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**FINAL REPORT OF THE STSM AT ZUSE INSTITUTE BERLIN (ZIB)**

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The main aim of this Short Term Scientific Mission was to discuss the different techniques used to solve problems related to gas transport networks. The research group I belong to employs approaches related to Sequential Linear Programming and Control Theory techniques while the group from ZIB used other different methodologies. Thus, one of the main purposes of the stay was to compare experimentally the algorithms developed for both groups working together with Robert Schwarz.

First, let me introduce briefly the problem related to gas transport networks. A gas network basically consists of a number of controllable elements such as compressor stations and control valves that are connected via pipes. In the pipes of the network, the pressure of flowing gas decreases due to the friction with the walls of the pipes. This pressure loss makes more difficult to guarantee the security of supply: to meet the demand at the exit points with gas supplied at the entry points within the pressure bounds. Therefore, compressor stations can be employed to counterbalance the pressure loss, but they consume some proportion of the gas that flows through the pipes. Taking this into account, we want to know how to manage the network (how to route the gas and manage the switching elements) such that the security of supplied is fulfilled. This yields to a difficult mathematical model with a lot of nonlinear aspects, and it involves solving a mixed integer nonlinear problem (MINLP).

There is a difference between the problem treated by each of the research groups. In my research group we are interested into manage the gas transport network efficiently in order to reduce the self-consumption in compressor stations. Thus, we consider as objective function the minimization of the gas consumed in the compressor stations. On the other hand, the group from ZIB is mainly interested in the validation of a given nomination without pay attention to any costs. In other words, they want to know, given the amount of gas supplied at each entry point and the gas consumed at each exit point, if there exists a network state meeting all the requirements without any optimization goal.

During the mission I gave a talk titled “A twist on sequential linear programming methods” in the optimization seminar organized by ZIB. In this talk I introduced the Sequential Linear Programming (SLP) which is a widely used approach to solve complex nonlinear optimization problems. Informally, it consists of an iterative procedure which, at each step, works with a linearization of the problem around the current solution. This solution is then updated by taking a certain step in the direction of the optimum of the LP problem at hand. I also explained a natural modification of the SLP in which, at each step of the iterative process, instead of moving towards the optimum of the current LP problem, we use this optimum as the new solution of the nonlinear problem. This modified SLP algorithm is easier to implement and it readily leads to a heuristic algorithm for mixed-integer nonlinear optimization problems (MINLP). Note that if one introduce integer constraints to the model, then it would be necessary to solve a mixed integer linear programming at every iteration of the SLP. We propose a twist approach to solve MINLP:

1. First, use the modified SLP which allows obtaining an initial solution considering also all the binary variables (mainly valves and compressors stations).
2. Second, apply the well-known Penalized Sequential Linear Programming considering as starting point the solution obtained in the previous step once we have fixed the values for the binary variables.

This is the approach that we use to solve the optimization of the Spanish gas transport network. In practice we have seen that this approach works quite good solving this kind of problems. We also have tested this approach with a benchmark set of multicommodity flow problems obtaining satisfactorily results.

Throughout the STSM we managed to get the data of the gas network instances in the GasLib library in the format required by Ganeso (the software developed by my research group where all the methodologies of the group are implemented). In particular, we employed four instances:

1. Gaslib-40: a small network composed by forty nodes. It does not contain valves or resistors.
2. Gaslib-135: a network with one hundred thirty five nodes. It does not contain valves or resistors.
3. Gaslib-582-cool: a network with five hundred eighty two nodes with a representative nomination of a cool day. It contains forty nine valves and eight resistors.

It is worth noting that the models of both groups do not require exactly the same input, so it was necessary to estimate some data and do some simplifications. The treatment of the compressors stations had to be simplified because the mathematical models employed for each group are quite different. Furthermore, Ganeso does not incorporate resistors as elements, so the simplification that we have done was consider that the resistors are similar to small pipes where a small pressure drop appears.

It was proved the feasibility of all the gas networks instances for the given nomination employing the methodologies developed in ZIB. For the smallest network Ganeso also found a solution but it was different from the one obtained employing ZIB methodologies (note that the solution is not unique, especially disregarding the objective). I also tried to find the same solution imposing some constraints, because this would help us to observe the differences between our models, but it was unsuccessful. The reason was that when I imposed these constraints to the model, Ganeso decided to activate a new compressor station and thus the solution changed to another different one. Concerning the gaslib-135, Ganeso found a solution but require relaxing the upper bound of a node, so it needed to use slack variables. Probably, the fact that Ganeso was not able to find a solution without slack variables is due to some differences of the modelling of the equations related to gas drop. For the biggest network some problems appeared with the constraints associated to pressure control valves. I spent over one day and a half solving this issue because it was necessary to remodel these equations in the software. Once I solved this problem, I faced the gaslib-582-cool and Ganeso found a feasible configuration of the gas network for the given demand. It is worth noting that due to the simplifications in the compressor stations Ganeso did not consider exactly the same operation diagrams considered by the approaches developed in ZIB.

Summarizing we can said that these first computational experiments showed that the models of both groups seem to obtain similar results. However, due to the simplifications that we have done, it would be necessary to do more accuracy experiments to get clearer conclusions. Some tasks that would be interesting to do in the future to obtain a more accuracy testing could be adapting Ganeso to:

- Include constraints associated to resistors.
- Include a similar modelling of the compressor stations than GasLib to impose exactly the same operation diagrams associated to compressors.
- Incorporate the so called “Subnetwork Operation Modes” which ensure that only one of the permitted switching combinations of the active elements is used.

In the course of the STSM I have also discussed some other related topics of gas transport networks with other researches of the Zuse Institute of Berlin. In particular, with Robert Schwarz, I discussed ideas about the problem related to the topology planning of a gas network. At this point, one interesting task would be to develop new mathematical techniques to tackle the problem of build a new gas transport network from scratch. I talked with Ralf Lenz about techniques to simplify the gas network in order to reduce the size of the network. I discussed with Felipe Serrano some theoretical properties related to the modified SLP that I presented in the optimization seminar. There are also some other researches who were interested into implementing the twist approach, and probably we will discuss some aspects related to the algorithm.

It is worth noting that some of the tasks related to gas transport networks studied at the Zuse Institute are also studied in my research group, so future collaborations could be profitable for both groups.