Water distribution network optimisation using HydroGen instances

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Urban Water - May 28th, 2014
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Overview

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  Problem formulation

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  Limits of benchmark networks
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References
A Water distribution network (WDN) is a network that consists of different components that transport drinking water from one or more resource nodes to multiple demand nodes.
Optimisation of water distribution networks

Daily planning (operational level)

"How to plan daily WDN operations at minimal cost?"

Network design (tactical level)

"What is the optimal placement of sensors in WDNs to detect maliciously injected contaminants?"

Network layout (strategic level)

"What is the optimal WDN topology when (re)designing the water supply of a city?"

→ Use OR techniques to create decision support tools
→ Focus WDN design optimisation
Problem formulation

**WDN design optimisation**

Finding optimal pipe-configuration out of a set of discrete pipe types in terms of investment cost, with respect to hydraulic principles, energy conservation laws and customer requirements.
Problem formulation

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Mathematical formulation

Objective:

\[
\text{minimize } \sum_{p \in P} \sum_{t \in T} L_p IC_t x_{p,t} \quad x_{p,t} \in \{0, 1\}
\]

Subject to: **Mass conservation law**

\[
\forall n \in N : \sum_{i \in N / n} Q_{in} - \sum_{j \in N / n} Q_{nj} = D_n - S_n
\]

**Energy conservation law**

\[
\forall l \in L : \sum_{p \in l} \Delta H_p = \sum_{p \in l} \frac{1.852}{10.6668 y_p Q_p^{1.852}} \left(\sum_{t \in T} (x_{p,t} C_t^{1.852} D_t^{4.871})\right) = 0 \quad y_p \in \{-1, 1\}
\]

**Minimal head requirement**

\[
\forall n \in N : H_n \geq H_n^{\text{min}}
\]
Challenging problem

Example network
- 12 pipes
- 5 pipe types
⇒ $5^{12}$ combinations
⇒ $2 \times 10^8$ combinations
⇒ 28 days (100 eval/s)

Balerma network [1]
- 500 pipes
- 14 pipe types
⇒ $14^{500}$ combinations
⇒ $1 \times 10^{573}$ combinations
⇒ start at Big Bang: $4 \times 10^{19}$ combinations completed (100 eval/s)...
Test networks: benchmarks

- Dimensions not comparable to those of real networks
- Only very few benchmark networks available

NYC tunnels [2]  
Hanoi [3]  
Two loop [4]
## Test networks: NY city tunnels problem

<table>
<thead>
<tr>
<th>Method</th>
<th>authors</th>
<th>w</th>
<th>total cost</th>
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<td>Scatter Search</td>
<td>Lin et al., 2007</td>
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<td>Ant Colony Optimisation</td>
<td>Maier et al., 2003</td>
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<td>Ant System</td>
<td>Zecchin et al., 2005</td>
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<td>Max-Min Ant System</td>
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<td>Vasan et al., 2010</td>
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<td>38.80</td>
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</tbody>
</table>

w = hydraulic coefficient // Full references can be found in [5]

⇒ Benchmarks are fit to demonstrate developed techniques, not for complex algorithm testing... [6, 7, 8]
Test networks: HydroGen

HydroGen algorithmically generates realistic WDNs of arbitrary size and varying characteristics. [9]
HydroGen: water demand nodes
HydroGen: water supply pipes
HydroGen: water reservoirs, tanks and pumps
HydroGen: intra-cluster pipes
HydroGen: inter-cluster pipes
HydroGen: base load and water demand patterns
Metaheuristics

Water distribution network design optimisation:

- Mixed-integer, non-linear optimisation problem
- Challenging problem (NP-hard [10])

⇒ Use metaheuristic techniques to find satisfying solutions in reasonable time

Iterated local search:

- Iteratively apply local search procedure
- Make small changes to current solution
- Use intelligence to decide changes
- Use perturbation to escape local optima

Detailed description in [11]
Iterated local search

Finding optimal pipe-configuration out of a set of discrete pipe types in terms of investment cost, with respect to hydraulic principles, energy conservation laws and customer requirements.

Discrete set of pipe types:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Cost/meter</th>
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<tr>
<td>40 mm</td>
<td>2 mu</td>
</tr>
<tr>
<td>50 mm</td>
<td>5 mu</td>
</tr>
<tr>
<td>80 mm</td>
<td>8 mu</td>
</tr>
<tr>
<td>100 mm</td>
<td>11 mu</td>
</tr>
</tbody>
</table>

\[ H_n > 30 \text{ m} \]
\[ H_{\text{reservoir}} = 35 \text{ m} \]
\[ D_n = 2 \text{ CMH} \]
ILS: initial solution

TC = 26,400 mu
feasible
ILS: local search

TC = 24,600 mu
feasible
ILS: local search

WDN
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ILS
Why metaheuristics?
Iterated local search

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TC = 23,100 \text{ mu}
feasible
ILS: local search
ILS: local search

TC = 15,900 mu
feasible
ILS: local search

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TC = 15,000 mu
infeasible
ILS: local search

TC = 15,900 μu feasible
ILS: local search

TC = 14,000 mu
feasible
local optimum
ILS: perturbation

TC = 15,200 mu
feasible
starting solution for next local search
ILS: local search

TC = 13,400 mu feasible
WDN

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ILS

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References
TC = 11,100 mu
feasible
best found solution in reasonable time
Optimised networks

3 clusters, 440 nodes
Optimised networks

1 cluster, 350 nodes
Conclusion and extensions

Conclusion

• Finding optimal pipe-configuration out of a set of discrete pipe types in terms of investment cost, with respect to hydraulic principles, energy conservation laws and customer requirements
• Mixed-integer, non-linear, NP-hard problem $\rightarrow$ use metaheuristics
• Benchmark networks are easy for demonstration, HydroGen networks for algorithm testing

Extensions

• Introduction of dynamic demands (multi-period)
• Addition of pumps
• Multi-objective problem formulation
Water distribution network optimisation using HydroGen instances

Slides available at http://webhost.ua.ac.be/antor/.

Research supported by the Research Foundation - Flanders (FWO).
References


