Hybridizing Cellular Automata Principles and NSGAII for Multi-objective Design of Urban Water Networks

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Abstract. Genetic algorithms are one of the state-of-the-art metaheuristic techniques for optimal design of capital-intensive infrastructural water networks. They are capable of finding near optimal cost solutions to these problems given certain cost and hydraulic parameters. Recently, multi-objective genetic algorithms have become prevalent due to the conflicting nature of these hydraulic and cost objectives. The Pareto-front of solutions obtained enables water engineers to have more flexibility by providing a set of design alternatives. However, multi-objective genetic algorithms tend to require a large number of objective function evaluations to achieve an acceptable Pareto-front. This paper describes a novel hybrid cellular automaton and genetic algorithm approach, called CAMOGA for multi-objective design of urban water networks. The method is applied to four large real-world networks. The results show that CAMOGA can outperform the standard multi-objective genetic algorithm in terms of optimization efficiency and quality of the obtained Pareto fronts.

Keywords: Multi-Objective Optimization, Pipe Networks, Cellular Automata, Genetic Algorithms.

1 Introduction

The optimal design of urban water networks, both water distribution and sewer networks, is of central importance to water industries due to the vast capital investments associated with these underground assets. The problem is normally interpreted as a pipe-sizing problem. A large variety of optimization techniques have been developed for this NP-hard task, including linear and dynamic programming, and recently meta-heuristic algorithms, such as genetic algorithms (GAs), simulated annealing and tabu search.

Amongst these meta-heuristic algorithms, genetic algorithms are the most prevailing algorithm explored [1], [2], [3], [4] tracing back to the mid-nineties. More recently, inline with advances in optimization techniques and also due to the multi-criterion nature of the problem, research in this area has moved from searching for a single “optimal” solution to using multi-objective techniques [5], [6], [7] for more alternatives. Throughout the optimization, a GA is combined with a hydraulic simulator, which evaluates hydraulic performance of each solution attained at every generation of the GA. Although having given promising results, this approach can be

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time-consuming, especially when designing large networks. One reason is that the hydraulic simulation time is often significantly increased for large networks. Furthermore, as a drawback common to all genetic algorithms, GAs require a large number of objective function evaluations to attain sound solutions, which increases with the complexity of the problem. Since water networks typically have a large number of pipes, the prohibitively high computation cost has become the bottleneck in optimal design practices.

Some attempts have recently been made to overcome this difficulty by accelerating the optimization by way of employing a quicker hydraulic simulator or applying a more efficient optimizer [5], [8], [9], [10]. In Jourdan's work [5], a hybrid optimization method is developed, which integrates machine learning to boost the convergence of a multi-objective genetic algorithm by intermittently intensifying the search on promising areas of the search space. The approach eventually achieves a speed up of the optimization process ranging from 20% to 36%. Keedwell and Khu [10] and Guo et al. [9] developed an efficient cellular automata (CA) based optimizer for designing, respectively, water distribution networks and sewer networks. These approaches can obtain good solutions in a very small number of function evaluations, typically one hundred or less. However as CA are primarily driven by the principle of localism, the cellular automata based approaches cannot guarantee to find global optimal Pareto-fronts.

In this paper, as an extension to our previous work, the authors describe a hybrid optimization method for multi-objective design of urban water networks, called CAMOGA which combines the CA based approaches and a multi-objective GA, specifically a constrained non-dominated sorting genetic algorithm (NSGAII) [11], [12]. The rationale behind this is to exploit the strengths of both approaches, namely the efficiency through localism in the CA and the ability to search for a global optimum from the GA. Two stages can be identified during the optimization. In the first stage, the CA based approach is applied to efficiently obtain a set of preliminary solutions, which are then used as high-quality seeds for the NSGAII implemented in the second stage. In this way, it is expected that a large amount of the initial computation cost incurred at the early stage of GA execution can be saved, and the optimization progress towards global optima can still be assured.

The remainder of the paper is organized as follows. In Section 2, a brief introduction to water network optimization is given. In Section 3, Cellular Automata and CA based optimization methods are described; then the methodology of CAMOGA is explained in detail; In Section 5, case studies are carried out on four real-world problems (two sewer networks and two water distribution networks), and the optimization results are compared with those of NSGAII. A general conclusion is drawn at the end.

2 Multi-objective Water Systems Design

2.1 Water Systems Design

Water systems design has primarily focused on finding a cost-effective solution which minimizes the system cost whilst achieving the requisite system serviceability, such