Bio-inspired and Evolutionary Algorithms Applied to a Bi-objective Network Design Problem

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ABSTRACT

Logistics network design is one of the principal parts of strategic decisions in the planning and control of production systems. It deals with determining the warehouses locations and the definition of product flow between facilities and clients. This work is focused in finding an approximation of the Pareto-optimal front for two conflicting objective functions in logistic networks design: minimize costs and maximize coverage. Since the establishing of which warehouses must be opened constitute a combinatorial optimization problem, two metaheuristic techniques, namely Improved Strength Pareto Evolutionary Algorithm - SPEA2 and a novel binary version of Bacterial Chemotaxis Multiobjective Optimization Algorithm - BCMOA, were applied. With the aim of finding the optimal flow between clients and warehouses, network flow algorithms were also used.

The performances of the above techniques were evaluated by comparative analysis of the results obtained in the solution of eight randomly generated problems by means of the dominated hypervolume metric (S-metric). The hybrid methodology here developed to solve the logistics network design problem - which combines metaheuristic techniques with a network flow algorithms - showed to be competitive regarding the Pareto Optimal Front approximation, and also displayed high efficiency in execution times.

Categories and Subject Descriptors

G.1.6 [**Numerical Analysis**]: Optimization—*Global optimization, Integer programming*

General Terms

Algorithms

Keywords

multi-objective, metaheuristics, network design

1. INTRODUCTION

Logistics network design problems are characterized by their high computational complexity even for simple models [1]. When formulated as mixed integer programming problems the time for finding the optimal solution increases both with the set of candidate locations and the set of clients sizes [5]. A comprehensive review of applications of analytical, heuristics and metaheuristics techniques to solve multiobjective logistics network design problems can be found in Farahani(2010)[2].

In this work, finding an approximation of the Pareto-optimal Front for the bi-objective optimization problem proposed is solved by using metaheuristics techniques for exploring the search space which is composed by the open-closed warehouses combinations. Minimizing the customer allocation cost to the open warehouses is solved by using network flow algorithms (Ford-Fulkerson and negative cycle canceling) embedded in the metaheuristic algorithms. To make the quantitative comparison of the performance of both metaheuristic algorithms, the hypervolume indicator was used taking advantage of its mathematical properties, which also allow to simultaneously represent the spread of solutions as well as their proximity to the Pareto-optimal Front[7].

2. METHODS

2.1 Mathematical Formulation

The formulation of the bi-objective optimization problem (minimizing cost and maximizing coverage) using mixed integer linear programming developed in this work, is an adaptation of that used by Melkote and Daskin (2001) [4], in which links between nodes are already constructed. The generation of the problem instances considers that there is a direct linear relationship between the travel cost and the distance, therefore the minimum travel cost is achieved when the units are sent through the minimum cost route.

2.2 Hybrid Optimization Strategy

Pseudo-code for the implementation of optimization strategy is shown in Algorithm 1. SPEA2 is a well-known metaheuristics technique developed by Zitzler et al. in 2001 [6]. BCMOA which was designed for solving continuous problems, was introduced by Guzman et al. (2010)[3] as simulation of the chemotactic behavior of bacterial colony; for solving the combinatorial optimization problem proposed, a modification of continuous version of BCMOA by handling binary variables is developed.

3. RESULTS

A set of eight bi-objective network design test problems was randomly generated following the methodology proposed by Melkote and Daskin(2001)[4]. In order to determine the

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Table 1: Performance comparison between SPEA2, Binary-BCMOA and MILP using dominated hypervolume (HV)

Problem	MILP		SPEA				BCMOA			
	HV %	Time Seconds	HV average %	HV Maximum	Time Seconds	Deviation HR MILP %	HV average %	HV Maximum	Time Seconds	Deviation HR MILP %
N20L2U5K25F17	61.2	154	60	60	57.2	2	59	59.8	54.9	3.6
N20L2U5K75F17	52.8	136	52.7	52.8	60.6	0.1	49.9	50.9	63	5.5
N20L4U5K75F10	68.9	813	63.3	63.3	62.9	8.2	62.1	62.8	64.2	9.8
N20L4U5K75F17	61.5	199.8	61.1	61.1	59.6	0.6	59.4	60.8	59.7	3.4
N40L2U5K75F10	72.5	439	71.2	71.7	342.5	1.7	66.9	69.7	417	7.7
N40L2U5K75F17	68.4	741	67.5	67.7	408.1	1.2	62.4	66.1	425	8.7
N40L4U5K75F10	73.2	15424.4	70.5	71	468	3.7	64.4	67	505	12
N40L4U5K75F17	76.1	14757.9	74.6	75	387.4	2	69.2	72	415.5	9.1

Algorithm 1 Hybrid-algorithms scheme

Require: P problem
Ensure: : $\hat{\mathcal{PF}}*$ an approximation of Pareto-optimal front
  Initialization : Randomly generate the initial set of solutions, $P_{t=0}$, for metaheuristics techniques
  while Not ending criteria **do**
    Generate the next set of solutions, P_{t+1} using a metaheuristics techniques
    Evaluate each solution of the set P_{t+1} using network flow algorithms
    Actualize the approximation of Pareto-optimal front according to criteria of metaheuristics techniques
  end while
  $\hat{\mathcal{PF}}*$

parameter levels for both algorithms, a 2^k experimental design was used. In Table 1, it can be seen that MILP based algorithm finds a better approximations of Pareto-optimal Fronts compare with SPEA2 and Binary-BCMOA. The time spent by MILP based algorithm increases depending on the number of nodes and arcs. The analytical method simultaneously explores the values of integer and binary decision variables, meanwhile the hybrid optimization strategy implemented separates the problem in two sub-problems, a combinatorial one which is handled by the metaheuristics technique and a network flow problem that is solved using network flow optimization algorithms. Excluding the instance $N40L4U5K75F10$ (12% for Binary-BCMOA) the approximations of all Pareto-optimal Front found by SPEA2 and BCMOA algorithms are within 10% the solution found by exact method. The execution times for the metaheuristics algorithms are affected only by the number of nodes and in all cases these times are shorter than time spent by the MILP based algorithm. Due to the network flow optimization algorithms are intended to find the minimum total cost and they do not regard alternative optimal solutions with better coverage, the number of points on the Pareto-optimal Front found by MILP in all cases is greater than those found by the hybrid optimization strategy.

4. CONCLUSIONS

The main purpose of this paper was to develop an alternative optimization strategy for solving multi-objective logistics network design problems. We use an hybrid optimization strategy that combines metaheuristics techniques based on bio inspired and evolutionary algorithms for guiding the exploration of search combinatorial with network flow optimization algorithms. The strategy developed showed to be competitive regarding the Pareto-optimal Front approximation and also displayed high efficiency in execution times. The binary version of BCMOA is a promissory method for finding good approximations of Pareto-optimal front for multi-objective combinatorial problems taking into account its easier and faster implementation. The comparative analysis of the two metaheuristics used showed that the SPEA2 have a better performance than the binary version of BCMOA. The effectiveness of both algorithms can be improve by modifying the network flow optimization algorithms for exploring alternative optimal solutions when the objective function is minimization of the total cost.

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