Model Generator for Water Distribution Systems

Corinna Hallmann and Stefan Kuhlemann

1 Motivation

In recent years, the optimization of water distribution systems has gained more and more attention. In the literature, there can be found different optimization problems, such as water network design [6], pipe optimization [8], tank optimization [7], energy minimization [2] or pump scheduling [4]. All those problems have in common that there exist many mathematical optimization models and a variety of different solution methods for each of them. Most research work is evaluated either on few realistic networks that are only available for one special use case or on those few test networks that are available in the literature. These networks are mostly very small and often lack in realistic properties, cf. [3]. In order to evaluate models and solution methods and compare them to other research work, it is inevitable to have many different water network models. These models require to be of realistic size and to have realistic properties. In this paper, we present a model generator for water distribution systems. With this generator it is possible to create network models with realistic properties and size. The generator can also control the structure of the network to guarantee a realistic reflection of a water distribution system. To ensure the hydraulic properties in the network we use a hydraulic simulation tool in our generator. Details about the generation process and the application of different use cases will be shown in this paper.

C. Hallmann (✉) · S. Kuhlemann
Paderborn University, 33098 Paderborn, Germany
e-mail: hallmann@dsor.de
URL: http://www.dsor.de

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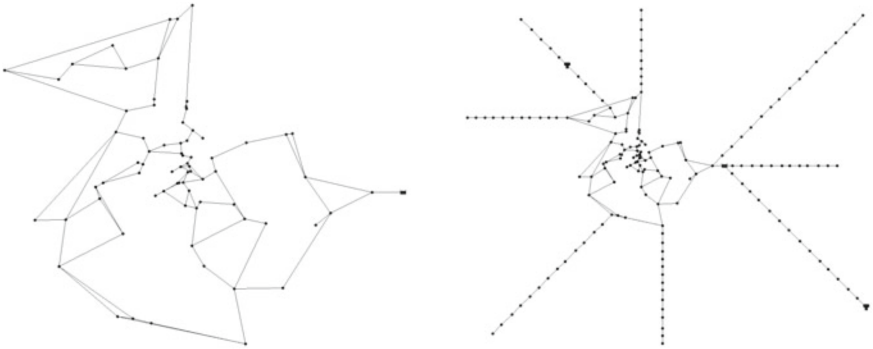
2 Literature Review

There are a few research papers that consider the generation of water network models. The generation approaches can be divided into manual and automatic ones. A manually generated network is the network *EXNET*, cf. [5]. It is a very large network model with several realistic properties and can be used as a test model to evaluate different use cases. Brumbelow et al. [1] developed two different network models *Micropolis* and *Mesopolis* representing a small and a large city with 5000 and 100,000 inhabitants, respectively. They use the models mainly for simulating cases of incidence such as electrical power failure. Those manually generated networks have very detailed and realistic properties, but it is a very time-consuming process to generate such networks. Thus, there are some research papers considering automatic generation of network models. Muranho et al. [10] developed the EPANET extension *WaterNetGen* for automatically generating network models. With this generator it is possible to generate network models with hundreds of nodes within a few minutes. The generator does not consider valves, pumps and reservoirs. Thus, the generated network models are not very realistic. Möderl et al. [9] present the graph-theory-based Modular Design System (MDS). This system generates networks depending on the demand of the nodes, the number of sources and the connectivity of the system. The authors present a set of 2280 virtual networks. In their approach the length of the pipes, the roughness and the elevation of the nodes are considered to be constant and pumps, valves and tanks are not integrated. De Corte and Sörensen [3] state that the generation of the networks is therefore not realistic. Sitzenfrei et al. [12]use the MDS to generate more realistic network models. Therefore, they use GIS data and the structure of the landscape and connect different graph structures. With these techniques it is possible to achieve more realistic structures. The tool HydroGen, cf. [3], can generate water network models of arbitrary size. It was developed to extend existing water network models.

3 Generator for Water Distribution Network Models

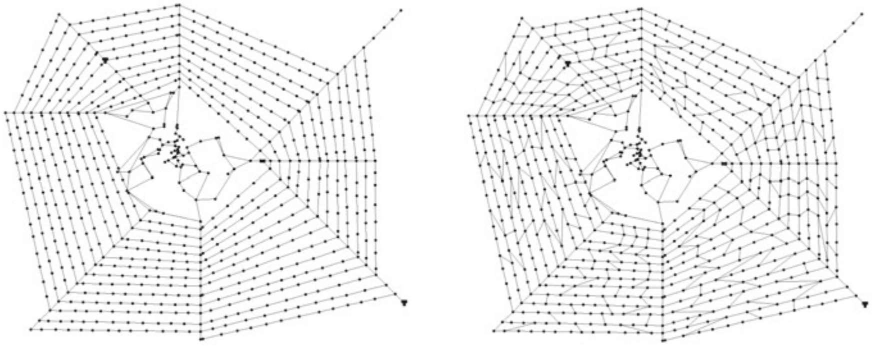
This section describes the process implemented in the generator for network models. The process can be divided into six different steps, which are described in the following. The application of these steps will be visualized in Fig. 1, where an example network is shown in Fig. 1a.

1. **Import Network**: The generator is able to import any network model in the *inp* format, which is commonly used when simulating and modeling water networks, cf. [11].
2. **Adding components for basic structure**: It is decided which components should be added to the network. It is possible to add pipes and nodes, which also can be tanks. Nodes are randomly added to one of the four edges or one of the four corners of the existing network model and then connected to the network via



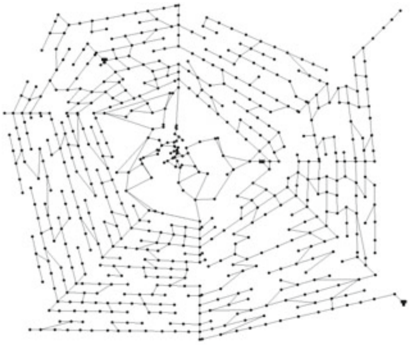
(a) Original network model

(b) Network model after adding nodes on edges and corners



(c) Network model after adding more nodes

(d) Network model after connecting nodes



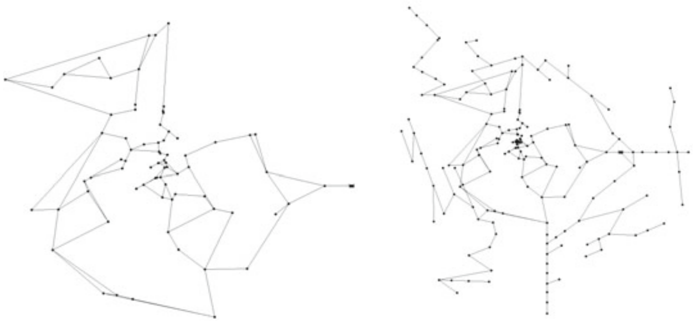
(e) Network model after deleting nodes

Fig. 1 Different steps of the generation process pipes. To determine the parameters of the new components, values of the existing components are used and are varied by predefined parameters. After adding a node with a corresponding pipe the network is simulated via a hydraulic simulation tool to check the modified network for infeasibilities. The simulation tool was recently developed by our industry partner *Rechenzentrum für Versorgungsnetze Wehr GmbH* and is based on EPANET [11]. The infeasibilities are for example a too low pressure on a node or numerical warnings of the algorithms. If numerical warnings occur, the node and the link that causes the problem will be deleted. If there are some infeasibilities, the parameters of the new node and link are modified until the network is feasible. If the modification of the parameters failed five times in a row, the node and the link will be deleted from the network as well. The user can decide how many of the new nodes should represent tanks. The implementation of tanks is important to ensure that there is enough water in the system also for the new components. Figure 1b shows the network after applying this step.

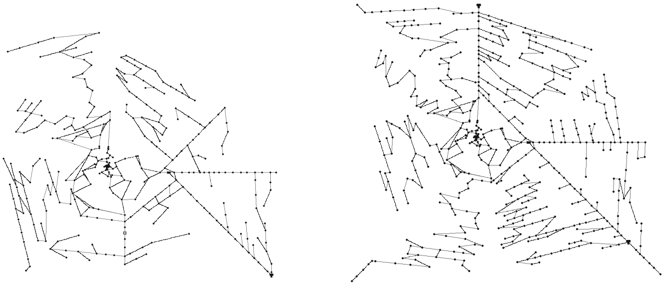
3. **Adding more nodes**: In this section more nodes are added to the network. These nodes are added to connect the nodes that were added in the previous step. The parameters of the pipes that are added to connect the nodes differ in such a manner that the resulting network is diversified and realistic. After adding new nodes and pipes, the network is simulated again to verify the correctness of the network. If some infeasibilities occur the parameters of the pipes are modified. If this fails, the new components are deleted from the network. The structure of the network is shown in Fig. 1c.
4. **Connect nodes**: This step connects the nodes of the previous step to each other. The nodes are chosen randomly but it is ensured that the new pipes do not intersect. The user can specify the maximal number of connections in order to vary the generated network. This step is displayed in Fig. 1d.
5. **Deleting Nodes**: In the previous steps a dense network with new nodes and pipes was generated around the original network. To get a more realistic network model, some of the new nodes and pipes are deleted in this step. With that, the network model gets a more realistic structure as the nodes are no longer aligned in the same way. The user can specify the rate of deleted nodes from the network. The resulting network is visualized in Fig. 1e.
6. **Export Network**: In this section the network is exported into the *inp* format.

4 Results

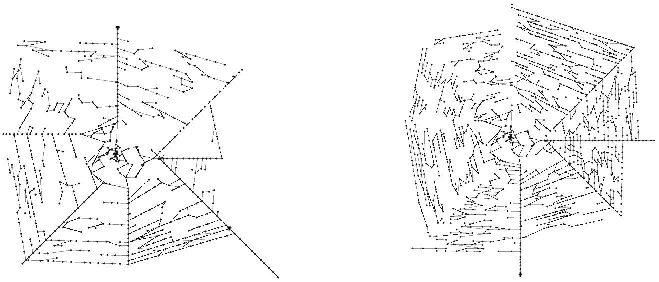
With the generator, any network model can be extended to an arbitrary size subject to the feasibility within a few minutes. In this section we present different versions of one network. Therefore, we use the network model *HG-SP-1-4*, which was generated by Hydrogen, cf. [3]. Figure 2 shows 6 different versions of the model and Table 1 shows the properties of those models. It can be seen, that it is possible to generate a



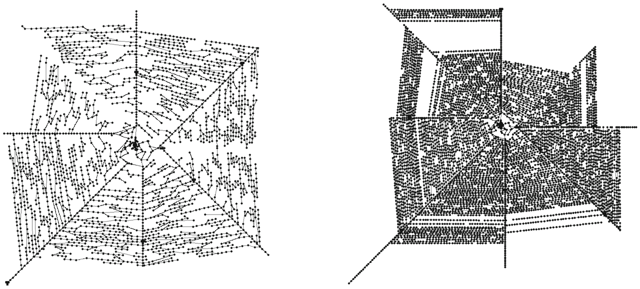
(a) Original network model (b) Network model version 1



(c) Network model version 2 (d) Network model version 3



(e) Network model version 4 (f) Network model version 5



(g) Network model version 6 (h) Network model version 7

Fig. 2 Different generated network models

Table 1 Properties of the generated network models

	Junctions	Pipes	Tanks
Original	73	102	0
Net1	163	198	1
Net2	311	355	2
Net3	515	565	5
Net4	555	627	3
Net5	1060	1171	4
Net6	2262	2357	6
Net7	6194	6796	10

variety of different network models with different sizes and different structures out of one original model. This shows the usefulness and the power of the presented generator.

5 Summary and Outlook

In this paper, we presented a generator for water network models. With this generator we can construct network models of arbitrary size. A simulation tool guarantees that the generated network model is feasible. The generator adds components in a structured manner and afterwards deletes some of those components to ensure a realistic structure of the model. In future work we would like to implement the adding of valves and pumps to the generation of network models.

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