Evolutionary Algorithms in Telecommunications

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***Abstract*— Telecommunications are an important symbol of our present information society. With a rapidly growing number of user services, Telecommunications is a field in which many open research lines are challenging the research community. Many of the problems found in this area can be formulated as optimization tasks. Some examples are assigning frequencies in radio link communications, developing error correcting codes for transmission of messages, and designing the telecommunication network. In practice, most of these optimization tasks are unaffordable with exact techniques. Hence, the utilization of heuristic approaches is in order. In this sense, Evolutionary Algorithms have constituted a popular choice. This paper summarizes some applications of the telecommunication field in which Evolutionary Algorithms have been successfully applied.**

I. Introduction

The fast development of network infrastructures, cellular networks, software, and Internet services has been influenced by the growing demand for data communications over the last decades. At the present time, new technologies like cellular mobile radio systems, optical fibers, and high speed networks are in widespread use around the globe, allowing fast data communications, new services and applications. In this situation, there is a renewed interest in technology and telecommunication problems, such as antennae design, optimal allocation of base stations, frequency assignment to cellular phones, and structural design problems relating to routing information through the network. Since the size of the existing telecommunication infrastructures is continuously enlarging, the underlying optimization problems frequently pose a challenge to existing algorithms. In consequence, the research community has been searching for new algorithms that are able to replace and improve the traditional exact ones, whose low efficiency and unrealistic assumptions often makes them useless for solving real-life problems of large size in reasonable time.

In this context, Evolutionary Algorithms (EAs) have been frequently applied to telecommunication problems in the last years. EAs [1] are heuristic search techniques loosely based on the principles of natural evolution, namely adaptation and survival of the fittest. They are based on a set of solutions (individuals) called population. The problem knowledge is enclosed in a function, the so-called fitness function, that assigns a quality value to the individuals. Initially, the algorithm creates a population randomly or by using a seeding algorithm. In each step, some individuals of the population are selected, and employed to create new individuals by means of variation operators. Then, a replacement operator decides what individual will form the new population. This process is repeated until a stop criterion, such as a maximum number of evaluations is fulfilled. We can distinguish four main types of EAs: genetic algorithm, evolutionary strategy, evolutionary programming, and genetic programming. Genetic algorithm is the most well-known EA and, for this reason, it is the most frequent algorithm in the papers considered in this work.

This introductory paper provides a very brief summary of telecommunication problems and works in which EAs have been successfully applied. We are not exhaustive in the present review but we try to offer a significant sample of the diverse application domains as well as reporting on open research lines, past and present international projects and guidelines on addressing actual telecommunication problems with EAs.

We have classified the application domains into three categories: hardware design, data transmission, and network level. The next three sections focus on these categories and Section V presents the conclusions.

II. Hardware Design

In this section we include the works using EAs to optimize parameters of the hardware infrastructure. The first hardware design application we consider here is the antenna design problem. Antenna design presents a challenge for designers since they should be as simple and low-cost as possible while at the same time satisfying the particular electrical requirements. Villegas et al. 2004 [2] use Parallel Genetic Algorithms (PGA) for a patch antennae design in wireless networks. They combine the accuracy of full-wave electromagnetic analysis with the robustness of Genetic Algorithms (GA) optimization and the speed of the parallel computing environment to solve the mentioned patch antennae design. They describe the design of a dual-band antenna element for wireless communication (1.9 and 2.4 GHz) applications. The resulting antenna exhibited acceptable dual-band operation while maintaining a cross-pol maximum field level at least 11 dB below the co-pol maximum.

Inside the COST Action 273 (entitled *Towards Mobile Broadband Multimedia Networks*) several hardware aspects are optimized by using GAs. First, a GA is applied to the optimization of antenna arrays used in mobile radio channel characterization devices. Simulation results show that the method succeeds in designing arrays with higher performance with respect to other techniques commonly used [3]. In addition, another GA is used for capacity optimization in Universal Mobile Telecommunication System with Frequency Division Duplexing (UMTS FDD) networks. The problem consists of finding the best settings of antenna tilt and common pilot channel power of the base stations. Improved genetic operators are introduced, which are adapted for the UMTS capacity optimization problem by taking into account the quality of the network. In addition to capacity, the coverage and the soft handover are also considered [4], [5]. Finally, a GA is used as the main part of a method proposed for Multiple-Input Multiple-Output (MIMO) wireless system array design, adapted to characterized radio environments. The method is compared against selection algorithms proposed in a previous work and an exhaustive search method. The robustness and versatility of GAs make the method efficient in instances with vast search spaces, outperforming other algorithms [6].

III. Data transmission

In the data transmission category we include applications optimizing aspects related to the direct communication of data between two components such as cellular phones and base stations. One problem arising in radio networks (such as cellular networks) that is known to be NP-hard is the Frequency Assignment Problem (FAP). This consists of assigning frequencies to a number of radio links minimizing the amount of different frequencies employed at the same time that a large number of constraints are simultaneously satisfied. In an early proposal, Hurley, Crompton, and Stephens [7] solve the problem with a PGA. The objective in this work is to minimize several parameters related to the electromagnetic interferences due to the use of similar frequency values for nearby transmitters. They compare two different representations for the problem considering a simulated but realistic military scenario.

The FAP is also tackled in the CALMA project (*Combinatorial ALgorithms for Millitary Applications*). They use exact and approximated solution techniques to solve the problem. Among the approximated techniques they pay special attention to GAs [8]. One of the conclusions of the project is that the GA approach must be tuned to the problem at hand in order to make it work, and then it will work very well.

The Dynamic Channel Assignment (DCA problem) is a variant of the FAP where channels must be allocated to cells dynamically, depending on the traffic demands. Kwok tackles this problem using a parallel hybrid algorithm [9]. Oriented to take advantage from static and dynamic assignment models, Kwok proposes a quasi-static dynamic approach, combining two modules: an offline module that employs a PGA to generate a set of allocation patterns and an online module using a parallel local search method based on table-lookup and reassignment strategies. The hybrid parallel model reports better results than other DCA algorithms, in terms of both solution quality and efficiency.

Another data transmission problem is the Error Correcting Code design problem (ECC). This problem consists of generating a code alphabet with a given number of codewords and bit length that maximizes the minimum Hamming distance between each pair of codewords. This problem plays an important role in the telecommunication systems because the generated code allows the correction in the destination of corrupted messages without requiring their resubmission. Alba and Chicano [10] solve an instance of this problem with distributed hybrid GAs. They study the influence of the parallelism and hybridization in the solutions obtained and conclude that using the two strategies simultaneously outperforms the results with respect to their isolated application. In a later paper, Blum solves several instances of the problem by using an Iterated Local Search (ILS) [11]. The results outperform the ones obtained in the relevant literature.

IV. Network Design

Due to the huge amount of applications in this area we have grouped them into four groups: reliability, antenna placement, network routing, and assignment.

A. Reliability and Connectivity

Reliability refers to the ability of the network of working when some of the nodes or links fail. The evaluation of reliability metrics is a difficult problem itself; an alternative is to impose connectivity constraints on the network topology. One usual objective is to ensure that the data flows may be re-routed to reach the destination in the presence of a single node or link failure. Then, to ensure that the data can reach the final node, two disjoint paths between any pair of nodes are necessary. This is the so-called 2-connectivity constraint. Huang et al. [12] present a PGA for solving the 2-connectivity network design problem with diameter constraints. Duarte et al. tackle a multiobjective version of the previous problem and solve it with multiobjective genetic algorithms [13].

In telecommunication network design there is a combinatorial optimization problem that frequently appears: the Steiner Tree Problem (STP). The STP consists of finding a minimum-weight subtree of a given graph spanning a set of distinguished terminal nodes. Its applications cover many telecommunication fields such, for instance, the VLSI and pipeline design, the Internet multicast routing, the telephone network design, etc. Lo Re and Lo Presti have studied the use of PGAs to solve the problem. In a first article with Di Fata [14], these researchers develop a master-slave PGA obtaining promising speedup values when solving Beasley's OR Library standard test problems. Recently, the same authors working with Storniolo and Urso extend their proposal [15], presenting a parallel hybrid method that combines a distributed GA and a local search strategy using a specific STP heuristic. Nesmachnow, Cancela, and Alba [16] tackle the harder Generalized Steiner Problem (GSP), which has been demonstrated NP-hard [17]. In this problem the objective is to find a minimum cost subgraph such that for each pair of nodes (i, j) there exists at least r_{ij} disjoint (or edge-disjoint) paths. This problem has applications in the reliability optimization. The authors present a comparative study of sequential and parallel versions of different metaheuristics (GA among them) applied to a number of medium-sized test cases. The results show that GAs obtain the best performances in solution quality.

B. Antenna Placement and Configuration

The localization and parameters of the antennae in a radio network have a clear influence on the quality and cost of the provided service. This problem is specially important in cellular networks where, in addition to cost and quality requirements, we find coverage and handover constraints. Watanabe, Hiroyasu, and Mikiand [18] work out a parallel evolutionary multiobjective approach for deciding the antennae placement and configuration in cellular networks. In the same line of work, Meunier, Talbi, and Reininger [19] present a parallel implementation of a GA with a multilevel encoding deciding the activation of sites, the number and type of antennae, and the parameters of each base station. Maple et al. [20] solve a base station transmitter location problem. The problem consists of deciding the placement of base stations and their parameters in a 3G mobile network. They propose a PGA and present the way of applying it to the problem.

In the APPOL II project (*Approximation and Online algorithms for Optimization Problems*), the problem of positioning base station transmitters of a mobile phone network and assigning frequencies to the transmitters is tackled with an evolutionary-based heuristic. The problem requires the minimization of both the cost and the channel interference. Two standard multiobjective EAs (NSGA-II and SPEA2) are examined and compared against a new algorithm: the steady-state evolutionary algorithm with Pareto tournaments [21].

Calègari et al. [22] tackle a simplified version of the general problem consisting of finding the optimal placement of antennae. The authors compare a greedy technique, a Darwinian algorithm, and a PGA. Alba and Chicano [23] tackle an artificial instance of the same problem with sequential and parallel GAs.

C. Network Routing

Several researchers have proposed EAs for solving different variants of network routing problems. As an example, Xingwei [24] presents a parallel algorithm combining an evolutionary approach and Simulated Annealing (SA) for solving routing and wavelength assignment for multicast in Dense Wavelength-Division Multiplexing (DWDM) networks. The hybrid approach consists of a synchronous distributed island PGA, incorporating an SA technique to decide whether or not to accept offspring and mutated individuals produced in the evolutionary operators when their fitness values are worse than the values of their fathers. The PGA-SA method is used to solve the routing problem (construction of a multicast tree), while the wavelength assignment is done via a deterministic procedure based on Dijkstra's shortest path algorithm.

The interdomain traffic engineering problem consists of optimally deciding which internet service provider (ISP) to choose for each destination Autonomous System (AS). Autonomous systems are telecommunication networks which belong to an institution. The communication between different ASs (interdomain traffic) is performed by the ISPs and the objective of the problem is to minimize the total cost due to the ISPs services. This problem has been tackled with EAs in the ATRIUM project (*A Testbed of terabit IP Routers Running MPLS over DWDM*) [25].

In the MESCAL project (*Management of End-to-end Quality of Service Across the Internet at Large*) two routing problems are solved with GAs: the interdomain offline resource optimization and the multicast traffic engineering problem. The former consists of mapping the predicted interdomain traffic matrix to the interdomain network resources, satisfying QoS requirements, while aiming at optimizing the use of network resources within or across autonomous systems boundaries [26]. The latter problem consists of selecting optimized link weights for the underlying link state routing protocols of a network in order to minimize the overall network resource consumption with bandwidth constraints. For this problem the results show that GA-based multicast traffic engineering consumes significantly less bandwidth resources in comparison with conventional IP approaches, while it also exhibits higher capability of eliminating/alleviating link congestion [27].

Other metaheuristic algorithms, not only EAs, have been used to solve routing problems. A representative sample is the work of Di Caro and Dorigo [28], where a new approach based on Ant Colony Optimization (ACO) and mobile agents is presented to optimize routing tables.

D. Assignment

The problem of determining minimum cost links to form a network by connecting a given set of terminals to a given collection of concentrators is a classical problem known as the Terminal Assignment (TA) problem. In this, the terminals have a known requirement of capacity and this requirement varies from one terminal to another. Each concentrator has an associated maximum capacity which limits the number of terminals it can handle. The capacity of all concentrators is also known. Khuri and Chiu [29] solve this problem with two GAs and a greedy algorithm. Their results suggest that the GAs work well with this problem outperforming the results of the greedy algorithm. Salcedo-Sanz and Yao [30] solve a variant of this problem in which the cost of assigning a terminal to a concentrator cannot be known until a complete feasible solution for the instance is evaluated. They propose a Hopfield Neural Network Genetic Algorithm (HNN-GA). The main search engine is a GA and the HNN is used after mutation as an operator in order to increase the probability of obtaining a feasible solution. They test their proposal over a set of TA instances of different difficulties and obtain very good results that outperform previous approaches to the problem.

The problem of assigning cells to switches in cellular networks consists of providing a cell assignment that minimizes the number and cost of required facilities when a mobile user changes the switch serving as relay. Quintero and Pierre [31] propose for this problem a parallel multipopulation memetic algorithm that combines the evolutive search of GAs with local refinement strategies based on Tabu Search (TS) and SA. The experiments show that the memetic approaches yield slight improvements in the cost function, which represent important fund savings over a 10-year period.

V. Conclusions

In this paper we have presented a brief summary of telecommunication applications solved in the literature with evolutionary algorithms. In addition, we have explored several european projects in the field of Telecommunications using EAs. Due to the limited room we have excluded some interesting applications such as protocol verification, signal processing, human-computer interaction, etc. As we can observe above, there are many and very diverse problems in the telecommunications domain that are computationally intractable with classic exact techniques. In these problems evolutionary algorithms are a good alternative to exhaustive methods because they can find a near optimal solution with a reasonable computational effort.

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