Bi-objective Combined Facility Location and Network Design

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Abstract. This paper presents a multicriterion algorithm for dealing with joint facility location and network design problems, formulated as bi-objective problems. The algorithm is composed of two modules: a multiobjective quasi-Newton algorithm, that is used to find the location of the facilities; and a multiobjective genetic algorithm, which is responsible for finding the efficient topologies. These modules are executed in an iterative way, to make the estimation of whole Pareto set possible. The algorithm has been applied to the expansion of a real energy distribution system. The minimization of financial cost and the maximization of reliability have been considered as the design objectives in this case.

1 Introduction

The problem of combined facility location and network topology design constitutes a difficult task that arises in several contexts, frequently when the facility is the source of a good that must be distributed via some network. Reference [1] discusses in detail this general class of optimization problems, which involves the simultaneous choice of continuous and discrete variables. This problem becomes even harder in the context of multi-objective formulations, since its intrinsic computational burden will affect the generation of a large number of solutions that are contained in the efficient solution set (the Pareto-set solutions). It should be noted that, very often, the real-world problems can be suitably cast in terms of a bi-objective formulation, for instance with the system cost competing with the system reliability, or the service quality. Up to the authors' knowledge, this problem has not been addressed in true multiobjective fashion in the literature, yet.

This paper discusses the structure of such an optimization problem, in the setting of nonlinear multiobjective optimization. For brief reference, the *Multiobjective Joint Facility Location and Network Design* problem is referred to here as the MJFLND problem. An algorithm is proposed here which combines

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a line search routine for the facility location sub-problem with a genetic algorithm (GA) for the network design sub-problem. Both routines are adapted to generate Pareto-set solutions in their own variables. A heuristic iterative procedure performs the switching between these routines, so that the Pareto-optimal solutions may be approached considering all variables. A convergence criterion based on the stabilization of the various Pareto-set "islands" that characterize this problem is proposed.

The proposed approach is discussed here through the analysis of a case study which is taken from a real joint electric distribution network design and one substation (SS) location problem. Two objectives have been considered: the system reliability and the sum of installation and operation financial costs. The multiobjective genetic algorithm employed here has been adapted from that presented in [2], in which several specific genetic operators are proposed for network design problems. The approach of combining a genetic algorithm with a line search optimization routine for the joint problem of substation location and network design has been used in [3], in an easier mono-objective setting. Here the problem is extended to a multiobjective setting.

The paper is structured as follows. The problem structure and the conceptual algorithm are discussed in sections 2 and 3. The statement of the real problem and the algorithm proposed to solve it are presented in sections 4 and 5. Finally, the numerical results gained for the real case are discussed, and some concluding remarks are drawn.

2 The Structure of Pareto-Sets in MJFLND

2.1 Multiobjective Optimization

Conventional mono-objective optimization is stated as the problem of finding the point, in a space of optimization variables, in which a certain function (the objective function) reaches its minimum (or maximum) value. The multiobjective optimization problem, instead of looking for a single point, searches for a set of points, the *Pareto-optimal set*, which is the set of optimal solutions of a problem with more than one objective functions [4]. The Pareto-optimal set, $\mathcal{X}^*$, is defined as follows.

Consider the minimization of a vector function $f(\cdot) : \mathcal{F} \mapsto \mathbb{R}^m$ (the vector of m objective functions of the problem) in which the set $\mathcal{F}$ represents the problem feasible set. In general, there may not be a single point $x \in \mathcal{F}$ in which $f(\cdot)$ reaches the minimum value for all its components. Then:

$$\begin{aligned}\mathcal{X}^* = \{x^* \in \mathcal{F} \mid \ \nexists\ z \in \mathcal{F} \text{ such that} \\ f(z) \leq f(x^*) \text{ and } f(z) \neq f(x^*)\}\end{aligned} \tag{1}$$

in which the relational operators $\leq$ and $\neq$ are defined for vectors $u, v \in \mathbb{R}^m$, as:

$$\begin{aligned} &u \leq v \Leftrightarrow u_i \leq v_i \ \forall\ i = 1, \ldots, m \\ &u \neq v \Leftrightarrow u_i \neq v_i \text{ for some } i = 1, \ldots, m \end{aligned} \tag{2}$$