A Two-Level Evolutionary Approach to Multi-criterion Optimization of Water Supply Systems

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Abstract. Purpose of the paper is to introduce a methodology for a parameter-free multi-criterion optimization of water distribution networks. It is based on a two-level approach, with a population of inner multi-objective genetic algorithms (MOGAs) and an outer simple GA (without crossover). The inner MOGAs represent the network optimizers, while the outer GA – the *meta* GA – is a supervisor process adapting mutation and crossover probabilities of the inner MOGAs. The hypervolume metric has been adopted as fitness for the individuals at the meta-level. The methodology has been applied to a small system often studied in the literature, for which an exhaustive search of the entire decision space has allowed the determination of all Pareto-optimal solutions of interest: the choice of this simple system was done in order to compare the hypervolume metric to two performance measures (a convergence and a sparsity index) introduced on purpose. Simulations carried out show how the proposed procedure proves robust, giving better results than a MOGA alone, thus allowing a considerable ease in the network optimization process.

1 Introduction

The problem of choosing the optimal combination of pipe diameters, in order to minimize the overall cost of a looped water distribution system (given a finite set of commercial available sizes), is proven to be NP-hard [1]. In the last decades, many authors have proposed several approaches based on different optimization techniques, mainly linear programming [2], [3], [4], [5], [6], [7] and non-linear programming [8], [9].

More recently, several researchers have applied genetic algorithms (GAs) to single-objective optimization of water supply systems, introducing some improvements with respect to the simple GA, [10], [11], [12], [13]. [14] applied GAs to optimal location of control valves, while [15] and [16] to leak detection and calibration problems; [17] used GAs for optimal scheduling of pipe replacement.

[18] have shown that networks designed taking into account only cost minimization (and in the case of just one loading condition) tend to branched config-

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urations, as also pointed out by [19]. In a recent editorial, [20] stressed the need of adopting a multi-objective approach for the design of water supply systems.

These last years have seen an increasing number of applications of multi-objective optimization algorithms: generally, only two-objective problems have been considered, the first criterion being the total cost of the system and the second representing a measure of the network performance: [21] adopted for the first time a multi-objective algorithm for water network rehabilitation, minimizing cost and maximizing benefits; [22] considered the minimization of cost and of the maximum pressure deficit at nodes; [23] took into account the maximization of entropy or demand supply ratio, while [24] and [25] the maximization of the reliability of the system.

A multi-objective evolutionary algorithm (MOEA) has two main goals [26]: firstly, to find a set of solutions as close as possible to the Pareto optimal front; secondly, to find a set of solutions as diverse as possible. However, the performance of the algorithm is quite affected by crossover and mutation type and probability: as a result, many runs with different starting populations and parameter sets are usually performed in order to find a good population of non-dominated solutions.

In this paper, a different approach is proposed, consisting of a population of MOGAs at the inner level, and an outer single-objective GA (meta GA) controlling the MOGAs crossover and mutation probabilities. The fitness of each individual of the meta GA is given by the hypervolume (that is, the amount of the objective space dominated by the obtained non-dominated front, [27], [28]) obtained by the inner MOGA it represents.

This methodology reconsiders some ideas of [29] and [30], and is *non-self-adaptive* [31], thus basically different from the *self-adaptive* mechanism based on the inclusion of operators and control parameters within the individual representation, [32], [33].

In order to asses the validity of the hypervolume metric, it has been compared to two performance measures, namely a convergence and a sparsity index [34], which quantify the exploitation and exploration issues of the inner MOGAs.

The paper is organized as follows: in Section 2, the mathematical formulation of the problem is presented, together with the test problem adopted for the numerical analyses; Section 3 describes the performance metrics, while Section 4 the two-level approach; Section 5 presents the results obtained and Section 6 some concluding remarks.

2 Two-Objective Water Supply System Optimization

2.1 Mathematical Formulation

The problem is formulated as the minimization of the total cost of the network and the maximization of the minimum pressure level at nodes: for pressure level, we mean the deviation from the required pressure (see Figure 1 for an explanation), and hence both negative and positive values are allowed; however, in this work, the attention is focused only on negative values, indicating situations of