Ph.D. research topic

- Title: Hybrid combinatorial optimization and machine learning algorithms for energy-efficient water networks.
- PhD
- Axis: AI for Smart and Secure Territories
- Supervisor: Sophie Demassey, MINES ParisTech, sophie.demassey@mines-paristech.fr
- Co-supervisor: Valentina Sessa, MINES ParisTech
- laboratory: Centre de Mathématiques Appliquées, Mines ParisTech/PSL

- description:

Drinking water distribution is an essential industry and it is also one of the most energy-intensive. In water networks equipped with pumps and storage devices (e.g., water towers), the electricity consumption is flexible and controllable. Optimizing the operation and design of these systems is thus a big opportunity for energy savings. However, these optimization problems are very challenging: they combine discrete decisions and nonconvex physical constraints, large-scale heterogeneous models and uncertain data.

The object of this PhD thesis is to develop new hybrid algorithms to solve this type of problems by mixing Operations Research (OR) and Artificial Intelligence (AI) techniques. Combining their respective abilities is an attractive topic in optimization that witnessed a return of interest with the progress recently achieved with deep learning. In particular, the domain of water networks lends itself well to the application of hybrid algorithms, because of the problem complexity and the entanglement of the mathematical models and the physical data. In the specific, our goal here is to achieve: optimality with integer nonlinear programming, genericity with constraint programming, and scalability with machine learning. From the conception of hybrid algorithms in the specific context of water network optimization, we want to derive new generic optimization frameworks to articulate the different techniques, mostly based on the well-known decomposition methods of mathematical programming (price, resource and Benders decompositions) and of constraint programming (global constraints). The main challenges are: (1) to identify the appropriate techniques, (2) to identify the information to exchange between the different modules and (3) to make this communication effective.

Several solution approaches will be explored. For instance, we propose to investigate a combination of machine learning and column generation with the objective to tackle large-size instances of the deterministic day-ahead pump scheduling problem. The idea is to populate a new extended mathematical programming formulation of the problem with pumping configurations learned from historical data. Duality information will be progressively communicated to the learning algorithm in order to solve implicitly the whole program. The approach will then be extended to the stochastic variant of the problem by considering multiple scenarios of uncertain demand. For the strategical design optimization problem, we propose to investigate the appropriate Benders decomposition, in a hybrid variant, combining deep logic-based feasibility cuts, obtained by inference from a constraint programming model, and duality-based optimality cuts, obtained from the solution of a nonconvex programming model.