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Spectral Clustering and Genetic Algorithm for Design of District Metered Areas in Water Distribution Systems

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Abstract

District metered areas (DMAs) is an innovative layout and control technology to improve efficiency for water distribution systems (WDSs), there are many factors to be considered in DMAs design to reduce the adverse impact due to closure of valves. A new methodology for DMAs design is proposed based on complex network spectral clustering algorithm and graph theory. Water distribution network is regarded as undirected graph, which is mapped by weighted topology matrix. And normalized Laplacian matrix can be deduced to calculate the nontrivial eigenvectors. The *k*-means and genetic algorithm are used to determine clusters to minimize the sum of squared distance error between nodes in clusters and their centroids in Euclidean space. Eigenvector centrality is adopted for importance analysis of nodes in order to ascertain the location of meter of each DMA, which should be in the shortest path among the source and the central node in each DMA, and the other pipes between different DMAs will be installed with valves, at last the design of DMAs is achieved. And a real water distribution system is tested to ascertain the feasibility of the proposed method.

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Keywords: Water distribution systems; District meter areas; Spectral clustering; Genetic algorithm

1. Introduction

District metered areas (DMAs) is an effective tool to manage water loss. After several years development, there are some empirical summary to guide DMAs design considering many criteria including size, pressure, leakage level,

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water quality, cost, reliability, and so on [1]. In other words, the adverse impact of DMA should be minimized while the benefit can be maximized. For DMAs design, the important issues are how to define DMAs boundary and where to locate meters. Due to the complexity, for a long time the DMAs design mainly rely on try-and-error method with hydraulic simulation to validate corresponding performance [2].

Recently researchers start to investigate the subject to automatically create DMAs. With regard to graph theory, Depth-first search (DFS), bread-first search (BFS) and spanning tree are the main methods to detect structure for DMAs design. In particular based on the principle of directly supplied by water source, the scope of different sources can be determined by DFS[3], and supposed the nodes at transmission mains are source nodes, water supply scope at scale of DMA size can be obtained using BFS [4]. Graph partitioning is an alternative to DMAs design, the aim is to obtain DMAs with equivalent sizes while to keep less boundary pipes between DMAs [5, 6]. As a metric to quantify the degree of uniformity of a particular partition, modularity-based DMAs design methods have been applied to network treated as a simple graph [7], or weighted graph [8].

Most approaches focus on obtaining DMAs with similar size, neglecting the topological structure. DMAs are maintained by closure of many boundary pipes, inappropriate pipe closure leads to low pressure, high water age. Therefore how to define the DMAs boundary with less pipe closure needs to be investigated deeply. The aim of this paper is to find the inherent clustering structure with less interaction for DMAs design to minimize the impact of pipe closure on water distribution performance.

Nomenclature

$\mathbf{W}$	adjacency weighted matrix of graph
$\mathbf{D}$	degree matrix of graph
$\mathbf{L}$	Laplacian matrix of graph
$\mathbf{L}_{sym}$	normalized Laplacian matrix of graph
$\mathbf{E}$	corresponding matrix of $\mathbf{L}_{sym}$
C_i	ith nodes cluster
c_i	centroid of C_i
SSE	sum of squared error
$\mathbf{Y}$	nontrivial eigenvectors selected
y_i	row vector of $\mathbf{Y}$
λ	largest eigenvalue of matrix

2. Methodology

The proposed method consists of four main steps including:

- Data input: Determine the number of DMAs to be created, select pipe weight to differentiate importance from hydraulic simulation, represent topology of graph.
- Matrix calculation: Construct Laplacian matrix, calculate eigenvectors.
- Spectral clustering: *k*-means and GA to find the best node clusters, which correspond to DMAs.
- Meter location: According to engineering experience, it is reasonable to install meter at supply point of each DMAs to measure flow.

2.1. Topology representation of water distribution network

Water distribution network (WDN) can be represented by a graph whose edges and vertices are the pipes and nodes, respectively. Given an undirected graph with node set , we assume that the graph is weighted, its adjacency matrix is defined to be constant matrix, whose ijth entry is if nodes and are connected, and is 0 otherwise. As G is undirected graph, adjacency matrix is always symmetrical. The sum