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Sequence Analysis-based Hyper-heuristics for Water Distribution Network Optimisation

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Abstract

Hyper-heuristics operate at the level above traditional (meta-)heuristics that 'optimise the optimiser'. These algorithms can combine low level heuristics to create bespoke algorithms for particular classes of problems. The low level heuristics can be mutation operators or hill climbing algorithms and can include industry expertise. This paper investigates the use of a new hyper-heuristic based on sequence analysis in the biosciences, to develop new optimisers that can outperform conventional evolutionary approaches. It demonstrates that the new algorithms develop high quality solutions on benchmark water distribution network optimisation problems efficiently, and can yield important information about the problem search space.

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Keywords: Hyper-heuristic; Water Distribution Network; Hidden Markov Model

1. Introduction

A wide variety of meta-heuristic algorithms have been applied to the problem of water distribution network optimisation. Evolutionary algorithms [1,10] remain the most popular methods although ant colony optimisation [2], particle swarm optimisation [3] and shuffled leapfrog complex algorithms [4] have also been applied. These meta-heuristic methods have generally been successful in optimising many aspects of water distribution network design and operation due to their ability to be used as off-the-shelf techniques. Network design, rehabilitation and calibration have all been tackled along with pump scheduling as the main operational problem to be solved. As meta-heuristics, each of these methods has a fixed set of operations that are performed during the optimisation, (e.g.

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crossover and mutation in evolutionary algorithms). These fixed processes are often inspired by natural or other phenomena that have demonstrated success in the real-world and thus are used in computational optimisation. However, there has been a recent move towards higher level optimisation through multi-method search and hyper-heuristics. Multi-method search runs several algorithms in parallel and dynamically allocates computational resources to the most successful techniques during the optimisation. This method provides a diversity of approach and is well suited to modern multi-core machines where each of the methods can be executed in parallel. Hyper-heuristics similarly, operate above the level of (meta-)heuristics, but do so by *selecting* and *generating* low level heuristics (LLHs) which are similar to operators in meta-heuristics and perturb solutions in a variety of different ways. There are two primary classes of hyper-heuristics, selection hyper-heuristics and generation hyper-heuristics. Selection hyper-heuristics are provided with a set of LLHs to control and the task for the selection approach is to determine which LLH to apply at a given point during the optimisation. Generation hyper-heuristics build new heuristics from a set of components. Due to their ability to adapt to particular problem characteristics by selecting the most appropriate LLH at a given point in the optimisation, hyper-heuristics have been shown to improve on meta-heuristics in a number of different fields, but particularly in operational research (e.g. scheduling, timetabling and resource management) [5]. Improved performance is also possible by incorporating problem-specific and human (engineer)-derived heuristics into to the optimisation process. In this paper we investigate the use of a new sequence-based hyper-heuristic for the optimisation of the New York Tunnels water distribution network rehabilitation problem. The method is shown to find the best known solution within relatively few objective function calculations and a detailed analysis of the hyper-heuristic reveals information on how the method solves the problem. The work points the way towards the use of hyper-heuristics as the method of choice for this optimisation.

1.1. Water Distribution Network Design/Rehabilitation Problem

Water distribution network design/rehabilitation is an important real-world application for optimisation techniques. These networks deliver fresh drinking water from reservoirs, tanks and water treatment works to consumers via a network of pipes and make use of a pumps and valves to meet the demand of consumers. Typically, the optimisation of these networks aims to design new networks or rehabilitate existing ones, to deliver drinking water at an adequate pressure to all demand points for the minimum possible cost. Although this is the primary task for optimisation in this domain, there are many other objectives that can be considered including the minimisation of water age, adherence to velocity and pressure constraints and increasing the robustness of the network to reduce the potential for supply outages. In this particular problem set, only the simplest problem is considered where the decision variables are a set of diameters for each pipe within the network and the objectives are to meet the required pressure (head) throughout the network and minimise the overall cost of constructing the network. Though simplified, this problem is still one of high real-world importance and optimality in the solutions developed can have large scale financial, social and environmental impacts when applied to large-scale real-world examples.

1.2. Problem Formulation

The WDN optimisation problem is characterised as an NP-Hard combinatorial optimisation problem with large-scale multi-modal search landscapes. The algorithm must select from a list of discrete diameter options for each pipe within the network which constitutes the set of decision variables for the algorithm. A full set of decision variables describes a new network that is simulated by a hydraulic simulator, in this case Epanet 2 [6], which provides the information necessary to calculate the hydraulic values and to determine to what extent the network meets the hydraulic constraints. In this formulation, the two objectives are:

$$cost = \sum_{i=1}^{k}(1.1{d_i}^{1.24} \times l_i) \qquad (1)$$

Where i represents one of the total number of pipes k in the WDN, and d represents the selected diameter of pipe i and l represents its length (in feet or metres), and: