A fast electric vehicle planner using clustering

A new speedup technique to find electric vehicle shortest paths

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Outline

Advantages of EV over conventional vehicles

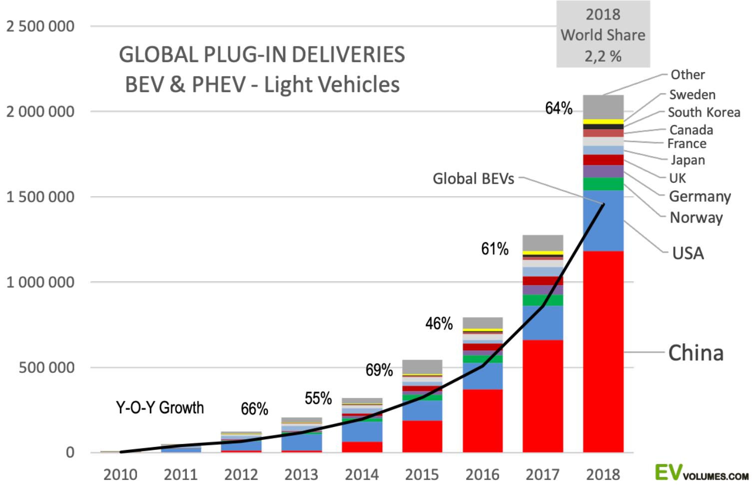
Less pollution

Less noisy

Cheaper in the long run

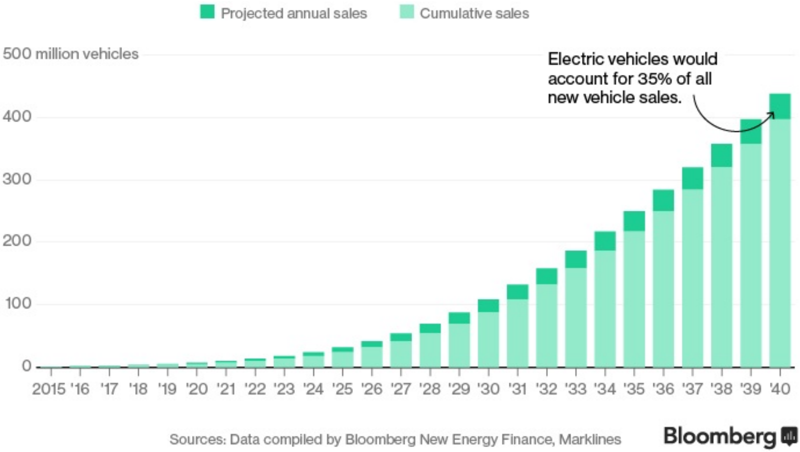
Less maintenance

Global EV market 2010–2018[1]



[1] http://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/

EV sales forecast[2]



[2] Bloomberg, February 25th, 2016, https://www.bloomberg.com/features/2016-ev-oil-crisis/

Comparison between a conventional vehicle and an EV

	Honda Civic	Nissan Leaf
Price	20 000 $	36 000 $[3]
Range	750 km	242 km
Refueling/Charging time	3 min	30 min
Gas/Charging stations[4]	2924	115

[3] Excluding governmental subsidies

[4] In Québec in 2018

Research problem

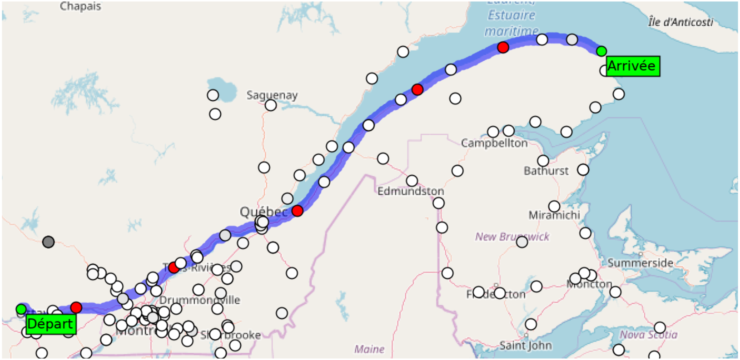
- The number of EV is increasing;
- The number of charging stations is increasing;
- Many paths need recharges to be feasible.

Objective

The objective is to have an EV planner that:

1. considers intermediate recharges at charging stations;
2. fastly computes an optimal path.

Example of an optimal plan



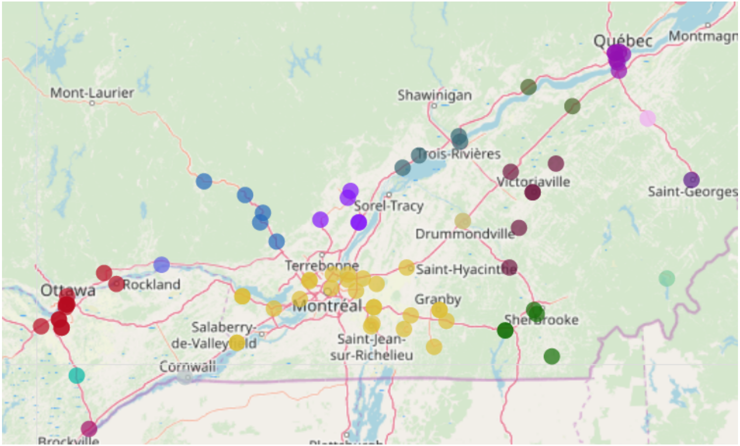
Existing techniques

- Use of the *Energy-A** algorithm for EV travel. Considers the recharge of the battery by regenerative braking, but does not consider charging stations[5].
- EV planning considering charging stations[6].

[5] Sachenbacher, M., M. Leucker, A. Artmeier and J. Haselmayr (2011). Efficient Energy-Optimal Routing for Electric Vehicles. In Proceedings of the AAAI, pp. 1402–1407. AAAI Press.

[6] Baouche, F., R. Billot, R. Trigui and N. E. El Faouzi (2014). Efficient allocation of electric vehicles charging stations. IEEE-ITSM 6(3), 33–43.

Idea: Grouping nearby stations into clusters



Formalism

Road map

The map is represented by an oriented valued graph (V, E, τ) and by a set S where:

- V is the set of locations considered on the map (nodes);
- E is the set of road segments (edges);
- $\lambda\colon E \to \mathbb{R}^+$ gives the length of the edges;
- S is the set of charging stations (we assume that $S \subseteq V$).

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EV planning

An EV planning problem is defined by the tuple $(M, \rho, \alpha, \omega)$ where:

- M is the road map;
- $\rho \in \mathbb{R}^+$ is the EV range (in km);
- $\alpha, \omega \in V$ are the departure and arrival nodes.

Base algorithm

Algorithm

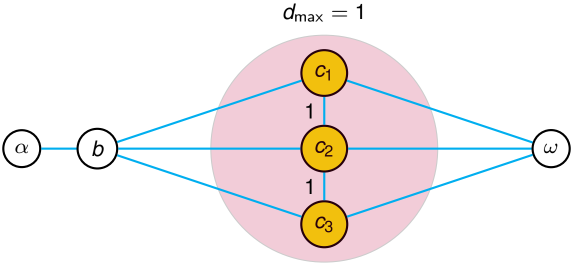
To find the most time-efficient EV plan from α to ω:

- A matrix of the distances between charging stations is precomputed;
- The distance between every stations to α, and between ω to every stations are computed (Dijkstra's algorithm performed twice);
- A complete graph (V', E') is constructed, where $V' = S \cup \{\alpha, \omega\}$.
- Edges longer than ρ are removed from the graph;
- A* algorithm is executed from α to ω on the new graph.

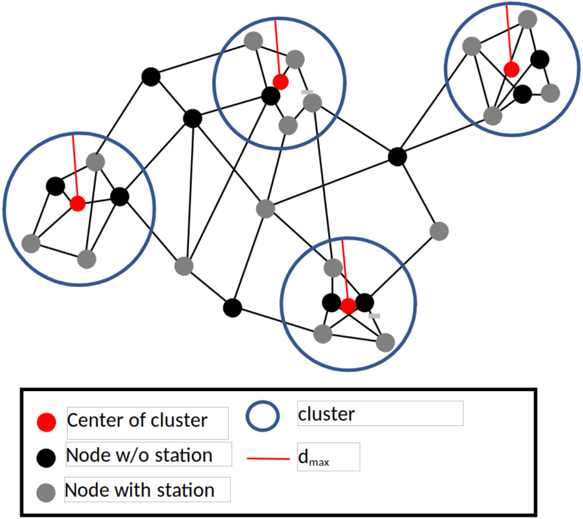
The asymptotic time complexity is $\mathcal{O}(|V| \log |V| + |E|)$.

The idea

- Regroup close stations into a single node;
- Consider a parameter $d_{\max} \in \mathbb{R}$ representing the **radius** of the generated clusters.



Example of the resulting graph



Clustering charging stations

Algorithm Clustering charging stations on the map

Find the two closest charging stations $s_1, s_2 \in S$
while distance$(s_1, s_2) \leq d_{\max}$ **do**
    Find the node m that is midway between s_1 and s_2
    Find $C = \{s \in S | dist(s, m) \leq d_{\max}\}$ $\triangleright$ $s_1, s_2 \in C$
    $S \leftarrow (S \setminus C) \cup \{m\}$
    Find the two closest charging stations $s_1, s_2 \in S$
end while

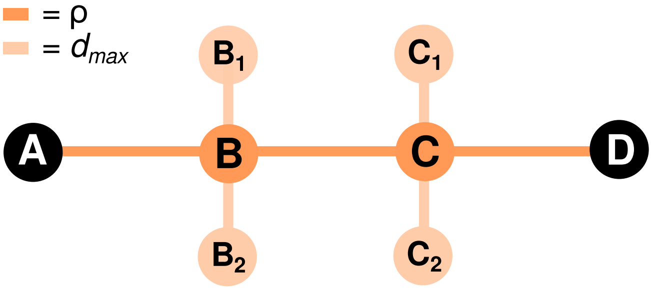
Time complexity: $\mathcal{O}(K(|S|^2 + |V|))$ (where K is the number of generated clusters)

Clustering charging stations — A problem

Adjusting the considered range

For the path returned by the planner to be feasible, the considered range must be:

- $R' = R - d_{\max}$ for the first and last clusters;
- $R' = R - 2d_{\max}$ between clusters.



Complete planner

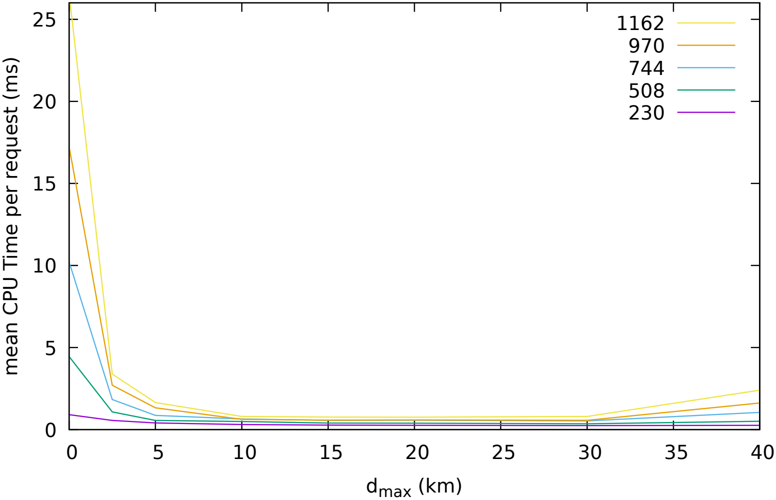
Algorithm EV Path-Planner including charging stations clustering

Generate the charging stations clustering ▷ using Algorithm 1
Compute the matrix D of pairwise distance between clusters' center
Construct the complete s-graph (S, E_S)
for each request (ρ, α, ω) **do**
    Execute Dijkstra from α on the original graph
    Execute Dijkstra from ω on the transposed graph
    Add α and ω to the s-graph including edges of length $\leq \rho$
    Execute A* on the s-graph from α to ω
    if the returned path is not feasible **then** ▷ Amortized strategy
        Execute A* on the s-graph (without clusters) from α to ω
    end if
    Find the complete path from the path in the s-graph
end for

Testing methodology

- The real map data comes from the OpenStreetMap project.
- The territory used is the Quebec province, Canada:
  - 2 580 388 nodes
  - 5 225 348 edges
  - 1162 charging stations
- 1000 requests:
  - EV range between 100 and 550 km
  - Travel distance between 200 and 1500 km

Results 1/2: Graph of the CPU time vs the d_{max} parameter



Results 2/2: Table showing the impact of clustering

Parameters		Clusters		Base version		Amortized version	
Stations #	d_{max} km	Clusters #	JDIR %	FR %	CT ms	FR %	CT ms
1162	0.0	1162	0.0	0.0	26.563	0	26.563
1162	2.5	487	0.0	0.0	3.385	0	3.385
1162	5.0	342	0.2	0.4	1.541	0	1.647
1162	10.0	236	0.2	0.8	0.588	0	0.801
1162	15.0	188	0.6	0.9	0.523	0	0.762
1162	20.0	150	1.0	1.4	0.382	0	0.754
1162	30.0	111	2.3	2.0	0.265	0	0.796
1162	40.0	87	2.8	8.2	0.226	0	2.404

JDIR: Journey duration increase rate; **FR**: Failure rate; **CT**: Computation time

Conclusion

- Finding the optimal solution for EV Path-Planning has a high computational cost;
- We presented a planner that uses graph clustering as a speedup technique;
- Our technique decreased by a factor of 35 the mean time of computation.

Questions ?

Acknowledgements

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