Empty Vehicle Repositioning for Autonomous Mobility-on-Demand systems via Coverage Control

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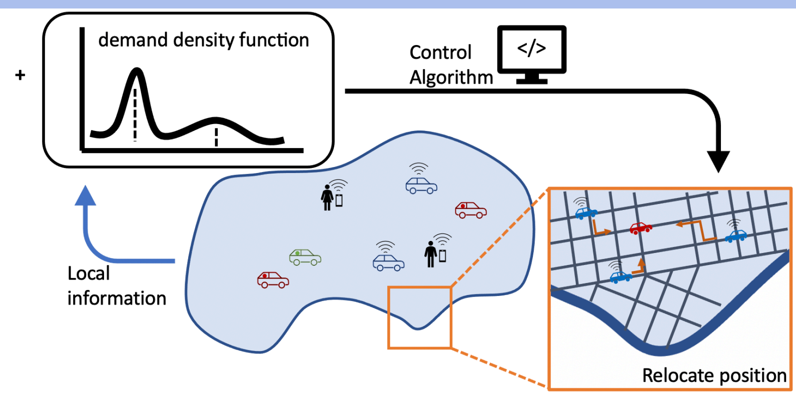
1 Introduction

Imbalance in the spatial distribution of vehicles:

- Asymmetric origin and destination distributions of trips
- Non-uniform demand for rides in different districts



Goal: empty vehicle repositioning

- Relocating idle vehicles to the high-demand regions

Coverage Control problem:

Every vehicle is responsible for covering a certain area

$$H(X,W)=\sum_{i=1}^{n} H(x_i,W_i)=\sum_{i=1}^{n}\int_{q\in W_i} -\|x_i-q\|^2\varphi(q)dq$$

where $\varphi(q)$ is the demand density function.

Proposition: The local maximum of H can be obtained when all x_i are located at centroids (centers of mass, C_{W_i}) of their respective Voronoi cells (W_i), i.e., *Centroidal Voronoi Configuration (CVC).*

Control Law Formulation:

$$\dot{x}_i = u_i,$$

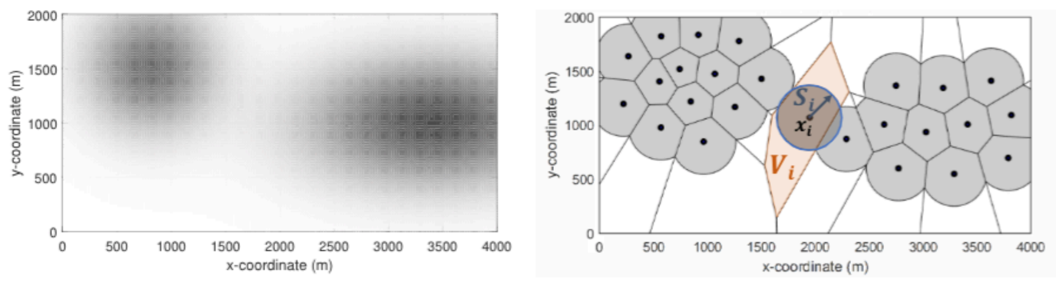
Let $\boldsymbol{u_i} = -\boldsymbol{k_p}(\boldsymbol{x_i}-\boldsymbol{C_{W_i}}),\ k_p > 0$,

which steers the agent team to converge to CVC and guarantees the monotonic increasing of H.

2 Methodology I: Coverage Control for Vehicle Repositioning **(CVR)**

Voronoi partition:

$$V_i\ (x_i) = \{q\in\Omega: \|x_i-q\| \le \|x_j-q\|, j\ne i\}$$



(a) Demand density function (b) Final configuration

x_i: position of idle AVs,
r: coverage radius,
S_i: covered area,
V_i: Voronoi cell,
$W_i = S_i \cap V_i$.

3 Methodology II: Idle fleet sizing problem

Motivation:

When Supply > Demand, empty kilometers traveled caused by repositioning result in energy consumption.

A possible solution:

Select a subset of idle vehicles not to be relocated.

Two questions:

1) How many AVs should be relocated for different demand levels?

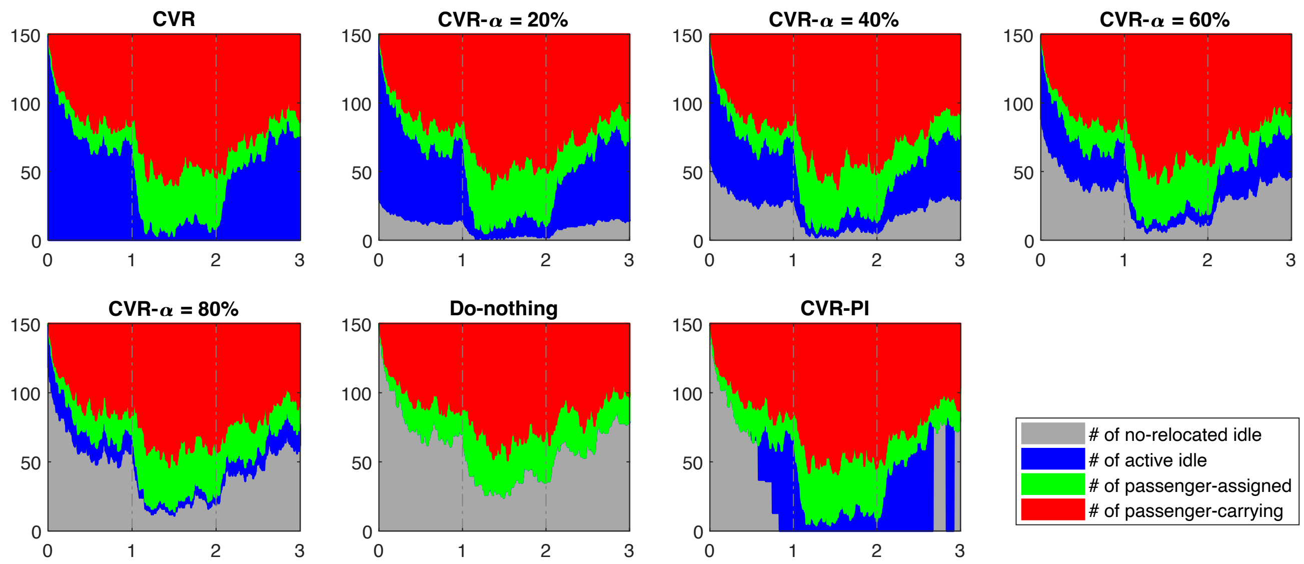
- **CVR-α** : $\lfloor n_{idle}\times\alpha\rfloor$ are selected as 'active idle AVs'. where $\alpha = 0\%, 20\%, 40\%, 60\%, 80\%, 100\%.$
- **CVR-PI**: a proportional–integral controller. The fleet size is determined on n_{idle} and the average waiting time in last 5 min.

2) Which ones should be chosen for not be relocated?

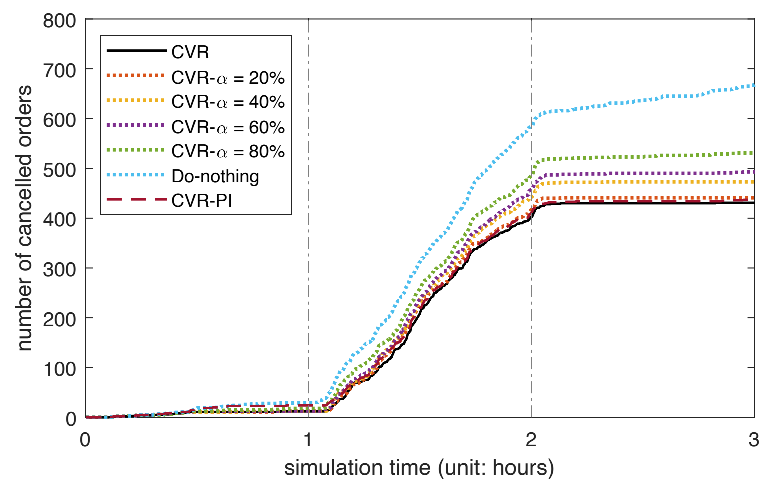
Considering the coverage objective, AVs with smallest value of $J(W_i,x_i)/J(V_i,x_i)$ will be selected as 'no-relocated' as they are around the high demand area, where

$$J(W_i,x_i) = \int_{q\in W_i} \|x_i - q\|^2\phi(q)dq.$$

$$J(V_i,x_i) = \int_{q\in V_i} \|x_i - q\|^2\phi(q)dq.$$



(a) No. of vehicles in different states



(b) No. of accumulated canceled orders

4 Conclusion

Our proposed methods dynamically rebalance spatial distribution of vehicles to **serve more trips with less waiting time.**

By selecting a subset of idle AVs not be relocated, we can serve almost the same number of requests while **reducing 51.8% empty travelling kilometers** with CVR-PI.

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