The 2nd International Symposium on Water System Operations
1-3 September 2021

Assessing the Resilience of Water Distribution Networks Under Different Sensor Network Architectures and Data Sampling Frequencies

S. Chen[1,2], F. Brokhausen[3], P. Wiesner[4], L. Thamsen[4], A. Cominola[1,2*]
[1] Chair of Smart Water Networks, Technische Universität Berlin, Berlin, Germany
[2] Einstein Center Digital Future, Berlin, Germany
[3] Chair of Fluid System Dynamics, Technische Universität Berlin, Berlin, Germany
[4] Chair of Distributed and Operating Systems, Technische Universität Berlin, Berlin, Germany
[*]*andrea.cominola@tu-berlin.de*

Keywords: smart urban water management, resilience assessment, water distribution networks, sensor networks

EXTENDED ABSTRACT

Introduction

Leakages and other infrastructure failures represent major challenges confronting the reliability, efficiency, and resilience of water distribution networks (WDNs). Timely identification and accurate localization of these anomalies is paramount to mitigate water and revenue losses, and avoid unwanted cascading effects. Previous resilience studies have demonstrated that the topology of WDNs affects their resilience, for instance to pipe failures. Moreover, several methodologies have been proposed in the last decades to identify optimal sensor locations in a WDN and monitor physical variables (e.g., pressure, flow, concentration of contaminants) in relation to specific objectives, including water contamination monitoring and leakage detection. Yet, most of the studies on optimal sensor placement in WDNs assume constant data logging frequency or number of available sensors, and do not comparatively analyze the influence of different sensor network architectures in relation to different WDN topologies. Here, we develop a simulation-based approach for WDN resilience assessment to quantify the influence and trade-offs of different sensor network architectures, data sampling frequencies, and WDN topologies on automatic leakage identification and localization capabilities.

Methods and Materials

The simulation-based approach for WDN resilience assessment under different sensor network architectures and data sampling frequencies we propose here is composed of the following four steps.

First, we selected two different WDNs with heterogeneous sizes and topologies. We rely on the state-of-the-art benchmark WDNs Net3 and Modena (see Figure 1): Net3 is smaller and comprises 97 nodes connected by 117 pipes and has tree-structure dead ends; Modena represents an average-size WDN with 272 nodes and 317 pipes. Modena is characterized by a loop/grid configuration, in contrast to Net3.

Second, we simulated the two selected WDNs using WNTR [1] with a time horizon of four months and a simulation step of 5 mins under randomized leak scenarios. In each scenario, the leak starting time, the leak size, and the location of the leaking pipe are randomly sampled. We sampled a total of 40 leak scenarios for each WDN.

Third, we post-processed the simulated time series of node pressure to emulate different sensor network architectures, with varying numbers of sensors and different data sampling frequencies. We generated in total five different random sensor placement scenarios with various sensor-to-node ratios (10%, 25%, 50%, 75%, and 100%) and aggregated the pressure data to 5 mins, 15 mins, 30 mins, and 1 hour. As a result, we analyzed 4000 combinations of leak scenarios, sensor network architectures (i.e., number of sensors and sensor placements), and data sampling frequencies for each network.

Finally, for each combination of scenarios we performed leak identification and localization using the LILA state-of-the-art algorithm [2]. Leakage identification and localization are assessed in terms of time until detection (i.e., the difference between its actual start time and its detection time) and the distance between the position of the sensor where the leak was identified and its actual location.

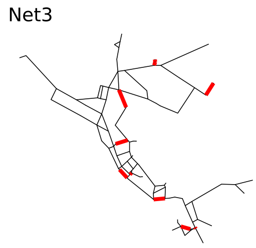

Figure 1. Overview of the Net3 (left) and L-Town (Modena) WDNs, with leaking pipes highlighted in red.

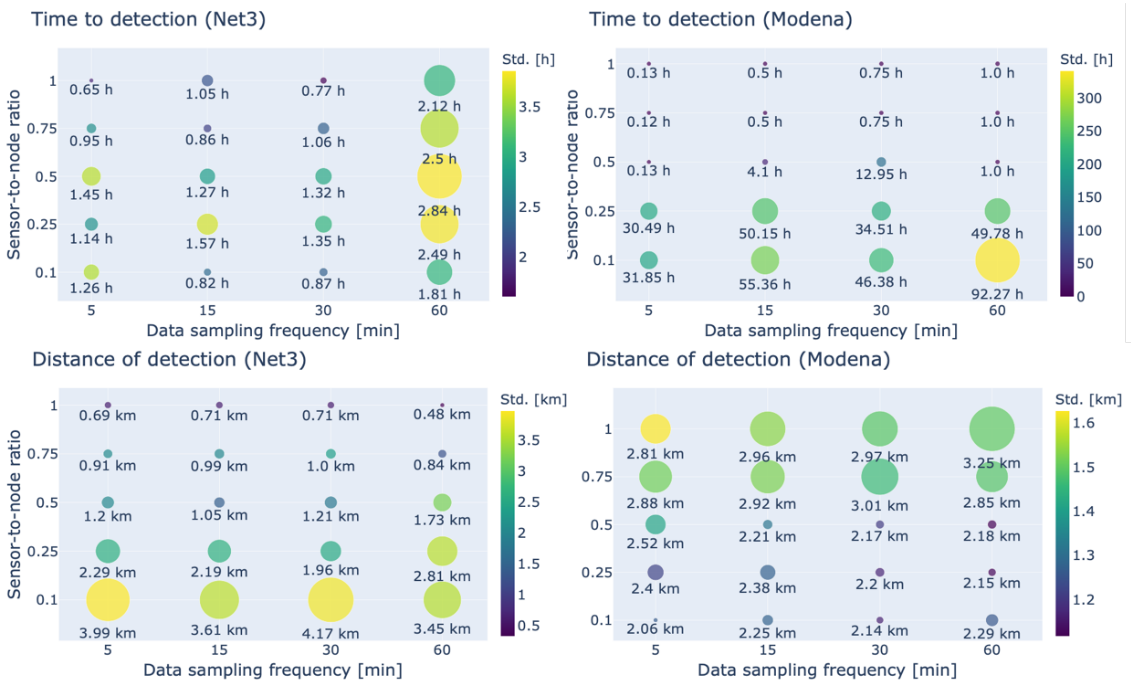

Figure 2. Time and distance of detection for Net3 and Modena WDNs (marker size and color: average and standard deviation over 200 leak scenarios) under different data sampling frequencies (x-axis) and sensor-to-node ratios (y-axis).

Results and Conclusions

Our preliminary results (see Figure 2) provide insights on the trade-offs between leak detection performance and temporal as well as spatial resolutions of pressure sensor data, which shows also dependencies on the WDN topologies. For Net3, time to detection tends to be primarily affected by data sampling frequencies, whilst distances of detection show higher dependency on the number of active sensors. This is nonetheless distinct for Modena, where the distances of detection are in a narrower range, likely due to the different, more articulated topology, sensor placement, and the effect of signal noise on the accuracy of the leak detection algorithm. Two major improvements to be prioritized for future investigation are (i) the implementation of an optimal sensor placement module to upgrade the current randomized sensor placement procedure and (ii) the comparative assessment of different leak identification and localization methods to achieve more generalizable conclusions.

REFERENCES

[1] Klise, K.A., Hart, D.B., Moriarty, D., Bynum, M., Murray, R., Burkhardt, J., and Haxton, T. (2017). Water Network Tool for Resilience (WNTR) User Manual, U.S. Environmental Protection Agency Technical Report, EPA/600/R-17/264, 47p.

[2] Daniel, I., Pesantez, J., Letzgus, S., Khaksar Fasaee, M. A., Alghamdi, F., Mahinthakumar, K., Berglund, E., and Cominola, A. (2020). A High-Resolution Pressure-Driven Method for Leakage Identification and Localization in Water Distribution Networks. Zenodo. http://doi.org/10.5281/zenodo.3924632