Bio-Inspired Algorithms for Mobile Location Management—A New Paradigm

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Abstract Mobile location management (MLM) has gained a new aspect in today's cellular wireless communication scenario. It has two perspectives: location registration and location search and a trade-off between the two give optimal cost for location management. An outline of the prominent solutions for the cost optimization in location management using various bio-inspired computations is surveyed. For solving complex optimization problems in various engineering applications more and more such bio-inspired algorithms are recently being explored along with incremental improvement in the existing algorithms. This paper surveys and discusses potential approaches for cost optimization using fifteen bio-inspired algorithms such as Artificial Neural Network, Genetic Algorithm to newly developed Flower Pollination Algorithm and Artificial Plant Optimization. Finally, we survey the potential application of these bio-inspired algorithms for cost optimization in mobile location management issue available in the recent literature and point out the motivation for the use of bio-inspired algorithms in cost optimization and design of optimal cellular network.

Keywords Mobile location management · Bio-inspired algorithms · Location update · Paging · Optimization

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1 Introduction

In the current times, one of the research focus in the wireless communication domain lies in the design of computationally efficient next generation mobility management system based on bio-inspired algorithms which can provide optimal network configuration by reducing the spectrum utilization as well as the overhead location management cost. Due to rapid progress in technology with multiple applications and exponential rise in mobile users, there is an utmost need to track the mobility pattern of the mobile terminals by the networks. The current location update is required so that an incoming call can be routed to the particular mobile terminal without much delay. Mobile location management (MLM) involves two problems in particular i.e. location update and paging and the ongoing research focuses a tradeoff between the two such that the MLM cost is optimized [1].

Currently, one of the most challenging issues in MLM in mobile communications is selection of suitable strategy for various network environments [2] and choosing appropriate intelligent algorithms from a range of bio-inspired techniques for the optimization of the overhead cost. The developing stages of bio-inspired computing techniques are introduced from its application perspective to MLM by describing the upgrades of its importance in cellular networks design, and the relationship between mobility management technology and bio-inspired optimization.

In course of time the area of bio-inspired computing is getting highlighted. Because of the growing complexity of the optimization problems whose exact solution is not feasible, the bio-inspired techniques prove beneficial. Among the metaheuristics, the bio-inspired algorithms are gaining prominence which can adapt, adjust and accommodate just like the biological entities. Each algorithm is presented for MLM strategies effectively and efficiently.

The remaining paper is structures into the following sections: the second section presents the problem formulation for MLM as an optimization problem. The third section gives an overview of the bio-inspired algorithms. This is followed by the potential scope of application of these algorithms in MLM field. The last section provides useful insights on the exploration of bio-inspired optimization algorithms for location management domain. This paper does not provide implementation details of bio-inspired techniques rather the unexplored areas are identified for future research.

2 Problem Formulation for Mobile Location Management

MLM constitutes two operations: location registration and location inquiry. The mobile terminal updates its current position once it changes the operating cell location which is referred to as location registration whereas, in location search the cellular network traces the cellular position of the residing mobile station so that the arriving call for the mobile user can be directed to the corresponding user.

MLM cost comprises of weighted sum of location registration cost and location search cost given in Eq. (1)

$$Cost = C \times N_{UP} + N_P \tag{1}$$

where, N_{UP} represents the location registration or update cost and N_P represents the paging or search cost over a period of time. The registration cost is generally higher than the search cost by a factor represented as C which is usually taken as a constant set to 10.

Here the fitness function *Cost* is to be optimized (reduced) to obtain best cellular wireless communication network configuration using the heuristic and meta-heuristic optimization techniques which is summarized in the next section.

3 Bio-Inspired Algorithms—An Overview

3.1 Artificial Neural Networks (ANN)

Artificial Neural Networks are a class of machine learning which imitates the functioning of the neurons, the nerve cells of human brain which corresponds to continuous-time nonlinear dynamic system [3]. The strength of ANN lies in the learning and adaptation to the changing environment where numerous processing units are connected to each other in a network in multiple layers. The neural network depicts a layered network structure which works on the inputs to give outputs with learning ability based on inputs and feedbacks which may be positive or negative. It consists of a set of adaptive weights which are tuned by a learning algorithm.

3.2 Genetic Algorithm (GA)

GA was proposed by Holland [4] and was developed by Goldberg and De Jong. GAs is stochastic search mechanisms that utilize a Darwinian criterion of population evolution. The survival of an individual depends on ability to adapt to its environment which reproduces better individuals as well with each growing generation. The population (set of chromosomes) is updated via crossover, mutation and selection which give new set of population called offspring. In the selection stage the individuals having better fitness survive for the future generations following the "survival of the fittest" criterion.

3.3 Differential Evolution (DE)

First introduced by Storn and Price [5] DE is a simple, stochastic and effective tool for global numerical optimization. It is very much similar to GA where the initial population also goes through genetic cycle where differential mutation is performed prior to the crossover operation. The selection of the best individuals for next generation depends on the optimized cost criterion. DE is used for multidimensional real-valued functions optimization which does not require the optimization problem to be differentiable.

3.4 Artificial Immunological Computation (AIC)

AIC came to prominence in mid 1990 where significant work is done using immune networks. It is inspired by the immune system, immune functions, principles and models and is based on human body's immune function of memory and learning [6].

Immunity refers to a condition in which an organism can resist disease which can be innate or acquired. In the immunological computation model there are mechanisms for antigen–antibody recognition. There are various approaches associated with this theory like immune network model, negative selection algorithm, clonal selection algorithm, dendritic cell algorithms, and danger theory which have also been modified for improved solutions.

3.5 Particle Swarm Optimization (PSO)

PSO is swarm-based optimization technique proposed in 1995 by Shi and Eberhart [7]. It is inspired by the food search mechanism of bird flock. The main idea is to simulate the choreography of the flock of birds. The scenario illustrated here suggests the methodology that the PSO follows: A bird flock is searching for food-grains which are in one particular location of that area. None of the birds know the location of the grains but in each iteration they have the knowledge of how far the food is. So, the most effective principle is following the bird which is almost near to the food-grain location. Each bird or particle is considered as a potential solution in the d-dimensional space having some fitness value. The fitness function to be optimized is evaluated for every particle, and velocity and position update is carried out in every cycle where two values called pbest (personal best) and gbest (global best) are also evaluated for every particle. Thus, the optimal solution is achieved by updating the subsequent generations.

3.6 Ant Colony Optimization (ACO)

ACO proposed by an Italian scientist Dorigo is successful in solving many discrete optimization problems [8]. The pheromone, a chemical secreted by the ants influences the travel pattern of its peer ants when they are locating the food. When the ants are confronted to the obstacle on the chosen route, they immediately change their path to the next efficient route to the food source. A higher quantity of pheromone implies a stronger impetus on the path chosen by the ants. It is a very promising research field as it involves derivative free optimization having lot of application areas.

3.7 Artificial Bee Colony (ABC)

ABC algorithm was developed by Karaboga and Basturk [9] is based on the foraging behavior of honey bees swarm. Since then several variants of the basic algorithm have been proposed. The steps of this algorithm are: the employed bees identify the food sources (candidate solutions) with a random stimulus initially. Then the fitness value of the food sources is computed and in the following step better food sources are identified. Meanwhile this knowledge of the food sources is passed on by the employed bees to the onlooker bees who in turn choose the food sources with better fitness values.

3.8 Bacterial Foraging Optimization (BFO)

Developed in 2009, this technique is based on the food gathering behavior of E-Coli bacterium which is replicated as an optimization problem [10]. The principle underlying the foraging theory is that the bacteria find its food in such a mechanism that the energy derived from it per unit time is maximum. The foraging constraints include physiology, predators/prey, environment etc. BFO consists of four prominent stages namely chemotaxis, swarming, reproduction and elimination and dispersion. Chemotaxis involves a tumble followed by a tumble or tumble followed by a run. Swarming means cell to cell signaling via an attractant. In the reproduction stage the population is sorted in ascending order of fitness function. Finally, in the elimination and dispersion cycle the bacterium moves to a new location according to a preset probability.

3.9 Leaping Frog Algorithm (LFA)

LFA technique is inspired from the hunting nature of the frogs [11]. The initial population comprises of virtual frogs generated randomly. First, the whole set of

frogs is divided into partitions called memeplexes which in turn is again subdivided into subsets of sub-memeplexes. Here the frog giving worst result will jump towards its prey based on its own memory as well as the experience of the frog giving best results in that memeplex. If the new jump gives better results this process will be repeated otherwise there is generation of a new frog. The sub-memeplexes which gives better results are chosen and again partitioned into new memeplexes and the process continues till the termination criteria is met.

3.10 Cuckoo Search (CS)

Proposed in 2009 Cuckoo search is a bio-inspired technique inspired by the breeding nature of the cuckoo which lay eggs in the host bird's nest [12]. It is a metaheuristic algorithm that can address complex nonlinear optimization problems in practical engineering domain. The cuckoo search is as follows: In the nest the eggs are the solutions and the egg of the cuckoo is a newer solution. At a time, each cuckoo lays one egg in the nest which is randomly selected. The nests of the host birds are fixed in number and with a certain probability the cuckoo's egg is discovered by the host bird. The nests with better solutions are passed on to the future generations.

3.11 Firefly Algorithm (FA)

Yang [13] proposed the firefly algorithm which is based on the flashing nature of the fireflies. The firefly's flash attracts other fireflies by acting as a signal. The intensity of the flashlight corresponds to the fitness value. The bioluminescence signaling indicates other fireflies to deter the predators. This algorithm gives the training for balance between global exploitation and local exploitation. Currently many variants of FA are proposed like adaptive FA, discrete FA, multiobjective FA, chaotic FA, lagrangian FA and modified FA. This algorithm has also been hybridized with bio-inspired algorithms.

3.12 Cat Swarm Optimization (CSO)

CSO, a bio-inspired technique formulated in 2006 by Chu, Tsai and Pan based on the behavior of cats [14]. For most of the time the cats are in their resting period but still active called seeking mode and they take speedy move when awake called tracing mode. In CSO the cats are the candidate solutions having a fitness value. There are two modes: First, the seeking mode which is a resting phase where the cat alertly looks around for its next movement and the second, tracing mode where the

cat's velocity and position update takes place. The parameters involved in the seeking mode are seeking memory pool (SMP), counts of dimension to change (CDC) and seeking range of the selected dimension (SRD). Many complex optimisation problems have been solved using CSO which provides satisfactory results.

3.13 Artificial Bat Algorithm (ABA)

ABA is a popular meta-heuristic, which can solve the global optimization tasks. In 2010, Xin-She Yang proposed this algorithm which is based on the echolocation nature of the bats, a flying mammal [15]. It has a very promising application as seen from its implementation and comparison. The control parameters are the pulse frequencies, rate of pulse emission and the loudness which can be fine-tuned to improve the convergence rate of the bat algorithm and control the generation of new solutions close to global optimal solution.

3.14 Flower Pollination Algorithm (FPA)

Yang (2012) proposed the FPA which is based on the process of pollination in the flowering plants. In this algorithm the cross-pollination corresponds to global optimization where a Levy flight is performed by the vectors carrying pollen grains [16]; while the local optimization corresponds to the mechanism of self-pollination. The cross-pollination involves the transfer of the pollens between flowers of two different plants using biotic vectors like insects and birds whereas the self-pollination corresponds to pollination in the flowers of same plant by means of abiotic factors like wind or water. This bio-inspired algorithm can be used for solving real-world applications.

3.15 Artificial Plant Optimization Algorithm (APO)

APO is a bio-inspired algorithm designed to address non-differential, multimodal optimization problems which are based on the growing plant. The branches of the plant represent the potential solution which is initially selected in random. The environment of the growing plant corresponds to the search space. The branches are evaluated for calculating the fitness value and the photosynthesis and phototropism mechanisms determines the new solutions. The photosynthesis operator measures the amount of energy produced whereas, phototropism operator controls the movement of the branches corresponding to the light source [17].

4 Potential Application of Bio-Inspired Algorithms in MLM

In mobile location management, the objective is minimizing the total location registration cost and the search cost which can be potentially performed by the bio-inspired algorithms. The cost reduction in location management has been carried out using various heuristic and meta-heuristic approaches but there is significant scope in applicability of newly developed bio-inspired techniques in this field. The Fig. 1 shows the percentage distribution of publications in Scopus for the location management problem using different bio-inspired algorithms which illustrates that MLM using ANN has 14 % distribution and MLM using GA, PSO, DE, ACO, ABC has less than 4 % distribution in Scopus. So, from the analysis plot it is ascertained that a lot of work can be explored in this area by the scientific community. There are some reviews of bio-inspired algorithms which have focused mainly on the classic algorithms but the newly developed ones have not been captured. Reviews of bio-inspired algorithms for cost minimization in mobile location management are also somewhat sparse. So, this paper significantly overviews the application of bio-inspired optimization tools for reducing the location registration cost and location search cost in mobile location management problem. Such review will definitely add to the knowledge the scope of application in this domain which is still unexplored.

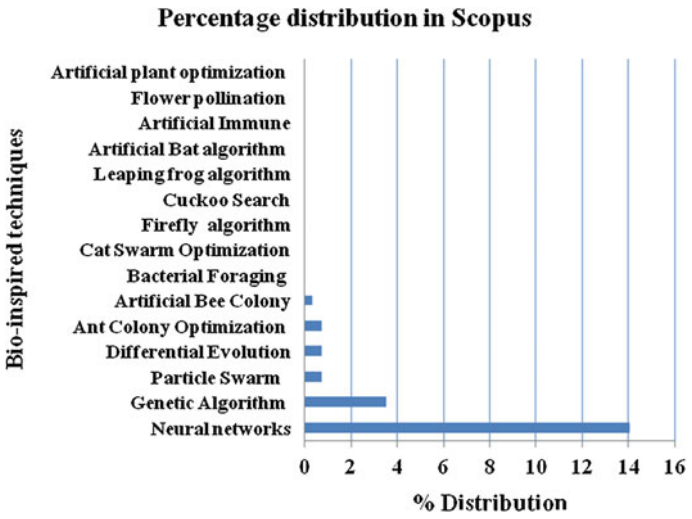

Fig. 1 Percentage distribution of application of bio-inspired algorithms for MLM in Scopus

5 Conclusion and Future Direction

This paper presents an overview of the bio-inspired algorithms which have potential application for cost optimization in location management problem. In recent years, these meta-heuristic optimization techniques have been the focal point of research in this domain except the newly developed ones whose applicability still remains unexplored. While there are different approaches for cost optimization in mobile location management problem, presently the bio-inspired algorithms have captured the attention of the research community for solving the cellular network related issue. The objective of this work is not only to introduce the importance of these algorithms for solving the real time applications but also to provide insights in terms of scope and applicability of these techniques for mobile location management. This survey provides a direction for further research to choose the appropriate bio-inspired algorithms based on their fitment and investigate their performance in comparison to conventional techniques for mobile location management problem.

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