A Survey on the Applications of Bee Colony Optimization Techniques

Dr. Arvinder Kaur
Associate Professor, University School of Information Technology
Guru Gobind Singh Indraprastha University, Dwarka
Delhi, India
arvinderkaurtakkar@yahoo.com

Shivangi Goyal
Research Scholar, University School of Information Technology
Guru Gobind Singh Indraprastha University, Dwarka
Delhi, India
goyal_shivangi@yahoo.co.in

***Abstract*—In this paper an overview of the areas where the Bee Colony Optimization (BCO) and its variants are applied have been given. Bee System was identified by Sato and Hagiwara in 1997 and the Bee Colony Optimization (BCO) was identified by Lucic and Teodorovic in 2001. BCO has emerged as a specialized class of Swarm Intelligence with bees as agents. It is an emerging field for researchers in the field of optimization problems because it provides immense problem solving scope for combinatorial and NP-hard problems. BCO is one of the benchmark systems portraying team work, collaborative work. BCO is a bottom-up approach of modeling where agents form global solution by optimizing the local solution.**

Keywords-Evolutionary Computing (EC), Swarm Intelligence(SI); Bee Colony Optimization (BCO); Artificial Bee Colony Optimization (ABC)

I. INTRODUCTION

Evolutionary Computing (EC) is a class of algorithmic approach based on the biological evolution or biological behavior of members in a population. Swarm Intelligence is an off-spring of EC where the dynamics of group becomes the sole reason for its survival. SI is the name given to the mechanism or system where in a group of workers/particles/agents work in collaboration with each other to find optimal solution for the problem in hand. Various examples of SI groups are bird flocks, bee colony, ant colony, particle swarm, cockroaches, fishes, etc. SI systems have strong features like group defense as is in bee colony, labor division as in ant colony, synchronization as in flying birds' flock, collective clustering and sorting, cooperative working etc. In SI the agents form or build a local solution, on the basis of factors/conditions in hand. Based on the local solution, the global solution is developed which then gradually optimizes or channelizes to an optimal solution. So, SI is a bottom-up type of problem solving technique. SI has found immense applicability in fields like Robotics, Artificial Intelligence, process optimization, staff scheduling, telecommunications, entertainment, routing, software engineering, software testing, networking etc. Bee Colony Optimization (BCO) is a specialization to Swarm Intelligence (SI) where the workers/members/agents to the group are honey bees. They communicate by a mechanism called "Waggle Dance" and exchange important information regarding rich food source's location. ACO is a system where blind ants work in synchronization to each other to find best food sources. The have the pheromone deposition-pheromone evaporation mechanism to coordinate with each other.

In this paper a special SI group, Bee Colony Optimization has been discussed.

Organization of the paper is as following. In section 2 BCO in nature and Artificial Bee Colony optimization algorithm have been discussed. Then in section 3 the Applicability of BCO and ABC have been briefed respectively. Section 4 has the tabulated form of the papers studied in section 3. Then we have conclusion, future work and references.

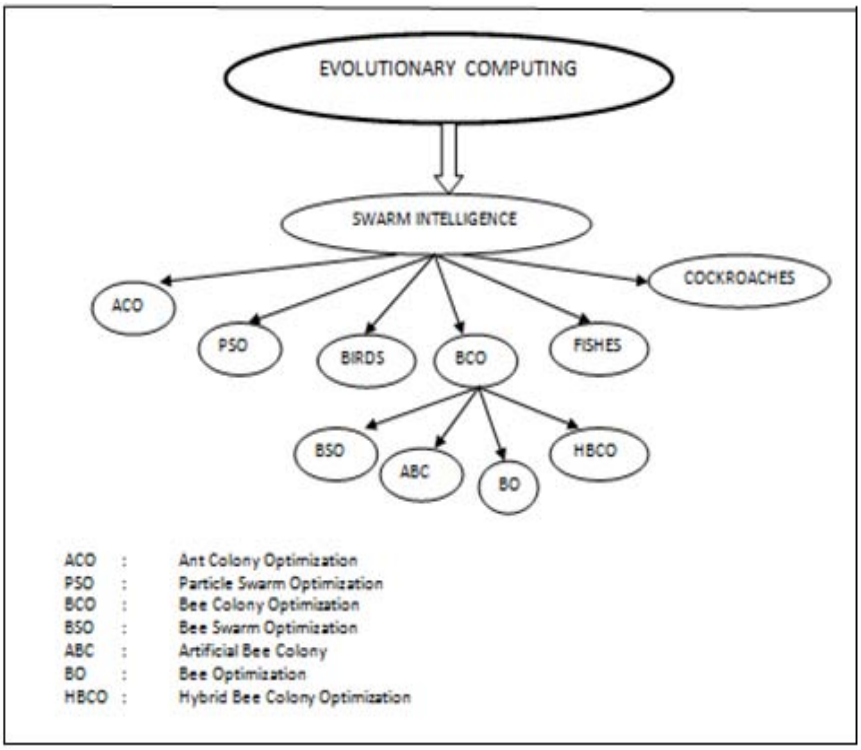

Figure 1. Hierarchical representation of Evolutionary Algorithms

II. WHAT IS BCO?

BCO is the SI system where the low level agent to the system is the bee. BCO is the name given to the collective food foraging behavior of honey bee. The bee system is a standard example of organized team work, well coordinated interaction, coordination, labor division, simultaneous task performance, specialized individuals, and well-knit communication.

In a typical bee colony there are different types of bees. There is a queen bee, many male drone bees and thousands of worker bees.

Types of bees:

1. The Queen's responsibility is of laying eggs so that new colonies can be formed.
2. The Drones are males of the hive and are responsible to mate with the Queen. This is their sole role in the hive. They are discarded from the colony during their down fall.
3. The worker bees are the females of the hive. They are the main building blocks of the hive. They build the honey bee comb, clean it, maintain it, guard it, feed the queen and drones. Apart these side responsibilities the main job of a worker bee is to search and collect rich food. There are two types of worker bees namely scout bees and forager bees. Both of them are collectively responsible for the collection of food but they play different roles.

What does Scout do?

1. The Scout bees fly around and search for food sources available randomly.
2. They return back to the hive after they exhaust their energy and distance limits.
3. Upon returning to the hive they share their exploration experience and a lot of important information with the forager bees.
4. The scouts tell the foragers about the location of rich food sources which comprises of the direction (angle) of the food source from the hive w.r.t. sun and distance from hive. This is done using a dance called "waggle dance" which is in the figure of digit "8". It also indicates the quality of food.

What does Forager do?

1. The forager bees closely observe the scout bee in order to learn the directions and information given by scout. It then goes to collect food.

Following is the flowchart which gives the basic structure of the working of the bee colony system.

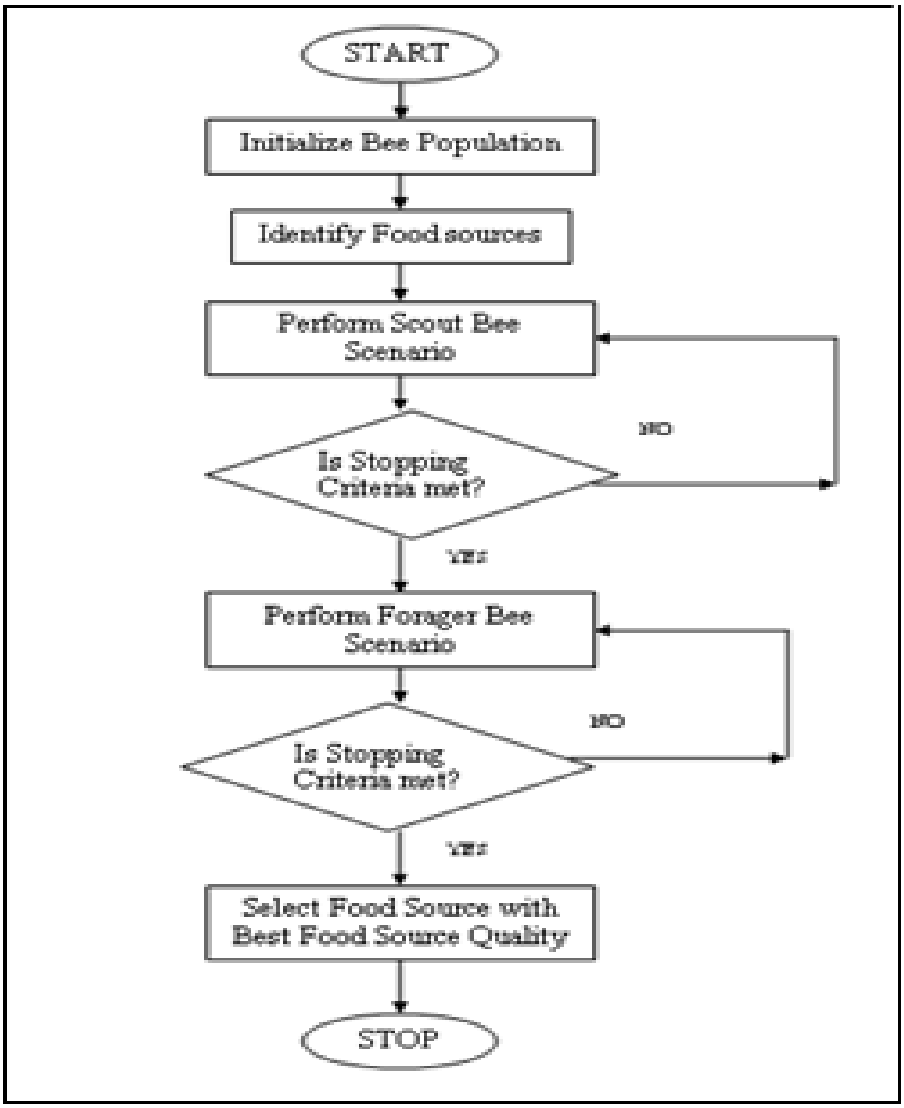

Figure 2. Flowchart for Basic BCO Steps.

Artificial Bee Colony (ABC) was introduced by Karabora in 2005. It was developed to solve real parameter optimization problem. In ABC the BCO's foraging behavior is simulated.

The ABC differs from a real BCO since in ABC we use only scouts and foragers in equal proportion as initial population. The main steps of ABC are:

1. Initialization of food sources.
2. Scouts perform exploration of available food sources randomly until stopping criteria is met.
3. Each Forager exploits the respective scout's food sources until stopping criteria is met.
4. Forager chooses the best food source as per quality.

III. Applications of Bee Colony Optimization Algorithm

Bee Colony Optimization algorithms are widely being used to solve problems belonging to diverse domains. It has been used to solve certain bench mark problems like Travelling Salesman Problem, routing problems, NP-hard problems. Some problems are solved using BCO concept while others are solved using ABC algorithms. In the following section the areas of applicability of BCO its variants have been explained. There is a very thin of distinction among all the variants of Bee system because the agent in all the algorithms is bee. All the algorithms are more or less the same.

1. To solve complex transportation problem

In this application [1] BCO has been used to solve transportation problem using ride-matching problem. This paper presents the BCO concept discussing the social insects' behavior and flexibilities in these colonies. Then it talks about natural bees focusing on their self-organizing behaviors and patterns. Then they have discussed the BCO meta heuristics in which the agent that is the artificial bees have been introduced. They collaborate with each other to find solution to different combinatorial optimization problems. Here a 5 step algorithm called Bee Colony Optimization has also been framed which comprises of initialization, forward pass and backward pass steps. The forward pass and backward pass are performed until the stopping criterion is met. Then they discussed the fuzzy bee system which brings forward the decision making strategy of artificial bees while searching the optimal solution. They have also given a fuzzy set which describes distance parameter. They have also discussed the calculation of solution component and the mechanism of choice of next solution component. They have introduced bee's partial solution badness concept, bee's nest mates recruiting decision, the calculation of path changes done by bees. Then they have solved the transportation problems faced by many congested countries which led to increased travelling time, increased number of waits, unexpected travelling delays, increased travelling costs, inconvenience to drivers and travelers and passengers, increased air and noise pollution and increased traffic accidents. The ride-matching problem have been solved using the fuzzy bee system using first forward pass, first backward pass, second forward pass steps of BCO algorithm explained in the paper earlier. The developed solution was tested on data collected from 97 travelers who demanded ridesharing and 96 could get best path.

2. MANET- Routing Protocol

In this paper [2] a Bee-inspired routing protocol for Mobile Adhoc network (MANET) has been presented. The algorithm developed here is a reactive source routing algorithm which consumes less energy as compared to conventional mobile adhoc routing algorithms. In this work the Bee-Adhoc algorithm has been used to route mobile adhoc network. The Bee-Adhoc algorithm was identified as an algorithm with major savings in energy of consumption packets. It was also identified to be a simpler and easier algorithm to implement.

3. Fault based Test Suite Prioritization

Kaur and Goyal in [3] presents a BCO algorithm for prioritization of regression test suite based on maximum fault coverage. The authors have discussed the natural bee system in detail. In this work the scouts and forager's food foraging scenarios have been mapped to prioritize the test suite. A well organized algorithm has been presented with brief explanation of all its steps. It has been designed in two parts for scouts and foragers. The algorithm has been explained using two examples and the values have been compared using APFD metric.

4. Solving Sudoku

Here in [4] a BCO has been developed to solve Sudoku puzzles which are NP-hard problems. A Sudoku is a logical 2D array in row, column, and diagonal without being repeated. The algorithm mimics the method through which bees forage food. The results obtained have been used to solve Sudoku puzzles more efficiently and effectively.

5. Problem Solving Mechanism

In this research work of [5] the two broad behaviors viz the self-organized decision making behavior of bees inside the hive and the problem solving behavior of bees outside the hive have been separated. These separations have been understood, studied and exploited to solve problems in wide variety of domains. The domains solved using the proposed BCO concepts are web searching problems, function optimization problems and hierarchical optimization problems.

6. Engineering Optimization

In the research paper [6] the shortcomings of multilevel optimization compared to biology-inspired algorithm has been compared. Here, a Virtual Bee Algorithm (VBA) for solving the engineering problem's function optimization has been presented. This has been developed for two variables. It has also been shown that one agent VBA, 2 agents VBA and multi agent VBA are all effective with genetic algorithms when compared to conventional algorithms.

7. Numerical Optimization

In this research work [7] an Improved Bee Colony Optimization algorithm, Bee Algorithm, Artificial Bee Colony algorithm and Harmony search algorithm are presented. These algorithms have been developed for unimodal and multimodal problems. In this work they have discussed all the above four algorithms in detail w.r.t. to numerical optimization concept. All the algorithms are designed for unimodal (Sphere, Rosenbrock) and multimodal (Griewank, Rastrigin, Ackley), that are all four algorithms have been designed with five test functions with minimum function value of zero. They have tabulated as well as plotted all the results. The resultant of their work was that ABC algorithm came out to be superior to other three discussed algorithms.

8. Accident Diagnosis

In this research work [8] the BCO has been applied to a new search algorithm capable of locating good solutions efficiently and within a reasonable running time. In the proposed algorithm the food foraging behavior of bees have been mapped to find solution of the problem. It is a population –based search algorithm. Initially the algorithm performs search randomly in synchronization with the neighborhood search. Next a new event classification system step is followed in which the algorithm centroids to the best solution and correctly identifies an accident in a nuclear power plant. Then the comparison and analysis of the proposed algorithm has been performed with other population-based algorithms and the proposed algorithm has been found to be more efficient and with an advantage of having fewer control parameters. The algorithm was implemented in MATLAB.

9. Maximum Satisfiability Problem

In [9] a BCO algorithm has been designed to solve maximum weighted satisfiability problem. In maximum weight satisfiability problem the maximum number of clauses for a given formula/expression that satisfies it as per some criterion is to be determined. This is an NP-hard problem. The proposed algorithm was implemented and tested on well known benchmark problems. The algorithm's performance was tested and analyzed by comparing with other evolutionary algorithms and BCO outperformed them.

10. Travelling Salesman Problem

TSP is a benchmark problem which has been solved by almost all latest researching algorithm. BCO is no exception to this trend. TSP has been solved using BCO. The BCO model constructed in [10] is algorithmically based on the collective intelligence of bee's food forging behavior. 2-opt heuristic have been combined with proposed BCO Algorithm to generate more promising results. Detailed analysis has also been done to compare and show the efficiency of BCO over other existing approaches on a set of benchmark problems.

11. Multi-Dimensional Knapsack Problem

Multi-Dimensional Knapsack Problem is a standard NP-hard problem and it has been solved using a number of approaches. Multi-Dimensional Knapsack Problem aims at finding the subsets of objects that maximizes the total profit while satisfying some resources constraints. A BCO algorithm for Multi-Dimensional Knapsack Problem has been proposed in [11] which very efficiently find the subsets with given constraints. The proposed BCO algorithm has been compared with 2 ACO algorithms of [12] and [13] and 1 GA of [14] in which BCO outperformed.

12. Developing Optimization Algorithm

In this research work [15] an Artificial Bee Colony optimization algorithm has been developed for optimization algorithms. This ABC exploits the working of scouts and forager's food foraging behavior to design the algorithm. The proposed algorithm assumes that the bee has short as well as long term memory. They have defined food taboo table and job sheet table to maintain the working of ABC algorithm. The author's suggested that the proposed algorithm can be applied to many combinatorial optimization problems, dynamic real variable problems, stochastic problems etc.

13. Application to Generalized Assignment Problem

In this research work [16] the use of natural metaphors to represent and solve complex optimization problems has been addressed because the authors believe that the classical optimization algorithms are now becoming inefficient due to inflexibility in adopting the solution algorithm. Also they add that classical methods impose

mathematical as well as operational limitations. So they have used the nature inspired metaheuristic algorithm called ABC algorithm to solve the NP-hard generalized assignment problem. In Generalized Assignment Problem a set of tasks have to be assigned to a set of agents with minimum cost. The agents have limited capacity. Each agent gets single task. An algorithm using ABC has been designed here. The algorithm has been implemented in C#. The algorithm has been tested for problems comprising of 5 agents-15 tasks to 10 agents-60 tasks.

14. Constrained Problem Optimization

In [17] an improved ABC algorithm for constrained problem. The ABC for the constrained problem does not use the concept of initial population but rather uses the concept of "Smart Bee". According to the Smart Bee concept the bee has memory capability for food sources' location and quality. Constrained optimization problem occurs in areas like VLSI design, economics, structural optimization, engineering design etc. The ABC algorithm modification for Constrained Optimization Problem has been developed. The authors have compared the SA-ABC [17] with ABC, PSO, SAPF-GA [17] algorithm and HCOEA [17]. Test functions proved that SA-ABC algorithm outperformed all the other algorithms.

15. Advisory Systems

In this research work [18] an expert ABC optimization for garlic expert system has been developed to advice farmers in villages online. An expert system has developed which is referred to as a system/ computer program that simulates the decision making and reacting power of human beings or another system. An expert system has expert domain knowledge in their respective fields. This system contains pre-written instructions and experiences and a set of rules and protocols to advice any scenario. The system here has been implemented in JSP for front end and MYSQL for backend.

16. Numerical Assignment Problem

An Interactive ABC (IABC) optimization algorithm for numerical optimization problem has been proposed in this work. The algorithm maps the forager bee's path development mechanism to pick new coordinates. The forager bee is directed by scout bee which evaluates the fitness values of all possible neighboring coordinates. The proposed algorithm in [19] has been analyzed using 5 benchmark functions to compare the efficiency/quality of IABC over ABC and PSO.

17. Job Shop Scheduling

Perrone et. al. in [20] have proposed a BCO algorithm for job shop scheduling. Job shop scheduling is a very vital process for the manufacturing industry because it improves machine utilization as well as reduces cycle-time, which is why it is an NP-hard problem. Perrone et. al. have proposed a BCO algorithm by mapping the food foraging behavior of honey bees to find solution. They have also analyzed and compared BCO with other algorithms like ACO and Tabu search and found out that BCO gave promising results.

18. Pairwise Test Sets Generation

Exhaustive testing with all possible inputs is not always feasible for all systems. So pairwise test sets are generated which reduces the test sets size. It is a combinatorial NP-hard technique. A simulated BCO algorithm for pairwise test sets generation have been proposed in [21]. Although the proposed algorithm requires significantly longer duration to generate test sets, the test sets generated are far better than those generated using deterministic approach.

IV. SUMMARIZATION

In Table 1 a brief summary of the applications discussed in this research paper have been summarized.

TABLE I. SUMMARY OF BEE SYSTEM APPLICATIONS

Sl. No	Algorithm Used	Problem Discussed and Solved	Brief Description of work done in the specified area	Implementation Language used (If implemented)	No. of benchmark problems solved using proposed algorithm	Is comparison Done with existing approaches? (Yes/No)
1.	Fuzzy BCO	Complex Transportation Problem	Use of forward and backward pass	NA	97	No

2.	Bee-Adhoc algorithm	Routing Protocol MANET	Simpler and easier, Remarkable savings in energy consumption	NA	NA	No
3.	BCO	Fault Based Test Suite Prioritization	Scout and Forager food foraging behavior has been mapped	NA	2	Yes
4.	BCO	Sudoku Puzzles	Food foraging behavior has been mapped	NA	NA	No
5.	BCO	Problem Solving Mechanism	decision making behavior and the problem solving behavior of bees	NA	NA	No
6.	Virtual Bee algorithm (VBA)	Engineering Optimization	one agent VBA, 2 agents VBA and multi agent VBA	NA	NA	Yes
7.	BCO	Numerical Optimization	designed with five test functions	NA	NA	Yes
8.	BCO	Accident Diagnosis	population – based search	MATLAB	NA	Yes
9.	BCO	Maximum Satisfiability Problem	Food foraging behavior has been mapped	NA	Yes	Yes
10.	BCO	Travelling Salesman Problem	collective intelligence of bee's food forging behavior and 2-opt heuristic	NA	Yes	Yes
11.	BCO	Multi-Dimensional Knapsack Problem	Food foraging behavior has been mapped	NA	Yes	Yes
12.	ABC	Developing Optimization Algorithm	1. exploits the working of scouts and forager's food foraging	NA	No	No

			behavior 2. assumes that the bee has short as well as long term memory			
13.	ABC	Generalized Assignment Problem	5 agents-15 tasks to 10 agents-60 tasks.	C#	Yes	Yes
14.	ABC	Constrained Problem Optimization	"Smart Bee" concept where the bee has memory capability for food sources' location and quality	NA	Yes	Yes
15.	ABC	Advisory System	expert domain based knowledge	JSP for front end and MYSQL for backend.	NA	No
16.	Interactive ABC (IABC)	Numerical Assignment Problem	maps the forager bee's path development mechanism to pick new coordinates	NA	5 Benchmark problems	Yes
17.	BCO	Job Shop Scheduling	Maps the Food foraging behavior of honey bee	NA	Yes	Yes
18.	Simulated BCO	Pairwise Test Sets Generation	requires significantly longer duration to generate test sets	PICT in C++ QICT in C#	7 Benchmark problems	Yes

V. CONCLUSION

In this paper an introduction to the nature inspired class of algorithms have been presented. Among the number of nature inspired systems Bee Colony system have been studied and explained along with its areas of applicability. A study on the application of BCO algorithm in various domains has been presented. It has been found that BCO is well suited for NP-hard problems like maximum satisfiability problem, Advisory problem, combinatorial problems, multidimensional knapsack problem, job shop scheduling problems, pairwise test sets generation etc. It has also been applied to software testing, puzzle solving, numerical complexity problems, routing problems, networking problems, assignment problems, optimization problems, accident diagosis etc. It can be now said that BCO has immense capabilities to solve problems with minimum scope to solution.

VI. REFERENCES

[1] D. Teodorovic and M. Dell' orco, "Bee Colony Optimization – A Cooperative learning approach to Complex Transportation Problems," In Proceedings of the 16th Mini-EURO Conference on Advanced OR and AI Methods in Transportation (2005), pp. 51-60, 2005.

[2] D. Chaudhary, "Bee-Inspired Routing Protocols for Mobile Ad HOC Network (MANET)," Journal of Emerging Technologies in Web Intelligence, vol. 2, pp. 86-88, May 2002.

[3] A. Kaur and S. Goyal, "A Bee Colony Optimization Algorithm for Fault Coverage Based Regression Test Suite Prioritization," International Journal of Advanced Science and Technology, vol. 29, pp. 17-30, April 2011.

[4] J.A. Pacurib, G.M.M. Seno and J..P.T. Yusiong, "Solving Sudoku Puzzles Using Improved Artificial Bee Colony Algorithm," Fourth International Conference on Innovative Computing, Information and Control (ICICIC) Kaohsiung, pp. 885 – 888, 7-9 Dec. 2009.

[5] P.Navrat, T. Jelinek, and L. Jastrzembska, "Bee hive at work: A problem solving, optimizing mechanism," World Congress on Nature & Biologically Inspired Computing, NaBIC, Coimbatore, pp. 122 - 127 , 9-11 Dec. 2009 .

[6] X. S. Yang, "Engineering Optimizations via Nature-Inspired Virtual Bee Algorithms," Artificial Intelligence and Knowledge Engineering Applications: A Bioinspired Approach, pp. 317-323, 2005.

[7] D. Karaboga and B. Akay, "Artificial Bee Colony (ABC), Harmony Search and Bees Algorithms on Numerical Optimization," pp. 1-6.

[8] M. S. Oliveira, R. Schirru and J. A. C. C. de Medeiros1, "On the Performance of an Artificial Bee Colony Optimization Alogithm Applied to the Accident Diagnosis in a PWR Nuclear Pwer Plant," In Proceedings of International Nuclear Atlantic Conference - INAC Brazil, pp. 1-11, 27 Sep-2 October 2009.

[9] D. Teodorovic, BCO-Book.

[10] L. P. Wong, M. Y. H. Low and C. S. Chong, "Bee Colony Optimization with Local Search for Traveling Salesman Problem," International Journal on Artificial Intelligence Tools (IJAIT), vol. 19, pp. 305-334, 2010.

[11] P. N. Nhicolaievna and L. V. Thanh, "Bee Colony Algorithm for the Multidimensional Knapsack Problem," Proceedings of the International Multi Conference of Engineers and Computer Scientists Hong Kong, vol. 1, pp. 20-25, 19-21 March 2008.

[12] G. Leguizamon and Z. Michalewicz, "A new version of Ant System for Subset Problem," Congress on Evolutionary Computation, pp. 1459-1464, 1999.

[13] I.Alaya, C.Solnon and K.Ghedira, "Ant algorithm for the multidimensional Knapsack Problem," In Proceedings of Bioinspired Methods and their applications, pp. 1-10, 2004.

[14] P.C. Chu and J.E. Beasley, "A Genetic algorithm for the Multidimentional Knapsack Problem," Journal of heuristic, vol. 4, pp. 63-86, May 1998.

[15] S. M. Saab, N. K. T. El-Omari and H. H. Owaied, "Developing Optimization Algorithm Using Artificial Bee Colony System."

[16] B. Lu1, L. Özbakır and P. Tapkan, "Artificial Bee Colony Algorithm and Its Application to Generalized Assignment Problem," Computer and Information Science, vol. 5, pp. 113–144, Dec. 2004.

[17] N. Stanarevic, M. Tuba, and N. Bacanin, "Modified Artificial Bee Colony algorithm for Constrained Problems Optimization," International Journal of Mathematical Models and Methods in applied Sciences, vol. 5, pp.644-651, 2011.

[18] M. S. P. Babu1and N. T. Rao, "Implementation of Artificial Bee Colony (ABC) Algorithm On Garlic Expert Advisory System," International Journal of Computer Science and Research, vol. 1, pp. 69-74, 2010.

[19] P. W. Tsai1, J. S. Pan1, B. Y. Liao1, and S. C. Chu, "Enhanced Artificial Bee Colony Optimization," International Journal of Innovative Computing, Information and Control, vol. 5, pp. 1-14, Dec. 2009.

[20] L. F. Perrone , F. P. Wiel , J. Liu , B. G. Lawson , D. M. Nicol , R. M. Fujimoto ,and C. S. Chong, "A Bee Colony Optimization Algorithm to Job Shop Scheduling," 2006.

[21] J. D. McCaffrey, "Generation of Pairwise Test Sets using using a simulated bee colony algorithm ", IEEE International Conference on Information Reuse & Integration,pp. 115-119, Aug 2009.

Author's Profile

Dr. ArvinderKaur is an Associate Professor with the University School of Information Technology, Guru Gobind Singh Indraprastha University, India. She obtained her doctorate from Guru Gobind Singh Indraprastha University and her master's degree in computer science from Thapar Institute of Engineering and Technology. Prior to joining the school, she worked with B.R. Ambedkar Regional Engineering College, Jalandhar and Thapar Institute of Engineering and Technology. She is a recipient of the Career Award for Young Teachers from the All India Council of Technical Education, India. Her research interests include software engineering, object-oriented software engineering, software metrics, software quality, software project management, and software testing. She also is a lifetime member of ISTE and CSI. Kaur has published 65 research papers in national and international journals and conferences.

Shivangi Goyal received B. Tech in IT from Guru Gobind Singh Indraprastha University in 2009. She is currently pursuing M.Tech from Guru Gobind Singh Indraprastha University. Her area of interest is Software Engineering.