17th International Computing & Control for the Water Industry Conference
1-4 September 2019, Exeter, United Kingdom

A Diameter Probability Distribution Genetic Algorithm for Least-cost Water Distribution Network Design

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Keywords: Evolutionary Algorithm; Water Distribution Network Design; Heuristic Optimisation

EXTENDED ABSTRACT

Introduction

Evolutionary Algorithms (EAs) have been applied to the least-cost Water Distribution Network (WDN) design problem for decades. However, the application of EAs to complex real-world networks has been limited in the literature due to the significant compute time required to evaluate solutions. To address this issue, some researchers have investigated reducing the solution space in which the algorithm searches, effectively limiting the algorithm's search to areas where the optimal solution is thought to reside. One popular approach is to seed the initial population of an EA with high quality solutions generated using knowledge-based heuristics to focus the EA's search in the feasible solution space [1], [2]. Another method is to constrain the diameters that can be used for each pipe in the network based on initial hydraulic calculations [3]. In this paper we propose a method which uses search data from previous EA runs to generate diameter probability distributions for use in an EA's mutation operator. The resultant Diameter Probability Distribution GA (DPD-GA) is designed to reduce the effective search space, improving algorithm performance whilst maintaining solution optimality.

Methods and Materials

To generate the diameter probability distributions for use in the mutation operator, a standard generational Genetic Algorithm (GA) is used. Before initialisation, a single hydraulic simulation of the network is conducted to determine the natural flow rate for each pipe. The natural flow rate is determined by setting all decision pipes to their maximum allowable diameter and recording the flow for each pipe. The flow rates are then normalised between 0-1. This gives an indictor as to how hydraulically influential a pipe is in the network, a parameter we will refer to as pipe influence. From previous experimentation, there is a correlation between pipe influence and optimal diameter sizing, where the higher the influence, the larger the required diameter. The GA is then run and the normalised diameter of each pipe in the best solution is recorded every generation.

Diameter probability data was gathered on 3 different small/medium WDN design problems: Blacksburg, Foss Poly 1 and Pescara. For each problem the GA was run 30 times for 10,000 fitness evaluations. The diameters of all decision pipes in the current best solution were recorded at the end of each generation (100 fitness evaluations). Following the runs, the normalised pipe diameters were aggregated into 10 discrete distributions according to their pipes influence value. Figure 1 shows the diameter probability distributions for each pipe influence group, where the x-axis is the normalised diameter small to large, left to right respectively and the y-axis is the diameter frequency.

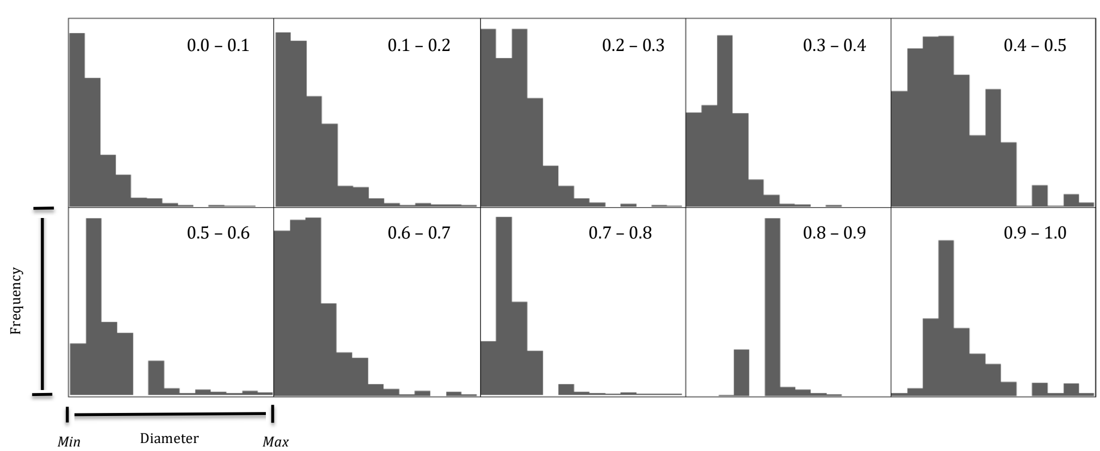

Figure 1. Diameter Probability Distributions for Each Influence Range (indicated in top right of each distribution)

DPD-GA is based on a standard generational GA with the generated diameter probability distribution data integrated into its mutation operator. The mutation operator randomly selects a pipe from the network and a diameter probability distribution is assigned based on the pipe's influence value. The diameter probability distribution is used by a proportionate selection method to select a new diameter value. The diameter of the pipe is then changed to the closest matching available diameter. DPD-GA was tested on the Modena problem, a large WDN from the literature that was unseen by the DPD-GA approach prior to testing. For this experiment, DPD-GA was compared with a standard GA. Each algorithm was run 12 times for 500,000 evaluations.

Results and Discussion

Figure 2. shows the mean network cost of the Standard GA and DPD-GA over the 500,000-evaluation search. It is clear from these results that DPD-GA exhibits much faster convergence than that of the standard GA. DPD-GA also achieves a better mean network cost after the allotted evaluations. By constraining the mutation operator with the diameter probability distribution data, the algorithm reduces the solution space in which it is searching, resulting in fewer wasted evaluations compared to the standard GA.

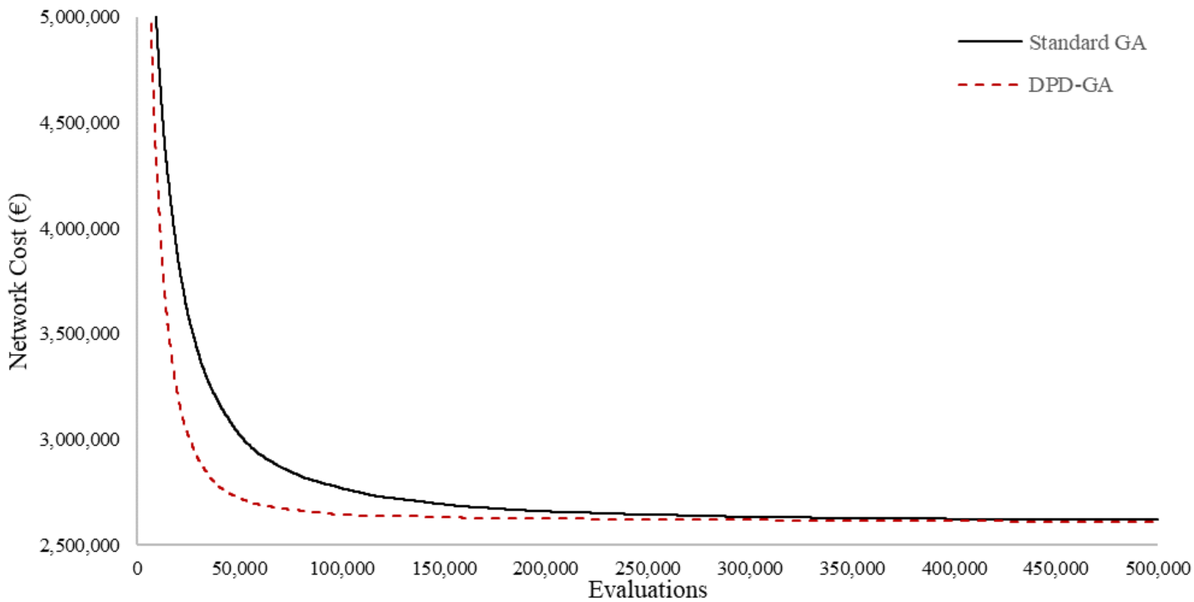

Figure 2. Mean Network Cost for the Modena Problem – Standard GA and DPD-GA

Conclusions

This paper demonstrates the potential for an EA to utilise data from previous optimisation runs on different WDN problems to reduce a new problems' search space. Specifically, the DPD derived from short automated runs of a GA on small problems have learned the relationship between pipe influence and a useful diameter range. When integrated into the mutation operator of a GA the DPD system results in improved performance. The developments presented in this paper point to EAs that could effectively learn how to solve WDN problems more efficiently each time they are tasked with a different WDN problem. Furthermore, it suggests that an algorithm trained on small benchmark problems could be used to effectively solve much larger industrial WDNs with minimal parameter tuning.

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