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IoT for Supervision and Control of Water Distribution Systems

Henrique DONÂNCIO and Laurent VERCOUTER

INSA Rouen Normandie

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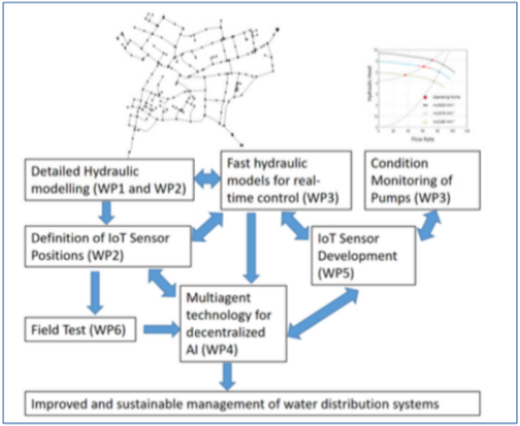
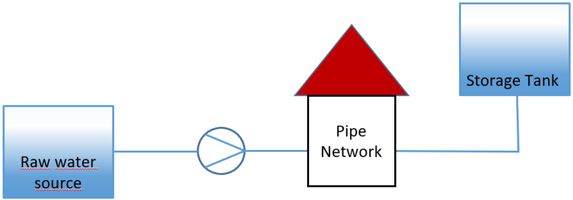
Project IoT.H2O

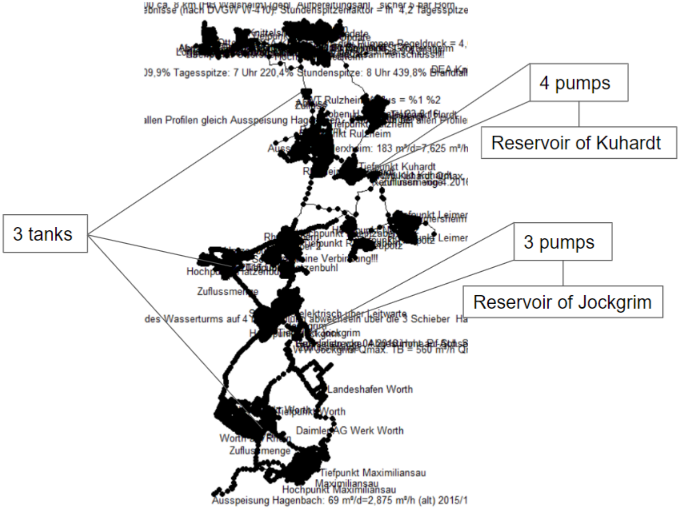


The topology of water distribution systems

Reservoir - Pumps - Network - Tanks



Water distribution network



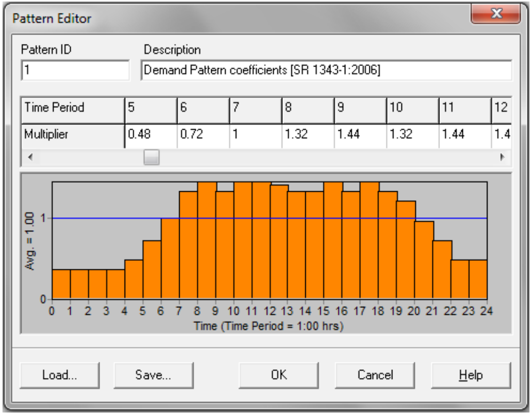
Characteristics of Water Systems

Which pressure is necessary to deliver a certain amount of water into the system?

- Water demand has to be delivered
- Storage tanks must not overflow or run out of water
- A minimum water reserve has to be in the tanks
- Pumps must be operated efficiently
- A minimum pressure must be guaranteed in the pipe network
- Guarantee water exchange in tanks

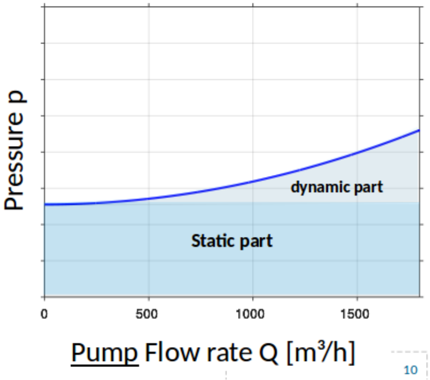
Pump Scheduling: the demand of water

- The demand water change over time



Pump scheduling: the system curve

- Static part: geodesic height difference
- Dynamic part: flow losses in pipe networks



Which is the challenge?

Supply water to the system with high efficiency

- Water demand and system curve change over time
- Pumps of different size are necessary
- When to start which pump with which speed?
  Recent works use Evolutionary Algorithms

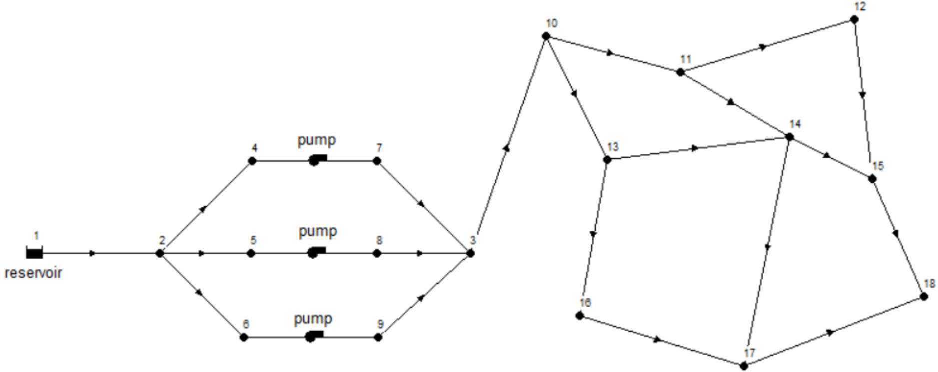
Dec-POMDP

- Pros: cooperative sequential decision making under uncertainty
- Cons: high complexity
- Incremental Clustering and Expansion for Faster Optimal Planning in Dec-POMDPs. Oliehoek et al. 2013.
  - MADP Toolbox (http://www.fransoliehoek.net/madp/)
  - Several heuristics available: QMDP $<$ QPOMDP $<$ QBG

EPANET

- A tool for simulation and analysis of water distribution systems
  - Design water distribution networks: reservoir, tanks, pipes and pumps
  - Model patterns: demand, electricity tariff, head
  - Simulation: time steps and analysis granularity
  - Rule-based control: control the system given some conditions of the components

Georgescu et al. 2015 - Modeling WDS using EPANET



Nodes the demand water: 11, 14, 16 and 18

Model-based Dec-POMDP

- Model tanks and demand as states
- The actions are the pumping levels executed by pumps
- The observations are the water level of the tanks and information about the current demand

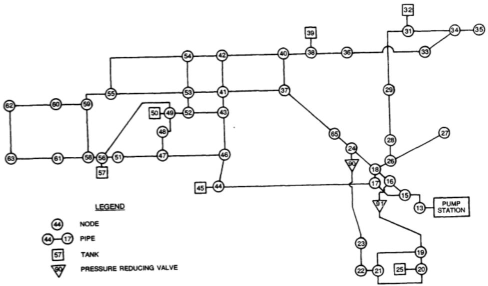
Discretization issue

- How to discretize the continuous action-state space?
  - Reinforcement learning in continuous state and action spaces. Van Hasselt, Hado. 2012.
- Trade-off: granularity of the discretization x quality of the solution

A Dec-POMDP for IoT.H2O

Model states as tanks and demand

- Water tank levels are the components of the environment that we want to change
- Sensors measuring the water tank levels provide observations



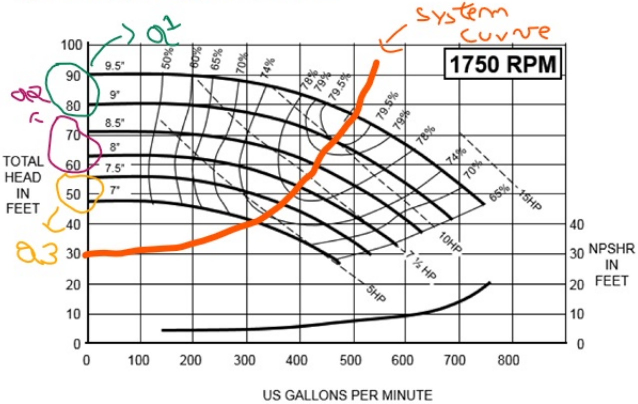
A Dec-POMDP for IoT.H2O - States

Discretization

- **[shortage, low, medium, high, overflow]** = For 3 tanks, 127 combinations
- **[low, medium, high]** = For 3 tanks, 27 combinations
- **[enough to supply, not enough to supply]** = For 3 tanks, 8 combinations

A Dec-POMDP for IoT.H2O - Actions

Typical Single Stage Pump Curve



A Dec-POMDP for IoT.H2O - Peak hours

- The cost of electricity variety during the day

2am - 6am	6am - 10am	10am - 2pm	2pm - 6pm	6pm - 10pm	10pm - 2am
t1	t2	t3	t4	t5	t6

Actions

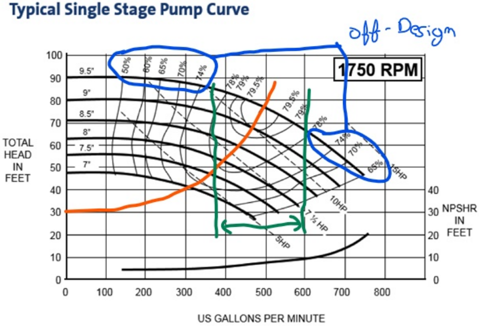
[pumping level - NOP - get data from the sensors] = The discretization of pumping levels and also the option to not operate and get data from sensors

The question is: which is the impact of the cycles in pumps?

A Dec-POMDP for IoT.H2O - Rewards

For the Rewards, we have to consider the **supply of water**, **the efficiency of the pumps**, **the pressure constraints** and the **electricity cost**

- Supply water depends of the water level in the tank
- The efficiency of the pumps can be extracted using the system curve



Model based Dec-POMDP

Can the agent make predictions about what the next state and reward will be before it takes each action?

- Using EPANET we are able to run simulations to extract a model for Dec-POMDP
- Using MADP Toolbox we are able to build policies to be evaluated and improve this model
- Learning S,A → R is a regression problem

  The reward can be modeled based on electricity consumption
- Learning S,A→ S’ is a density estimation problem

Next steps

- Model the water distribution system in EPANET to collect data
- The question resides on the best way to discretize the continuous action-space in a multi-agent setting. For that:
  - Deep Q Networks
  - Dyna-based algorithms
  - Binary Action Search for Learning Continuous-Action Control Policies. Jason Pazis and Michail G. Lagoudakis. 2009
  - Tree Based Discretization for Continuous State Space Reinforcement Learning. William T. B. Uther and Manuela M. Veloso. 1998

Thank you for the attention!