenna array structures are available, but our survey is limited to that literature about specific algorithms, analysis methods, and array design procedures that required for our design problem.

Some basic keywords of the survey are: fitness function, multi-objective function, optimization, Taguchi’s method, orthogonal array, cuckoo search, particle swarm optimization, bacteria foraging, biogeography based algorithm, gravitational search algorithm, fuzzy-logic, array factor method, moment method, mutual coupling, directivity, super-directive, performance parameters, half power beamwidth, first null
beamwidth, front-to-back ratio, sidelobe level, and directional antenna arrays, Yagi-Uda arrays, log-periodic arrays, linear arrays, planar arrays, circular arrays.

2.2 Review of Literatures on Various Evolutionary Algorithms

The algorithms except the gradient-based optimization algorithms are coined as the heuristic or metaheuristic algorithms. The meaning of heuristic was ‘to find’ or ‘to discover’ or ‘learn something for themselves’ or ‘processing to a solution by trial and error’ or ‘rules loosely defined’. We can say that the heuristic optimization algorithm discovers an optimal solution with the loosely defined rules by learning themselves through trial and error approach. The ‘meta’ has a different meaning as ‘with’, ‘across’, ‘after’, and ‘beyond’. So for these reasons, most of the algorithms are known as the metaheuristic algorithms. Metaheuristic algorithms can have different forms as stochastic, population-based, trajectory-based, evolutionary, and swarm intelligence.

One of the oldest and most used metaheuristic algorithms was the genetic algorithm (GA), which was based on Darwinian evolution and natural selection in the biological system with the help of crossover, mutation, and choice of fitness. The GA was developed by Holland in between 1960’s to 1970’s, and he published a book on “Adaptation in Natural and Artificial Systems” [162] after summarizing the development of genetic algorithms. The potential of GA was tested with different objective functions by Jong during his research [163]. Some researchers try to use the concept of mutation only, without a crossover to reproduce the offspring and kept the superior solution at each generation to solve the optimization problem. This category of metaheuristic algorithm was widely classified as evolutionary algorithms, which was a subset of the Evolutionary Computation (EC). Initially, the Fogel and his group developed the Evolutionary Programming (EP) technique [164-166]. The memetic algorithm was one of the recent growing areas in evolutionary algorithms, which was introduced by Moscato technical report in the year 1989 [167]. The memetic algorithm was one of the population-based approaches to individual learning and incorporates the local improvement procedure for searching. The memetic algorithm also referred as cultural algorithms and genetic local search. The most recent advancement of memetic algorithms is given in [168, 169].

The next phase of metaheuristic algorithm was interesting, and they are more inspired by the collective behavior shown by the biological agents in the natural process.
or organism. The collective behavior of decentralized, self-organized system was known as the swarm intelligence, which was the most prominent metaheuristic algorithm domain at present and useful in future. The swarm intelligence was first applied to the cellular robotic system by Beni and Wang in 1989 [5]. After this, many researchers showed interest in the development of swarm intelligence based metaheuristic algorithms. In the year 1992, Dorigo proposed Ant Colony Optimization (ACO) [170] in his dissertation ‘Optimization, Learning and Natural Algorithms’ which can find the shortest path, inspired by ant behavior. The detailed survey of ACO has been reported in the book ‘Ant Colony Optimization’ [171]. Storn developed a differential evolution (DE) [172] in the year 1996, which was well suited for robust and parallel computation. Further enhancements on DE are proposed in [173] and prove that this algorithm was more efficient than GA. The more details of function optimization on DE are reported in the book [174] by Price et al., and in another book [175] by Feoktistov. The advancements of DE are presented in the book [176] by Chakraborty.

Until 1997, the researcher compares the algorithms considering the average function result and expresses algorithm A1 is better than A2 or algorithm A2 outperform A1. In the year 1997, Wolpert and Macready published ‘no free lunch theorems for optimization’ [177] send a shocking message to optimization community. The theorems stated that if algorithm A1 is superior to algorithm A2 for some optimization problem, then A2 may outperform A1 for other optimization function of some optimization problem. Thereafter, researchers realized that there was no universal algorithm. This leads to more focus on finding better and more efficient algorithm related to a specific problem.

The next development was particle swarm optimization (PSO) in the year 1995, which was inspired by birds flocking, fish schooling, and swarm theory. Kennedy and Eberhart in 1995 proposed the metaheuristic optimization algorithm known as PSO [6]. In this algorithm, the researchers described the paradigm related to the development of the PSO algorithm and its applications to nonlinear function optimizations. Gazi and Passino, in the year 2002 [7], study the underlying principle of stability analysis of swarms in a biological system. They proposed a model for an aggregating swarm, and the aggregation of the swarm can be represented with an attraction/repulsion function. In this paper, an analysis of swarm cohesion and swarm member in a cohesion swarm was presented. They found that individual agents or biological creatures form a
cohesive swarm within a finite time. So this leads to the development of swarm based-optimization algorithm. Robinson and Rahmat-Samii in 2004 [8] introduced PSO technique in the field of electromagnetics. They stated a detailed explanation of implementing the same in electromagnetics; besides, its parameters selection; its boundary conditions; its binary versions; and finally was compared with GA optimization to show its efficacy.

In the 21st century, the researchers were more focused to design the metaheuristic algorithms inspired from nature. Passino in 2002 [9], taking inspiration from *E.coli* bacteria found in the human intestine and swarm intelligence [7], came up with the gradient-free optimization for distributed optimization and control known as the BFO algorithm. The BFO was inspired by the E. coli bacterium’s social foraging for nutrients. They also explain the different process involving in foraging like chemotaxis, swarming, reproduction, elimination, and dispersal. They gave suggestions that how one can choose the parameters for the algorithm. In this paper, a brief discussion was also presented for BFO in connections with other gradient-free optimization algorithms. They also apply the BFO for function optimization, and design of an adaptive control system. Liu and Passino, in the year 2002 [10], proposed two gradient-free optimization model based on foraging theory taking inspiration from *E. coli* and *M. Xanthus* bacteria. They exhibit the property of social foraging and have the potential to climb noisy gradients in nutrients. In that paper, they discussed the model, principles, and behaviors of both bacteria. They show a possibility of global optimization algorithms over noisy environment using the social foraging and distributed gradient free nature of the bacterium. In the year 2005, Mishra [11] proposed a fuzzy bacterial foraging (FBG) strategy for harmonic estimation. He used the foraging behavior of *E. coli* bacteria to estimate the harmonic components of the power system current and voltage waveforms. The foraging strategy made adaptive using Takagi-Sugeno fuzzy scheme, making the convergence of FBG faster than the BFO algorithm. They also compared the performance with GA, and show a significant improvement in the accuracy and speed. The Karaboga presented a technical report on Artificial Bee Colony (ABC) in the year 2005 [178] taking inspiration from honey bees. The ABC algorithm can be successfully implemented for constrained optimization such as in [179]. Further, in [180], ABC algorithm was compared with the well-known algorithms: GA and PSO; it has been shown that it can work for a high dimensional problem.
After several years of frequent use, new and different optimization algorithm, such as Biogeography Based Algorithm (BBA) [12-14], and Gravitational Search Algorithm (GSA) [15-17] are developed in the search for a most efficient algorithm. These two new techniques are dissimilar in their approach. Many researchers have found its application in various kinds of optimization problems. According to Simon in 2008 [12], and in 2011 [13], and Singh et al. in 2010 [14], BBA was the study of geographical distribution of the biological organism. Mathematical models of biogeography describe the evolution of new species, migration of species (animals, birds, and insects) among islands and extinction of species. Islands that are friendly to life are said to have a high habitat suitability index (HSI). Rashedi et al. in 2009 [15] proposed a novel metaheuristic search method named as the GSA based on the principle of laws of gravity and mass interaction in the year 2009. According to Rashedi, the agents in GSA algorithm were considered as natural elements, and their performance are measured by their masses and positions. These agents interact with each other through the gravitational force among themselves. This gravitational force causes global movement of one agent towards the other agent with heavier mass. In GSA, a set of an agent is called as population and position of each agent corresponds to a starting solution of the problem, which may not be the optimum solution. Each solution is associated with a fitness value. A good solution corresponds to an agent with heavier mass, and poor solution corresponds to an agent with lighter mass. If a problem has ‘Q’ parameters to be optimized, then the position of each mass corresponds to ‘Q’ dimensions. In their publication, the author reported that GSA method of function optimization was outperforming, when compared with the PSO, and the real coded GA (RGA). The GSA algorithm shows faster convergence as compared to others. Chatterjee et al. in 2010 [16] applied GSA and Modified PSO (MPSO) to an optimization synthesis problem of reducing SLL at fixed FNBW for a concentric circular array. The authors in their study found that GSA outpaced MPSO concerning computation time and fitness values. Mangaraj and Swain in 2011 described application of different optimization technique such as GA, PSO, BFA, SA, and BBA in the design of LAA and they observed that BBA perform better than the above-mentioned optimization algorithms [17].

algorithms, steps involving the development of algorithms, and implementation of various methods. The metaheuristic methods described are random walks, Simulated Annealing (SA), GA, DE, ACO, bee-inspired algorithm Honey Bee Algorithm (HA), Virtual Bee Algorithm (VBA), ABC optimization, PSO, Harmony search (HS), firefly algorithm (FA), and Cuckoo search (CS). In this year, Yang also proposed an FA in his book based on the behavior of male-female firefly on light flashing and light intensity. Later, Yang proposed a CS algorithm [19] in the year 2009 and bat-inspired algorithm (BA) [24] in the year 2010. The CS algorithm was based on the behavior of Cuckoo birds, and a random walk inspired using L’evy flight [20-24]. They utilized the proposed algorithm for function optimization and reported a good advancement in performance. The more developments in FA is reported in [25], and CS is reported in [25, 26].

Fuzzy sets were first classified and brought into the notice of others by Zadeh in 1965 [27]. He defined a fuzzy set as a class of objects, which was characterized by their grade of membership functions in the range of 0 to 1(to handle the partial truth) instead of 0 or 1, i.e., completely True or False as in binary logic (BL). In fuzzy logic (FL) everything including truth is a matter of degree, therefore quite helpful for human reasoning. According to Verma and Shukla in 2015 [28], demanding a global solution to a particular multi-objective problem was not at all possible without compromising some objectives or fixing any criteria. In this regard involving FL will be a big help to provide a global solution as per its systematic application procedure. FL is specifically considered to determine the best compromise solution out of a group of optimal solutions obtained using metaheuristic algorithms.

Taguchi’s method optimization (TMO) was based on a construction of Orthogonal Arrays (OAs), which have a profound background in statistics [31], and play an essential role in the optimization process. Orthogonal arrays which constitute latin square and mutually orthogonal latin squares were introduced in the 1940s by Kishen (1942) [29] and later modified by Rao in 1947 [30]. This was a statistical method to improve the quality of goods, and more recently also applied to engineering, biotechnology, marketing and advertising fields. Macdonald in 1990 [31] optimized a single piece tapered spiral cavity absorber by accomplishing the fractional factorial (orthogonal) method developed by Taguchi [31]. The purpose of using TMO was to reduce the computational time by constructing orthogonal arrays [32]. Weng et al., in
2006 [33] first introduced the use of TMO in the field of electromagnetics. They implemented the same for design synthesis of LAA and subsequently compared their results with GA and PSO optimized LAA and found its suitability in the whole synthesis design problem. In 2009, Weng and Choi [34] proposed two Co-Planar Waveguides (CPWs) slot antenna; a 1-element and a 2-element series aperiodic array optimization by TMO. The results were compared with PSO optimized results and concluded as Taguchi’s method outperformed the PSO method for these design problems.

2.3 Review of Literatures on Various Yagi-Uda Arrays and their Optimization

In 1976, Viezbicke [36] presented an optimal design of YUA for six different practical antenna element lengths in HF, VHF, and UHF range. The gain of the YUA was measured in terms of dipole antenna length and their inter-element separation. The lengths of the director and inter-element spacing were varied in the range 0.304 λ to 0.423 λ and 0.01 λ to 0.40 λ respectively. The length of the YUA, measured from the driven element to the last director, was varied in the range 0.2 λ to 10.2 λ. The reflector in all cases was fixed in length (0.482 λ) and spaced 0.2 λ behind the driven element. The dipole diameter was fixed in all the instances (i.e., 0.0085 λ). With these arrangements, he could able to achieve a gain in the range of 7.1 dB to 14.2 dB for the six different practical antenna lengths.

Liang and Cheng in 1983 [37] emphasized on a method, that took care of directivity maximization of a MoM based YUA, whose elements were not conventional straight conductors. The shape and positions of array elements, which depend on the radius of the conductors, were optimized by using the simplex method for function minimization. An example showed that an optimized YUA of three shaped dipole elements (each of 1.5 λ long) could achieve a maximum directivity of 11.8 dB with $E$-HPBW, $SLL$, and $FBR$ as 32 degree, -19.35 dB and -14.67 dB respectively.

In 1991, Crosswell [38] took some perturbations on spacing and length of antenna elements to increase the gain of the YUA. He observed that properly shaped wire antennas, more than a wavelength, could yield more directivity than straight dipoles. Again by assuming a sinusoidal distribution, which was not changed with the shape of the radius of the dipole, he obtained dipole geometry for maximum directivity by a piecewise linear approximation. With the help of experiments he also found that a 3-
element YUA of shaped wires, each $1.5\lambda$ long, could be tuned to produce a maximum gain of 11.5 dB.

Chen et al. [39] proposed 6-elements YUAs of shaped dipoles; optimized by steepest descent method for low SLL patterns. The study carried out in 1994, showed that this type of antenna array could be designed to achieve not only low SLL but also higher DR and much greater FBR than the usual straight-wire arrays. The directivity found was 33.78 dB and the input impedance found was $27.61 + j34.49$ ohms. The highest sidelobe appeared in the E-plane at 49.2 degree was -23.73 dB. The FBR was as great as 40.59 dB.

Altshuler and Linden [3] described the design of four YUA with seventeen elements using GA in 1997. The first was a monopole, loaded with a modified folded dipole that was designed to radiate uniform power over the hemisphere at a frequency of 1.6 GHz. The general shape of the loaded monopole was kept constant, but wire lengths were optimized by GA. The second was seven wires YUA, whose locations and lengths were GA optimized. It provided a radiation pattern with right-hand-circular polarization at elevation angles above 10 degree at the same frequency. The last two YUAs were modified YUAs out of which one was intended for a wide frequency band with low SLL at a center frequency of 235 MHz. The other was intended for high gain at a single frequency of 432 MHz. Jones and Joines [40] considered optimization of element spacing and lengths for YUA design. In this study, A MoM based Numerical Electromagnetics Code-2 (NEC-2), performed the task of assessing each of the GA optimized antenna designs. To illustrate the capabilities of this method, the length and spacing of several YUAs were optimized for various performance characteristics. The comparative optimized simulated results showed the efficacy of GA optimized YUAs over conventional YUAs.

Later in 2001, Lohn et al. [41] had emphasized on a Binary-coded GA (BGA) to optimize the gain of a YUA with constraints on the $Z_m$ and SLL. They stated that an inherent association between power gain and sidelobe/backlobe losses was allowed by the fitness function calculation, which was less complex compared to earlier methods. Their results revealed that the GA optimized YUA had produced an excellent gain-bandwidth product with good impedance characteristics. They also claimed that this optimized YUA had made 7.8% primary lobe gain compared to other YUAs; optimized by other evolutionary algorithms.
Venkatarayalu and Ray in 2003 [42] indicated that the GA and EAs optimizations had used some additional inputs such as scaling and aggregating factors to deal with constraints and objectives of these optimized YUA syntheses. They further studied that the same was not required for computationally efficient CI optimization technique used by them. In fact, the design of single and multi-objective CI optimized YUA had been performed to depict the restrictions of using an aggregate objective function in design optimization process. Ramos et al. [43] presented a new optimization algorithm, the Real-Biased Multi-Objective GA (RBMGA), to optimize multi-objective, multi-parameter problem of a six-element YUA. The design method of producing numerous Pareto-optimal solutions that were succumbed to the human decision allowed the adequate tuning of the designated YUA antenna enactment to the desires of the design problem at hand. The proposed algorithm delivered better-performing antenna geometries compared to those available in the earlier literature. Later, Venkatarayalu and Ray in 2004 [44] reinvestigated the earlier proclaimed idea (given in 2003) of additional inputs such as scaling and aggregating factors. In this paper, they took the concept of generating Pareto-optimal solutions presented by Ramos et al. 2003. They brought together a zeroth-order; stochastic CI optimization algorithm that handles constraints and objectives distinctly via Pareto ranking that reduces the problem of scaling and aggregation. The algorithm was based on values of learning and was entrenched with three key learning tactics that control whom to learn from (that includes leader identification and leader selection) and what to learn (that includes information acquisition) to search better. Finally, CI optimized results showed the effectiveness and benefits of the proposed algorithms over other published literature.

Modaresi et al. in 2005 [45] found that results of their proposed method of using a single mode cosine current distribution to each YUA element are in good agreement with the results obtained from MoM based NEC2. This proposed method was used together with GA for optimizing the gain of YUA. Their simulated results for 31-element YUA showed that a high gain of 19.2 dB was achieved for a wideband gain characteristic. Kuwahara [46] explored the use of Pareto-optimal solutions together with GA to design a multi-objective YUA problem. The usefulness of Pareto GA optimized performance parameters was compared with conventional GA optimized parameters and found better in performance analysis. According to Varlamos et al. [47], an improved YUA with additional parasitic elements in the radiating zone,
behaving either as reflectors or directors, is proposed. The GA technique was first applied for gain optimization only, then for both gain and FBR, and later combined with $Z_{in}$. The authors in their paper claimed that the proposed GA optimized proposed YUA structure outpaced the conventional YUA structures over a relative bandwidth of 8% at a 2.4 GHz center frequency. Baskar et al. [48] advocated some MPSO algorithms to optimize each element length and spacing of YUA. The modifications were done in terms of mitigating the problem of premature convergence. Thus they employed a novel learning strategy and developed three variants of PSO algorithms, namely the modified PSO, fitness distance ratio PSO (FDR-PSO), and comprehensive learning PSO (CL-PSO). The efficacy of each PSO had been shown by comparing their results obtained for three different optimized YUA designs. The results noticeably exhibited that the CL-PSO was a robust and useful optimization technique for designing YUAs for the desired performance parameters.

Bayraktar et al. in 2006 [49] proposed a method to reduce the overall array length and width as much as 70% and 50% respectively. They had employed a fixed grid structure of reduced length to create 3-element miniature stochastic YUA. The optimization of altering the element shape and inter-element distance for optimum gain, FBR, and better VSWR (2:1) had been done by using PSO, and subsequently compared with conventional YUA and binary valued GA optimized YUA published earlier. After two years, Lei et al. [50] promoted a vertically stacked 6-element YUA with an X-shape driven element at the VHF frequency. The optimized radiation characteristics of this YUA had been obtained by optimizing each element length and their spacing by using GA.

Singh et al. in 2010 [14] applied BBO algorithm to optimize each element length and inter-element spacing of a YUA to synthesize the desired radiation pattern. The BBO optimized YUA was designed for three different objectives consisting of gain, $Z_{in}$, and $SLL$ and simultaneously compared with other YUA optimizations such as using GA, EP, CLPSO, SA, and CI. The findings addressed that BBO was no less than other optimization techniques, even found better in some of the cases. In the same year, Khodier and Aqeel [51] presented design and optimization of YUAs using PSO. The optimum element location and/or lengths were found to achieve optimum DR. In general; the PSO technique was able to yield an array with higher DR despite increasing the overall array size. Yan et al. [52] focused on a wide-band DE optimized YUA.
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having X-shape driven elements and additional parasitic elements. The capabilities of this method had been illustrated by the design of 9-element YUA structure. They could able to achieve a good impedance matching with an impedance bandwidth about 19% for VSWR < 1.8. The full gain over the working frequency band was found to be 12.7 dB. Mangaraj et al. [53] introduced a multi-objective-multi-parameter synthesis problem of a YUA in 2011. They designed the optimal structure (incorporating MoM) using MATLAB code, the optimal design parameters were found using BFO code properly linked to the YUA code.

Later, Formato [54] had developed a novel method for enhancing antenna bandwidth via a 6-element YUA design in 2012. They could able to fetch impedance bandwidth of about 33.09% by applying novel Central Force Optimized (CFO)-variable $Z_0$ technology. The simultaneous results were compared with CFO-optimized fixed $Z_0$ and Dominating Cone Line Search (DCLS)-optimized YUA. The simulation results showed the better performance of CFO-optimized YUA over DCLS-optimized YUA.

Arceo and Balanis [55] put forward a basic design methodology, which superimposed the E-field of an individual element along with multi-objective optimization. The design methodology was established in a 3-element, reactively loaded, symmetrical, compact Yagi–Uda antenna. This approach could permit for the proposal of a reactively loaded compact YUA with the competency of steering its main beam in two directions. The YUA attained a high absolute gain of 9 dBi and a 10% fractional bandwidth for a low VSWR (less than 2) with an inter-element spacing of 0.053 $\lambda$. Yuan et al. [56] performed a similar approach to those Lei et al. had done in 2008. This time the designs were made for 3-element YUA optimized using DE. Authors claimed that they had achieved impedance bandwidth about 22% for VSWR < 1.4 and maximum gain nearly 10 dB without wide azimuth HPBW and nearly 8 dB with wide azimuth HPBW (90 deg.)

2.4 Review of Literatures on Various Log-Periodic Dipole Arrays and their Optimization

In the late 60’s; Carel [57] presented a detailed analysis of LPDA and modeled it as a parallel connection of two $N$-port decoupled circuits. One having $N$-dipole elements mutually coupled and another having transmission line with feed points of the dipoles. Subsequently, he derived systems of equations to relate the currents at the input of the antenna elements to the current at the input terminals of the whole antenna. Chong [58],
King [59, 60], and King et al. [61] revised dipole elements in LPDA and LAA structures with unequal length and inter-element spacing.

Subsequently, in 1973, Vito and Stracca [62] reinvestigated the sets of equations developed by Carel in 1961 and re-formulated two admittance matrices, namely $Y_A$ (total admittance created due to mutually coupled $N$-dipole elements) and $Y_L$ (total admittance due to transmission line and feed points of dipoles) for each side (input/output) of the two $N$-port networks. They stated that the current distributions (governed by a set of integral equations) on the two networks decide the $Y_A$ and $Y_L$ parameters. Therefore, by solving these metrics, the current distribution could be known, which could further assist in plotting the radiation patterns along with its gain and $DR$.

Calmon et al. [63] introduced a reconfigurable ultra-wideband LPDA antenna in the year 2006. On a given frequency band, the gain of the LPDA could change by the reconfiguration of array elements. Pitzer et al. [64] in the same year explored optimization of LPDA by using GA. The LPDA was optimized through a proposed integrated technique with a weighted sum type fitness function. This array synthesis was finally compared with YUA design. One year later, Pantoja et al. [65] first put forward a tutorial on PSO and then presented PSO optimized LPDA to display contour graphs of several radiation patterns for different geometrical parameters and feed characteristics. PSO with NEC was applied to analyze the performance parameter of optimized LPDA and was finally compared with non-optimized standard LPDA design. Mangaraj et al. discussed the role of geometry factor and spacing factor of a LPDA to decide its performance [66]. They tested the design of LPDA for 134 frequency points in the entire UHF band. This LPDA design problem is also analyzed and solved by comparing it to a 2-port network of circuit theory.

Almalkawi et al. [67] in their paper emphasized a design of miniaturized printed planar LPDA antenna in the year 2014. They replaced the conventional uniform dipole elements by the dipole elements that have variable impedance profiles ruled by a curtailed Fourier series. This was possible by exploiting the concept of compact non-uniform transmission lines and antenna radiator elements whose impedance profiles were modulated according to Fourier series. Both conventional and miniaturized LPDA exhibited a gain of 7 dB over a range 2 GHz to 4 GHz. Lehmensiek and de-Villiers [68] applied brute force optimization to obtain correct excitation voltage on individual
elements of a LPDA so that a constant radiation characteristic could be achieved for an omnidirectional radiation pattern. They corrected to previously reported oversimplification that assumed no excitation to a dipole terminal/feed element means no radiation from that dipole element. This conversely had an impact on the physical design where no element excitation was as good as disconnecting its two arms that had an result of completely removing the two arms. So to counteract the previous assumption, the author had shown the effect of the induced terminal excitation in the disconnected arms of a dipole; through global optimization. Dallmann and Heberling [69] studied the effect of a frequency-dependent phase center shift onto a LPDA in the time domain and also examined the simulated LPDA impulse responses. Both designs were compared and discussed in their literature with a conclusion that the movement of the LPDA phase center was responsible for the dispersion behavior of the LPDA. According to Zaharis et al. [70] in the same year, an application of Invasive Weed optimization (IWO) to optimize the geometry of a realistic LPDA for several RF services in the range 800 MHz to 3300 MHz could be more effective compared to other evolutionary algorithms. In this synthesis process, the chosen constraints of the design process were; VSWR, forward gain, Gain flatness, and SLL over a varied frequency range. The optimized design parameters were length, radius of each element, inter-element spacing and the characteristic impedance of the transmission line. They found this optimized LPDA to be far more superior to conventional one.

Lehmensiek and de-Villiers [71] in 2015 extended the same work they proposed in the year 2014, but they applied population-based incremental learning algorithm, and a downhill simplex method to obtain correct excitation voltage on individual elements of a LPDA, to get constant radiation patterns. Aihua and Changwu [72] brought some modification to small dual-stacked LPDA antenna. The modification was done in terms of replacing some elements of low-frequency pattern with optimum ones for attaining the high field strength up to 100 V/m in vertical polarization from 80 MHz to 200 MHz. The gain was incremented by 4.0 dB after this modification.

2.5 Review of Literatures on Various Linear Antenna Arrays and their Optimization

The idea of a pencil beam antenna array, so-called super-directive LAA was first introduced by Hansen [73] in 1992. This idea was about physical values based on an assignment of zeros of the array polynomial. The control of side lobe topology in
narrow pencil beam patterns and the synthesis of shaped beam patterns were also discussed. Guney and Akdagli in 2001 [74] presented Tabu Search (TS) optimization of radiation patterns by assigning desired nulls of LAA. The desired nulls were obtained by controlling the amplitude only in one instance and in another instance, both amplitude and phase of each array element. The design parameters include null depth, SLL, and dynamic range ratio. This technique was capable of selecting the element excitations for shaping the array pattern with the single, multiple and broad nulls executed at the directions of interference, whereas the main beam and the sidelobes are quite near to the initial Chebyshev pattern. One year later, Karaboga et al. [75] did similar analysis and design done by Guney and Akdagli in 2001; but applied ACO instead of TS to the synthesis of LAA to provide desired nulls in the prescribed direction.

Yang et al. in 2002 [76] presented DE optimized time-modulated LAA to provide reduced SLL. This was made possible by reordering the stationary excitation amplitudes as well as the switch-on time intervals of each element. Simulation results of the synthesized LAA were compared with RGA optimized LAA and outpace RGA for low SLL array synthesis. The proposed DE was applied to unequally spaced arrays with equal and unequal phases by Kurup et al. in 2003 [77]. A comparison was made between Phase-only synthesis and the synthesis of uniformly excited unequally spaced arrays. It was seen that; unequal spacing could reduce SLL with a significant reduction in the number of array elements. From the simulated results they found that synthesis technique using uniform amplitudes, unequal spacing, and unequal phases decreased the size of the array for the same SLL.

In 2005, Kumar and Branner [78] did a similar design that had been proposed by Kurup et al. in 2003, but the usefulness of the method was confirmed by its generalized use to a synthesis of rectangular, cylindrical and spherical arrays. Panduro et al. [79] showed the optimization of an LAA multi-objective problem using GA. The multi-objective performance parameters include HPBW; SLL and design parameters include element spacing; element excitation. Simulation results for non-uniform spacing with uniform and non-uniform excitations applied across the array; provided improved radiation pattern concerning reduced SLL. Yang et al. [80] introduced a method that combines the complex embedded element patterns and the DE algorithm. The compensated complex excitations were obtained by using DE algorithm. This proposed
method was implemented in the design of a 16-element printed LAA with an objective to reduce mutual coupling and SLL. Yang and Nie [81] again applied the same concept to a time-modulated 16-element LAA to obtain a -30 dB SLL discrete Taylor pattern.

Pandura, further in 2007 [82] studied the behavior of Mutual Coupling (MC) among the array elements for a design of coherently radiating structures in an LAA geometry using GA. This design of coherently radiating structures considered the GA optimization of the spacing between antenna elements and was achieved by placing additional passive radiating elements in between the active ones. Mahanti et al. [83] in their paper compared the phase only for sum pattern and amplitude-phase synthesis of symmetrical dual-pattern LAA for sectorial beam pattern using Floating-point GA (FGA) or RGA. Phase-only optimization was done with predetermined Gaussian amplitude distribution of fixed dynamic range, and amplitude-phase optimization was done with less dynamic range ratio than the former and yet shares a common amplitude distribution. Guney et al. [84] presented null controlling pattern synthesis by using Bees Algorithm (BA). This was achieved by controlling only the amplitude of each array element. The flexibility and accuracy of the BA were shown through numerical models of Chebyshev pattern with the single, multiple and broad nulls levied at the directions of interference. One year later in 2008, Guney and Basbug in their paper discussed the null controlling synthesis of LAA [85]. This was done by optimizing the amplitude of the weights only by using BFA. Datta et al. [86] proposed Adaptive BFA (ABFA) to optimize both the amplitude and phase of the weights to obtain both nulls in the desired direction and maximum directive radiation pattern. Subsequently, Oliveri and Poli [87] in the year 2009 proposed that the synthesis of a linear array could be dealt with by formulating sub-array configuration to diminish the SLL of the synthesized difference beam instead of an optimum sum pattern created by a comprehensive and dedicated feed network. This synthesis was optimized by Modified Contiguous Partition Method (M-CPM).

Lin et al. synthesized non-uniform spaced LAA; optimizing both position (in one instance) and position-phase (in another instance) of the array elements by using DE in the year 2010 [88]. The effect of angle resolution was also studied in the design process to provide improved radiation pattern concerning low SLL. Guney and Onay [89] in their paper later presented the same desired objective that they put in the year 2007 and 2008. But this time they used the controlling parameters as phase-only and both the
amplitude and phase of the array elements instead of phase only in the year 2007 and
optimization technique they used was Bees Algorithm (BA) instead of BFA in the year
2008. Dib et al. [90] modeled an LAA problem onto a single objective function
optimized using Taguchi’s method and self-adaptive differential evolution (SADE)
technique. The single objective function considered was low SLL, and null steering and
the controlling parameters considered were the positions, amplitude, and phase of the
array elements. The results showed that Taguchi’s method converges faster with good
agreement with those attained using the SADE technique.

In the late 90s’, the research was carried out by applying several monotonous
purebred optimization techniques in the field of array design. Recently, some of the
new (hybrid) metaheuristic algorithms in the field of antenna array synthesis design
have been developed. Elragal et al. [91] in 2011 studied a new design method for
reconfigurable phased arrays using a hybrid technique, i.e., combined DE and Enhanced
PSO (EPSO) technique. To establish the usefulness of the proposed algorithm an LAA
was designed for null controlling. This is realized by location perturbation of array
elements in arbitrary directions with low SLL. Zhang et al. [92] synthesized low SLL
profile aperiodic LAA by using SADE. Their results were compared with other
aperiodic LAA; optimized by PSO, ACO, DE, and Modified GA (MGA) published
earlier and found that their approach was better than others. Goudos et al. [93]
investigated the synthesis of an optimal sparse LAA that included design parameters
such as inter-element spacing; individual element length and performance parameters
such as low SLL in the prescribed direction; HPBW. The optimization process used was
SADE. Smida et al. [94] in their paper obtained an optimal adaptive beam steering to
attain a better radiation pattern for LAA using Taguchi’s method. A set of phase shift
weights were generated to steer the beam towards any desired direction. The phase shift
weights were calculated by evaluating the fitness function of the optimization process.
Mandal et al. [95] compared a Novel PSO and PSO with constriction factor approach to
synthesize null restriction in the desired direction of symmetrical LAA. Symmetric null
about the main beam for single or multiple wide nulls was accomplished by
optimization of elements excitation amplitude weights. Better optimized results were
also achieved regarding low SLL compared to a uniformly excited array element. Guney
and Basbug, [96] similar to their earlier published literature concentrated on nulling
pattern of an LAA using Seeker Optimization Algorithm (SOA) for the input
controlling parameters: position-only, phase-only, and amplitude-only. The statistical results of simulations showed that SOA was superior to the other algorithms such as SA and TS. Zaharis and Yioultsis [97] introduced a new PSO variant called Adaptive Mutated Boolean PSO (AMBPSO) optimization technique for adaptive beam-forming of LAAs. This optimization technique was using excitation weights updated in Boolean form by using a competently adaptive mutation process. The purpose of this design was to avoid interference from adjacent signals direction of arrival to show its robustness and reliability objective.

In 2012, Roy et al. [98] discussed an optimal design of multi-objective LAA using decomposition-based Multi-Objective PSO (dMOPSO). This multi-objective function was used in twofold. First they considered to optimize minimum average $SLL$, null control, and second to reduce maximum $SLL$ to achieve more excellent $DR$. The authors claimed that considering the performance this multi-objective optimization process outperforms those achieved by single-objective or multi-objective evolutionary algorithms published earlier. Li and Yin [99] in their article proposed hybrid DE with ABC and its application for the design of a reconfigurable antenna array with discrete phase shifters. The main objective of the reconfigurable design problem is to find the element excitation that will result in a sectorial pattern main beam with low $SLL$. Li and Yin [100] in another article proposed composite differential evolution (CoDE), to optimize element spacing to provide low $SLL$ and desired null control of LAA. Zhang and Jia [101] introduced a Modified DE (MDE) for the synthesis of non-uniformly spaced but uniformly excited LAA elements for $SLL$ suppression. Both position-only, as well as position-phase of the array elements, was synthesized by using MDE. Mandal et al. [102] applied MDE for designing optimum LAA with shaped beam radiation pattern. This was achieved by assigning suitable excitation current amplitude and phase distribution for LAA elements. In this optimization, a modification was done to DE regarding new mutation and crossover strategies.

Goswami and Mandal [103] designed a uniform LAA and modeled the constraints of low $SLL$ and fixed $FNBW$ as their optimization problem in the year 2013. The design parameters such as each element current excitation and inter-element spacing were optimized using RGA. Pappula and Ghosh [104] in 2014 proposed Cat Swarm Algorithm (CSA) for a synthesis of $SLL$ suppression and prescribing desired nulls of LAA pattern. The optimization of design parameters includes antenna element position.
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Various LAA designs were conducted to show the superiority of CSA over ACO for the multi-objective optimization problem. Singh and Rattan [105] employed CSO to optimize a non-linear multi-objective problem that includes design parameter such as position only and performance parameters such as SLL suppression and desired nulls of the radiation pattern. Same was also applied to circular ring array to show its efficacy over other evolutionary meta-heuristic algorithms. Ram et al. [106] had analyzed an improved PSO with wavelet mutation (IPSOWM) used for the improvement of the radiation performance of time modulated LAA. In this design process, the optimized SLL was achieved by optimizing inter-element spacing and switching time sequence of each element. In 2015, Ram et al. [107] considered the same concept of wavelet mutation that they provided in 2014, but this time with DE and named it as DE with wavelet mutation (DEWM). The performance evaluation was same as that of they delivered in the year 2014. Authors claimed that DEWM was superior to RGA, PSO, and DE.

Saxena and Kothari [108] in the year 2016 introduced Ant Lion Optimization (ALO), mimicking the hunting behavior of ant-lions. Authors claimed that ALO have very few tuning parameters, making it flexible for solving diverse problems. The ALO considers design parameters that include individual element current amplitude excitation; element position and performance parameters that include minimum SLL; null control in a specified direction. The efficacy of ALO was shown by comparing the simulation results of this algorithm with other nature-inspired meta-heuristic algorithms such as PSO, ACO, CSO, and BBO. Later on, another nature-inspired metaheuristic algorithm known as Flower Pollination Algorithm (FPA) was introduced in 2015 by Saxena and Kothari [109] to optimize the same objective functions they proposed in the year 2016 for the synthesis of LAA.

2.6 Review of Literatures on Various Planar Antenna Arrays and their Optimization

Vankoughnett and Yen [110] in 1967 gave a solution on active impedance and current dispersal of uniform planar array elements. They first found the current distribution of a linear array by linking element current and electric variation on the cylindrical surface of the array elements and the same is extended to realize a planar dipole array. Castella and Marable [111] in 1993 derived a new theoretical method for Planar Antenna Array (PAA) to provide high gain in a particular direction with imposing nulls in other
directions. This was achieved by controlling the phase of individual element irrespective of any amplitude tapering. Darwood [112] in 1998 suggested that conventional use of tapering algorithm might not sufficiently reduce the effect of mutual coupling. So instead of that, they formulated a matrix that consisted of calculated coupling coefficients of small PAA. Experimental results showed that the SLL reduction and increase in DR were possible due to this process.

Kumar and Branner [78] in 2005 proposed a generalized analytical technique for the synthesis of fixed current distribution with a non-uniform inter-element spacing of an array structure with an objective to reduce SLL or beamwidth. Moreover, it also provided a reduced number of elements, size, and hence weight of the array. The aim of their work was to define an integrated mathematical tactic to nonlinear optimization of multi-dimensional array structures. The usefulness of the process was verified by its comprehensive application to the synthesis of rectangular and other arrays. Later Petrella et al. [113] in 2006 described a planar array synthesis to have a radiation pattern with minimum SLL and/or null control in the desired direction by using PSO solver for optimized element locations. The PSO optimized PAA was compared with a conventional uniform PAA to show its efficacy concerning the directive radiation pattern. In 2007 Alicano [114] et al. in their paper approached two ways to synthesize an array pattern of PAA to obtain low SLL. First, the SLL of LAA was reduced by using DE algorithm and second, the same optimized LAA was repeated to form a RPAA. Later RGA was applied to make the same RPAA as thinned RPAA to further reduce the SLL. Zhao et al. [115] in 2008 presented an idea regarding how switched parasitic elements could act as a reflector by changing their positions from directors to reflectors and consequently could reduce the overall size of the PAA.

Synthesis of the controlled null radiation pattern of a RPAA using DE was proposed by Aksoy and Afacan [116] in 2009. The nulls were controlled by position only and position-amplitude of the individual array element. Nulls of a RPAA in the desired direction were achieved by position control only, and nulls with thinning of the same RPAA were achieved by position-amplitude control only but limited to a maximum of two nulls. Djennas et al. [117] presented a novel stochastic (governed by deterministic rules) optimization process of immunity tactic based on conceives and baptize, which was greatly inspired by immune activity. This technique involved in eliminating the strange foreign bodies (weak solutions) while keeping self-organism (best solution).
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Background and Related Works

Unlike the other evolutionary algorithms where the animals search for their foods in a way that maximizes the ratio: energy obtained/time spent in foraging (considering physiological constraints); in this technique, the goal was to equilibrate the proliferation-destruction scenarios, to retrieve the solution with faster convergence. After that, they exploited this original optimization process in the radiation synthesis of PAAs.

According to Aboul-Seoud et al. in 2010, array signal processing at element level was a critical technology of phased array system, for which analog weighting at element level was used for sidelobe reduction of patterns [118]. The aim was to adjust the weight coefficients of the array attenuators in -30 dB precision to achieve a minimum SLL with narrower beam width. To achieve this, they applied GA to the optimization of PAA weights with -30 dB attenuators weight precision. Zhang et al. [119] introduced a new evolutionary computing technique known as Boolean Differential Evolution (BDE) for optimizing a thinned RPAA with minimum SLL. It is unlike Binary DE; adopts the binary codes so that the optimal variables could be directly optimized without being mapped from decimal to binary. Numerical results showed that BDE algorithm was an effective technique for thinned array synthesis. Later, Hammami et al. [120] in 2011 proposed a PAA synthesis that optimized radiation pattern to produce null control in the prescribed direction and SLL suppression by controlling phase only. The optimization process was based on efficient Sequential Quadratic Programming (SQP) algorithm. This synthesis problem was realized by using 10×10 PAA consisting of λ/2 spaced isotropic elements.

A comparison was made between two PAAs having an unequal number of dipole elements in X-axis and Y-axis by Vesa and Alexa [121] in 2012. They stated that if the number of elements was kept more than seven in X-direction, the opening angle of main lobe increases by 1deg. But if the number of elements was more than five, the opening angle was found constant irrespective of the number of elements in the other direction. Kawdungta et al. [122] implemented Multiple Sweep Method of Moments (MSMM) along with GA to realize a non-uniform PAA. The optimization process was carried out for length, excitation of each element, and inter-element spacing. Finally, efficiency and precision of MSMM/GA had been presented. Abderrahmane and Boussouar [123] proposed a Cross-Entropy (CE) stochastic optimization process to realize a synthesis problem of reduced SLL of a PAA. This CE method, which possesses
a good convergence property could able to produce $SLL$ of -22.7 dB for PAA with isotropic elements and -32.17 dB for non-isotropic elements. The best thinning that provides low $SLL$ was better searched by CE than GA with less number of iterations.

Chen et al. [124] developed Active Element Pattern (AEP) method and Fine-Grained Parallel Micro-Genetic Algorithm (FGPMGA) for radiation pattern synthesis of a large PAA in 2013. These synthesis problems of large PAAs were realized by dividing it into small LAA problems considering AEP method. Further, to reduce computational time, the FGPMGA was used. Charan et al. [125] in 2014 dealt with multi-objective optimization process of a PAA using cuckoo search optimization. The results ensured that they obtained the best compromise solution while optimizing multi-objective-multi-parameter such as gain, $DR$, $SLL$, and efficiency, etc.

2.7 Review of Literatures on Various Circular Antenna Arrays and their Optimization

Steinberg in 1973 [126] compared peak $SLL$ of a random array and algorithmically framed thinned aperiodic array published in the 1960’s. He studied 70 algorithmic arrays and 170 random arrays and observed their array peak sidelobes when suitably normalized to permit comparison, was indistinguishable in the mean and median. The distribution of their peak sidelobes for both the cases was found to near log normal with the same average and median values. However, the standard deviation of the random array distribution was approximately half that of the group of algorithmic arrays. Boerlinger [127] in 2002 proposed a sparse phased array comprising a normally logarithmic spiral lattice of several elements defining a logarithmic spiral of no translational periodicity which improves grating lobes, even for wide element location. It provided an improvement in phased array antennas which provided a sparse grid that reduces element density per unit area and thus reduces cost.

Panduro et al. [128] in their paper in 2006 applied GA to a Circular Ring Array (CRA) to obtain a set of optimum weights and inter-element spacing that provided radiation pattern with low $SLL$ for a fixed $HPBW$. The results of this non-uniform GA optimized CRA was compared to uniform CRA and found more suitable in terms of low $SLL$. Mahmoud et al. [129] in 2007 simultaneously examined uniform CRA, uniform Hexagonal Array (HA) and Concentric CA (CCA), Concentric HA (CHA) concerning their array pattern for smart antenna applications. The effect of outer ring rotation of CCA on the radiation pattern was also studied for beam steering. They used
PSO to optimize design parameters, namely complex excitations, amplitudes, and phases.

Later in 2008, Mahmoud et al. [130] again examined CRA and CCA for adaptive beamforming by controlling the nulls in the desired directions. They used the same design parameters, namely complex excitations, amplitudes, and phases; optimized by PSO. Further, Mahmoud et al. [131] developed circular Yagi-Uda Array (CYUA) and modified CYUA (MCYUA) to form a grid cylindrical-like structure whose individual antenna element length and spacing between the elements were optimized by PSO. The results were then compared with CCA for adaptive beamforming. AL-Husseini et al. [132] investigated the use of uniform CAs to synthesize steerable beam pattern to avoid inter-cell interference. They also explained the idea of reducing these interferences by stacking several CCAs to form a cylindrical array. Shihab et al. [133] in the same year obtained better results compared to Panduro et al. in 2006 for the same objective functions and design parameters, but optimized by using PSO technique instead of GA applied by Panduro et al.

Khodier and Al-Aqeel [134] in 2009, analyzed a PSO optimized LAA and CRA simultaneously by considering both isotropic and dipole array elements in each case. The analysis of both LAA and CRA had been done considering design parameters such as amplitude, excitation phase and locations in case of isotropic array elements and antenna length in addition to earlier design parameters in case of dipole array elements. The performance parameters considered were peak $SLL$, average $SLL$, beam steering for LAA design and low $SLL$, aperture length, $HPBW$ for CRA design. N. Pathak et al. [135] presented MPSO algorithm for thinning large multiple CCAs. The isotropic antennas were uniformly excited to produce a pencil beam in the vertical plane with minimum $SLL$. Two cases had been studied; one with fixed uniform and another with optimized uniform inter-element spacing to make a synthesis of pencil beam radiation pattern maintaining less variation in $HPBW$ for both cases. Vigano et al. [136] in the same year designed an aperiodic spiral PAA that promised to provide controlled $SLL$, grating lobe, and beamwidth to produce a rotationally symmetric pencil beam pattern without using amplitude tapering. To avoid amplitude tapering, the uniform spatial density of the elements had been modified in terms of their optimized new positions that best suit the unusual locations of the sunflower seeds.
Basak et al. [137] laid an optimal design of non-uniform CRA and CCA with an objective to provide low SLL for a fixed FNBW, maximum DR, and minimum size in terms of its circumference in 2010. The same was achieved through a proposed hybrid IWO technique which incorporates the difference vector based mutation schemes from the dominion of DE. Chatterjee et al. [138] developed a uniform CCA whose ring spacing and inter-element distance are optimized by DE. The objective was to produce a pattern with low SLL while keeping FNBW fixed or varying. Basu et al. [139] made a comparative study of MPSO, DE, and ABC optimization concerning their element spacing to optimize the CRA. The objective of the work was to produce a pencil beam with a low SLL and a possible more DR for fixed HPBW. The only design parameter considered for these optimizations was individual element’s excitation current. In the same year, an optimal design of a non-uniformly excited CCA with uniform spacing between the elements was presented by Mandal et al. [140]. The non-uniform excitations were determined by using two varieties of GA (BGA and RGA), two varieties of PSO (namely canonical PSO (CPSO) and craziness based PSO (CRPSO)), and two varieties of Evolutionary Programming (EP) (namely basic EP (BEP) and Hybrid EP (HEP)). HEP outperformed other optimization techniques concerning minimum SLL and minimum FNBW for the optimal design of CCA.

Chatterjee et al. [141] in the year 2011 studied a phase differentiated dual-beam CCA which produced dual radiation patterns in the form of pencil and sectorial beam. The dual patterns were generated by controlling the DE optimized radial phase switching distribution and amplitude distribution among the elements. The array with optimum radial amplitude and zero radial phase distributions generated a pencil beam while the array with the same amplitude but optimum radial phase generated a sector beam in the vertical plane. Roy et al. [142] designed a non-uniform CRA optimized by modified IWO (MIWO) that produced minimum SLL and maximum DR. The superiority of the proposed optimized array over other evolutionary optimization techniques such as PSO, DE, GA, and IWO had also been presented. In the same year, a hybrid DE/EPSO was introduced by Elragal et al. [91] to solve a reconfigurable phased LAA and CRA design problem on account of producing nulls in the desired direction with minimum SLL change constraint. The presented method had been applied for interference suppression by position-only control using least number of mobilized elements for both LAA and CRA phased array.
Sengupta et al. [143] in the year 2012 provided a novel approach to the design problem of non-uniform CRA to achieve low SLL and maximum DR. The design parameter constraints were current excitation amplitudes and phase of array elements, optimized by hybrid DE algorithm and Learning Automata (LA). Basu and Mahanti [144] described the application of Fire Fly Algorithm (FFA) to two-ring thinned CCA to accomplish minimum SLL with specific FNBW. The thinning effect was analyzed through some design problems using uniform and non-uniform excitation magnitude for different specific FNBW. The results showed that non-uniform excitation was efficient to diminish SLL for the same FNBW even more efficient to diminish SLL for wider FNBW. In the same year Mandal et al. [145], presented an optimal design of three-ring CCA to attain minimum SLL. IPSO was applied in the design problem to optimize design parameters, namely non-uniformly excited and non-uniform inter-element spacing. They obtained a maximum SLL reduction of -31.86 dB by this optimization process. M. Bhattacharya et al. [146] proposed an asymmetric CAA synthesis based on optimal angular positions to attain the radiation with the lowest probable SLL with least possible FNBW increment. The optimization algorithm used was RGA. In the same year, Ghosh et al. [147] explained the formation of a new optimization technique, which was a hybrid of Local Neighborhood-based PSO with Hierarchical PSO Algorithms termed as Hierarchical Dynamic Local Neighborhood Based PSO (HDLPSO) Algorithm. The HDLPSO was later applied to a CRA to realize minimum SLL and also a minimum size of the circumference. BBO Optimized thinning of large multiple CCAs was studied by Singh and Kamal [148] in 2012. In their literature study, the authors had proposed pattern synthesis method to reduce the SLLs with narrow beamwidth by making the ring array thinning using the BBO algorithm. The thinning percentage of the array was kept equal to, or more than 50 % and the beamwidth was kept equal to or less than that of a fully populated, uniformly excited, and 0.5 λ, spaced CCA. Civicioglu [149] in 2013 had intensively used 15 different Evolutionary Search Algorithms (ESAs) in solving three different CRA design problems. Results were analyzed regarding their statistical parameters. Simulation results revealed subjective differential search algorithm (S-DSA) were statistically better than other 14 EAs.

Guney and Basbug [150] in the year 2014 applied a parallel version of SOA for designing CRA and CCA to provide good SLL with a fixed beamwidth. The principle of implementing SOA was based on the perception of pretending the act of humans’
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intelligent quest with their memory, experience, and ambiguity reasoning. In the same year, CS optimization technique was employed by Singh and Rattan [105] to synthesize the desired radiation patterns for LAA and CRA design problem. The optimization process aimed to curtail the maximum SLL and to control nulls by adjusting the elements locations.

In the year 2015 Mandal et al. [4] created a shaped beam from a CCA by using DE and GA optimization techniques. They considered two cases to form shaped beam patterns; one, a flat top beam with desired specifications and another, a cosec² beam pattern. The desired beam pattern in each of the individual case was obtained by finding optimum excitations of the array elements using both DE and GA and finally compared to show the efficacy of DE over GA. Receiou [151] in the same year, synthesized two CAs namely, CRA and CCA to generate high DR and low SLL radiation pattern. The comprehensive learning DSA (CLDSA) was used for the design simulation of 1-ring and 3-ring CRA and CCA. This synthesis was done by finding the optimum inter-element spacing of rings, phases and/or positions that gave optimum SLL. The computational results exhibited that SLL was reduced ominously in the non-uniform case for CCA in comparison with CRA. In this year the application of a modified Teaching Learning Based Optimization (TLBO) algorithm (MTLBO), for the synthesis of thinned (CCAs) had been described by Lou et al. [152]. The self-learning phase of MTLBO was adjusted for CCA design according to the geometry arrangement of antenna elements so that it could produce low SLL keeping fixed FNBW. Both uniform and non-uniform excitation amplitudes had been optimized for attaining anticipated array factors.

In 2016, Krishna et al. in [153] presented the synthesis of maximum SLL reduction and beam steering by providing null controlling in the desired directions. Authors applied CS optimization to get each element amplitude excitation for four different cases of placing nulls to show its usefulness in narrow beam forming and broadband beamforming. A reflect-array with logarithmic spiral lattice (LSA) of elementary antennas on its aperture was proposed by Niaz et al. [154]. Subsequently, authors compared LSA with other two reflect-array lattice structures namely, CPA lattice and CCA lattice and found that there was a significant improvement on the total gain, low SLL, and HPBW in case of LSA. Sun et al. [155] one year later proposed an efficient BBO (EBBO) for CRA synthesis with the desired objectives such as low SLL and null
control in the year 2017. Three improvements had been brought to the optimization process, which includes chaotic search theory, model learning method, and a new random perturbation operator. The design parameters optimized by this process were excitation current and inter-element spacing. Authors demonstrated both null control and low \( SLL \) being achieved by EBBO were exceedingly better than other four compared algorithms in their literature. Li et al. [156] in this year studied optimization of LAAs and CRAs to suppress the \( SLL \) to show an efficient beam pattern synthesis. They modified the normal BBO and named it as Biogeography-Based Optimization based on Local Search (BBOLS). The modification was done firstly, by adding the local quest strategy into the migration and secondly, retaining the selection operator for the population after using the migration and local quest operators. Finally, authors compared the BBOLS simulated results with FA through various design problems to illustrate the effectiveness of BBOLS over FA.

2.8 Summary

In view of designing antenna arrays for long-range wireless communication systems, we confined our survey of literature on antenna array. A great deal of utmost attention is taken systematically and constructively to survey the literature relating to various antenna arrays, their numerical analysis, design synthesis and multi-objective optimization processes. We see that specific applications require certain performance parameters. It is never like we always should have all the performance parameters equally optimized. From the study, it is evident that some of the applications require very specific performance parameter, for example, a high \( DR \) is required which is achieved by YUAs and LAAs. If bandwidth is a constraint where multiple users can access simultaneously, then wideband antennas such as frequency independent antennas and LPDA antennas can be suitable replacements. Thus, LPDA is chosen for an enhanced BW with a major compromise with all other performance parameters. From the various literature, we realize that YUA and LPDA have unidirectional radiation pattern whereas LAA, PAA, and CAA has bi-directional or multi-directional radiation pattern. A transceiver which is mobile and scatters all around should have a phased array system. Thus one may think of LAAs or PAA as a suitable replacement. In a phased array system, null control, beam steering, and \( SLL \) suppression is a major concern. If we look into the circular array, it can scan in all azimuth directions
efficiently, thus has a wide application in the DOA estimation, navigation system, mobile communication, military, etc.

Further, we studied that optimal performance parameter can’t be obtained through simple intuitions and experiments based on trial and error basis. So an effort needs to be made to optimize these parameters. All the optimization techniques have their pros and cons and thus should be chosen very carefully to solve these single-objective or multi-objective array problems. The optimization techniques should be selected in a way to incorporate adaptability, good convergence, global solution, proper fitness function, etc. Some studies tell us about the reduction of MC by keeping inter-element distance to a suitable position, also by thinning due to which MC, SLL, and grating lobes are reduced (since the absence of edge elements and a number of elements). Accordingly, a proficient approach is made for the design of single objective and/or multi-objective functions of all possible directional arrays under one platform. In our approach to the design of different arrays, we have considered some of the most important directional arrays which are discussed in later chapters.