ESIGELEC – Project S8

The Overview of the thesis

Optimal Routing of Electric Vehicles in Networks with charging Nodes: A Dynamic Programming Approach

Project efficient itinerary – Team 1: Benoît Mangeard

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2. Introduction:

The efficient route for electric vehicles is a main topic, many research is already conducted by several scientists. To produce our own version of the ideal route, a state of the art is essential. After many researches, I could release an article that takes many parameters essential to our future work.

I choose the article "Optimal routing of electric vehicles in networks with load nodes: a dynamic programming approach" written by three scientists from Boston University and a scientist from the University of Oak Ridge. This article came from those three theses [1] [2] [3] made by the same authors. The purpose of the first two articles was to study routes with homogeneous recharge nodes [1] and non-homogeneous [2] by formulating the MINLP model (non-linear mixed integer programming problem) and by implementing traffic congestion. The article studied here attempts to provide another approach.

The article consists of two parts, one part focuses on the management of a single vehicle and a the second part on the management of multiple vehicles.

3. Single vehicle routing:

3.1. Hypothesis and limits:

3.1.1.Hypothesis:

- A define node number n.
- All node are recharging station.
- One starting node and one arrival node.
- (1, ..., n) 1 as a starting nodes and n the arrival nodes.
- An arc (i, j) takes as parameter the travel time $\tau_{ij}$and energy consumption e_{ij}necessary for the journey between i and j.
- If nodes are not connected, then the time is infinite.
- The energy required for the journey from i to j (e_{ij}) can be negative, if the car is recharged by braking or other (example, downhill mountain ...).
- r_i is the amount of energy recharged at the station i.
- The vehicle is the only one on the roads and is not influenced by traffic. Thus e_{ij} and τ_{ij} are fixed.
- g_i is the charging time at the station.

3.1.2.Limits:

- Calculate the amount of recharging r_i required per station.
- Found the travel time τ_{ij} for each arc (i, j).
- Found the useful energy e_{ij} for each arc (i, j).
- Found the electric capacity of each vehicle.
- Set the charging time g_i per station.

3.2. Used approach:

The approach used is related to the Dijkstra algorithm, an exact method algorithm. Each node have a cost Q linked by the travel time between i and j and the energy it requires. This calculation is made by the following formula:

$$Q(i, E_i) = \min[Q(j, E_j) + \tau_{ij} + (E_j - E_i + e_{ij})g_i]$$

With $E_j = E_i + r_i - e_{ij}$

To associate cost to each node of the route, like Dijkstra algorithm, we first set Q weights to infinite and then, we iterate the value of each cost:

$$Q^k(i, E_i) = \min[Q^{k-1}(j, E_j) + \tau_{ij} + (E_j - E_i + e_{ij})g_i]$$

The algorithm stops when:

$$Q^k(i, E_i) = Q^{k-1}(i, E_i)$$

With this process, each node gets a cost and the lower cost determine the most efficient path.

3.3. Results:

Two tests were carried out by giving different values to g_i, the first one is done with g_i= 1 to have a homogeneous grid behavior, then the second test was realized with different values of g_i to obtain a non-homogeneous grid.

As expected, the routes are different because of the values of g_i, moreover, the calculated routes are in each case the most efficient. The calculation time has been divided by 100 compared to the first two articles mentioned rather.

3.4. Advantages, disadvantages and errors:

3.4.1. Advantages:

- Process time
- The result route is efficient
- The ability to assign a recharge time value per node
- The parameters can be related to our project

3.4.2. Disadvantages:

- Only one car in the grid (unrealistic)
- The parameters are fixed
- Every node are linked to a recharging station

4. Multiple vehicle routing:

4.1. Hypothesis and limits:

4.1.1. Hypothesis:

- Treat vehicles as subsets of N "sub stream" where N must be selected to make the problem manageable.
- All vehicles enter the grid through node 1
- R is the rate of vehicles enter at the node 1

- Electric vehicles are grouped by type and are treated as flows
- Electric vehicles will be the only ones treated here
- For equations, same hypothesis as in 3.1.1

4.1.2. Limits:

- The number N has a direct impact on the computation time
- Group by type each vehicle
- For equations, same constraint as in 3.1.2

4.2. Used approach:

The approach used is like the previous one, the difference is that the electric vehicle is converted into a group of vehicles of the same type, this allow us to manage with traffic of several vehicles. All routes defined by N distributes the vehicle groups into the grid. The shortest route is not provided for all vehicles, but each vehicle can arrive at its destination using one of the route defined by N.

4.3. Results:

The results are good from a macroscopic point of view, but as soon as the number of sub streams increases, the calculations become unmanageable.

4.4. Advantages, disadvantages and errors:

4.4.1. Advantages:

- Very effective from a macroscopic point of view
- Distributes vehicles to avoid traffic jams when charging

4.4.2. Disadvantages:

- The calculation time is too important for large grids.
- The route is not necessarily the most efficient.
- The vehicles are supposed to start in the same node and arrive at the same node (unrealistic).

5. Conclusion:

The algorithm proposed here for a single vehicle is simple and efficient, it takes many parameters useful to our project, such as travel time and recharge time as well as energy management. In addition, the best route in terms of time and energy is guaranty. The traffic management proposed here doesn't work for large-scale use. One of the solutions mentioned in [1], allows us to change the parameters of travel time related to the traffic, and by updating the journey time data from i to j, the multi-vehicle management can be assured. This solution seems more suitable for our project.

Nevertheless, this article gives me some great idea that I can exchange with the team to find an optimal technical solution relating to our project.

6. References:

[1] T. Wang, C. Cassandras, and S. Pourazarm, “Energy-aware vehicle routing in networks with charging stations” in To appear in Proc. of 2014 IFAC World Congress-arXiv:1401.6478.

[2] S. Pourazarm and C. Cassandras, “Optimal routing of energy-aware vehicle in networks with inhomogeneous charging nodes” in Proc. of 22nd IEEE Mediterranean Conference on Control and Automation, June 2014, pp. 674–679.

[3] Sepideh Pourazarm, Christos G. Cassandras, Andreas Malikopoulos, “Optimal Routing of Electric Vehicles in Networks with