Power Distribution Scheduling for Electric Vehicles in Wireless Power Transfer Systems

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How does the ANTIQUE way of charging serve Electric Vehicles (EVs)?

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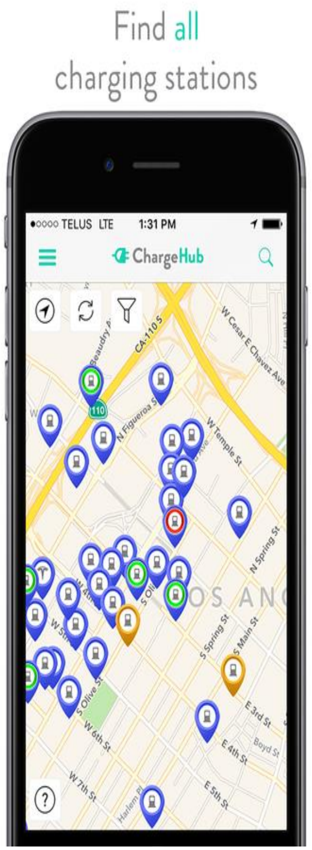

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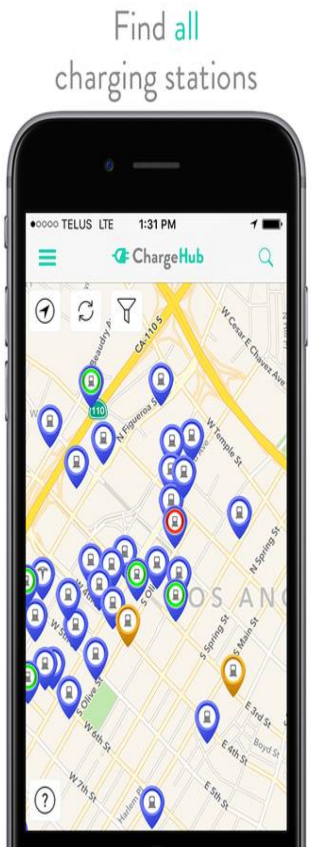

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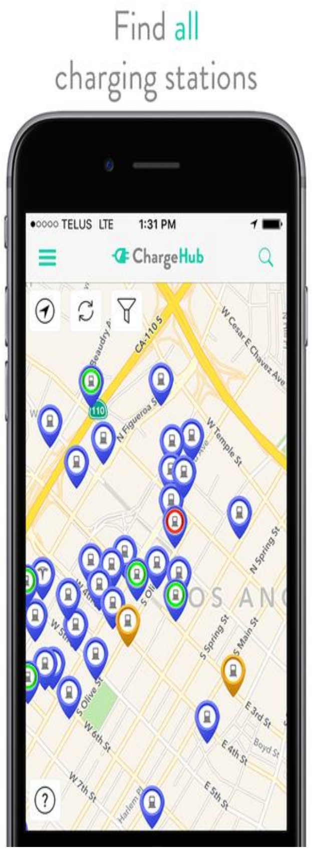

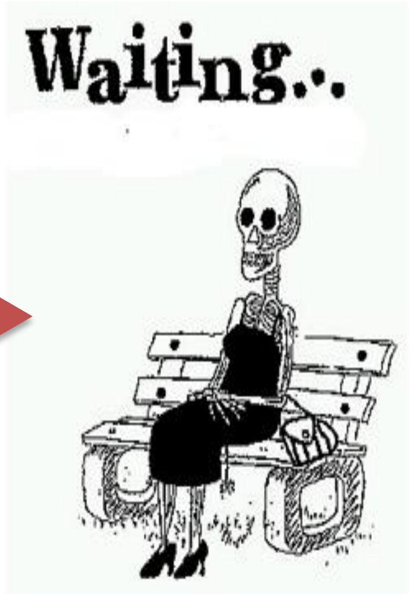

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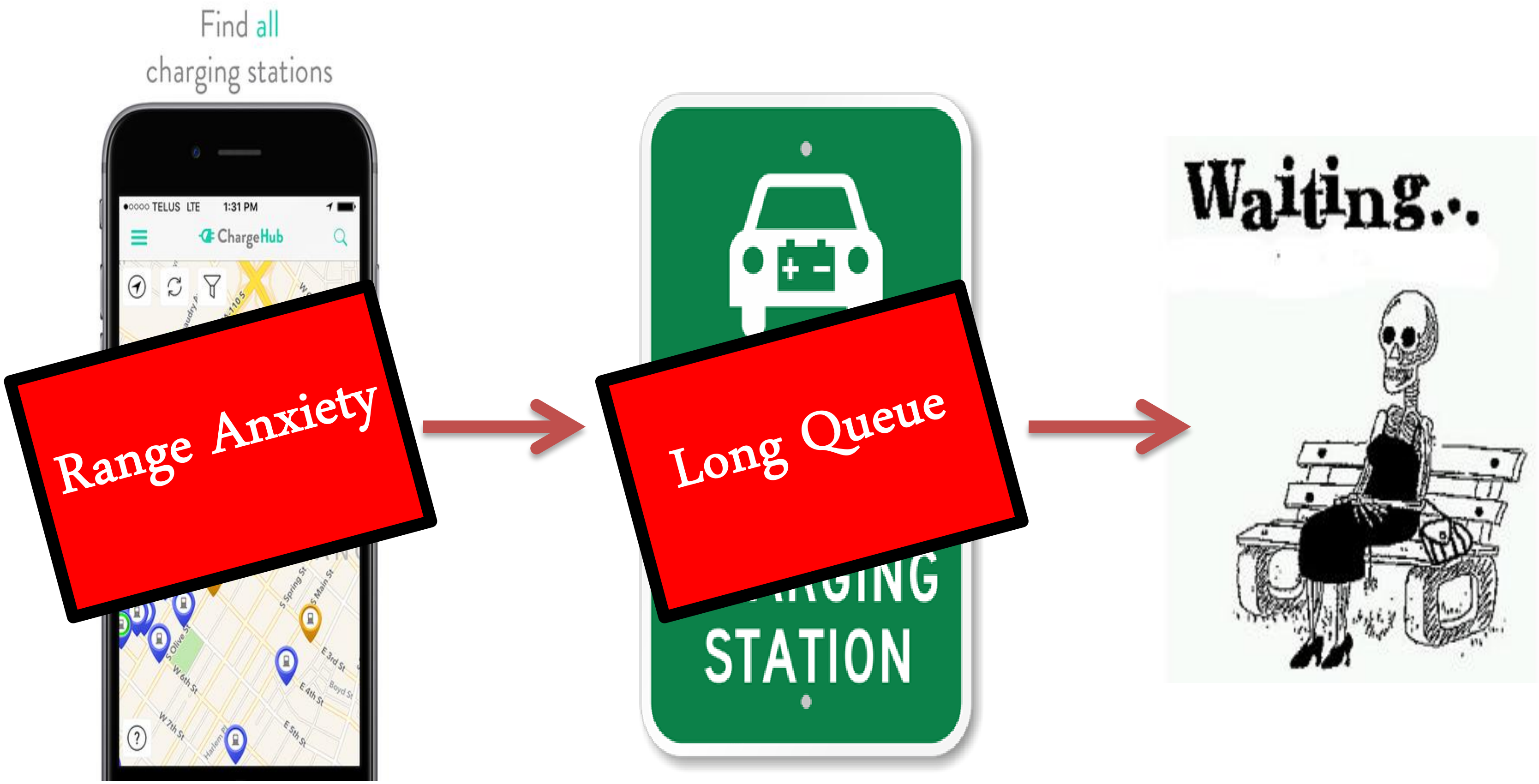

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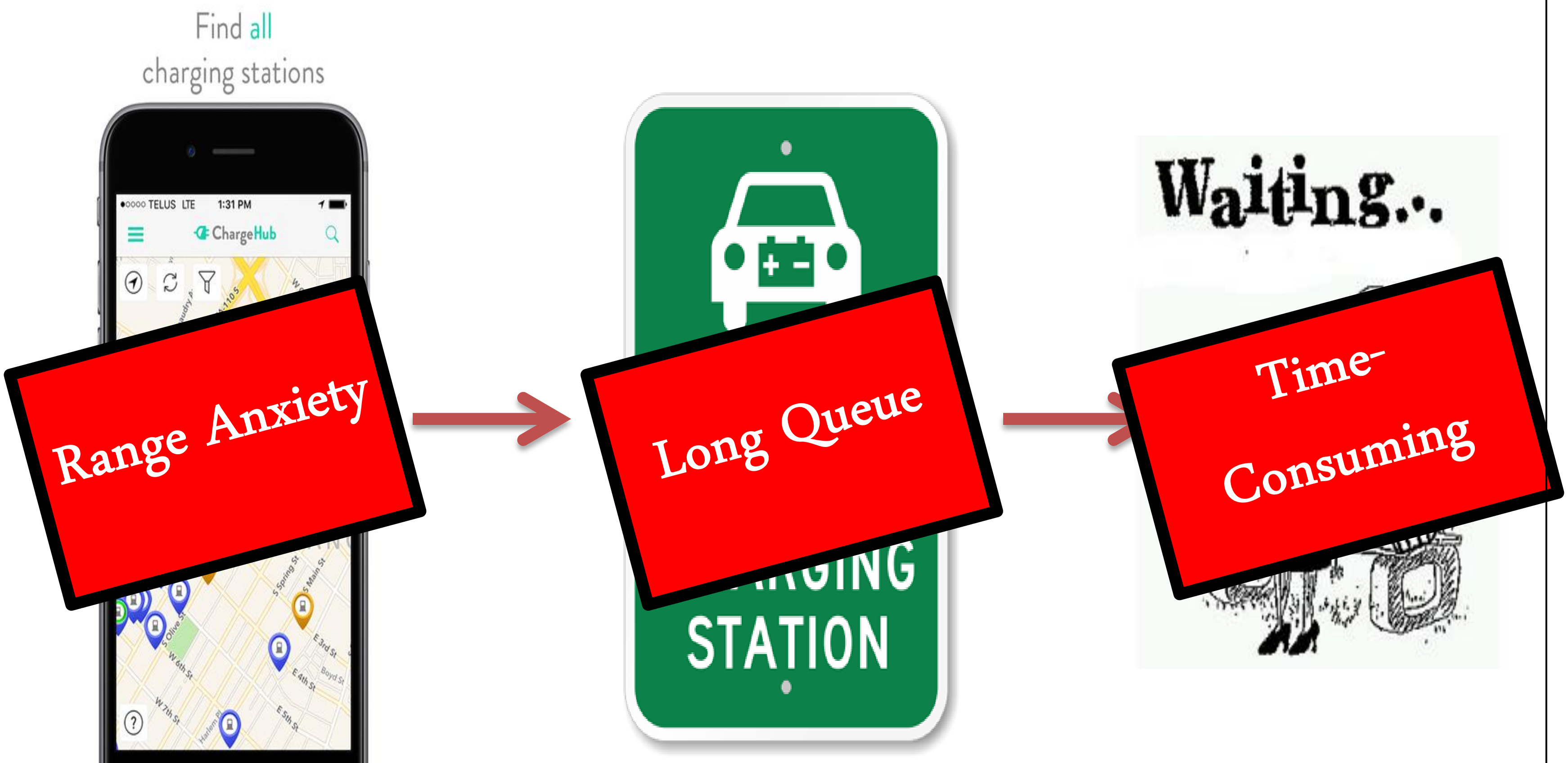


How does the ANTIQUE way of charging serve EVs?

Range Anxiety

Long Queue

Time-Consuming

Fail to maintain State-of-Charge (SoC)

Charge vehicles in motion

Charge vehicles in motion

Long Queue

✓

Charge vehicles in motion

Long Queue ✓

Time-Consuming ✓

Charge vehicles in motion

Long Queue ✓

Time-Consuming ✓

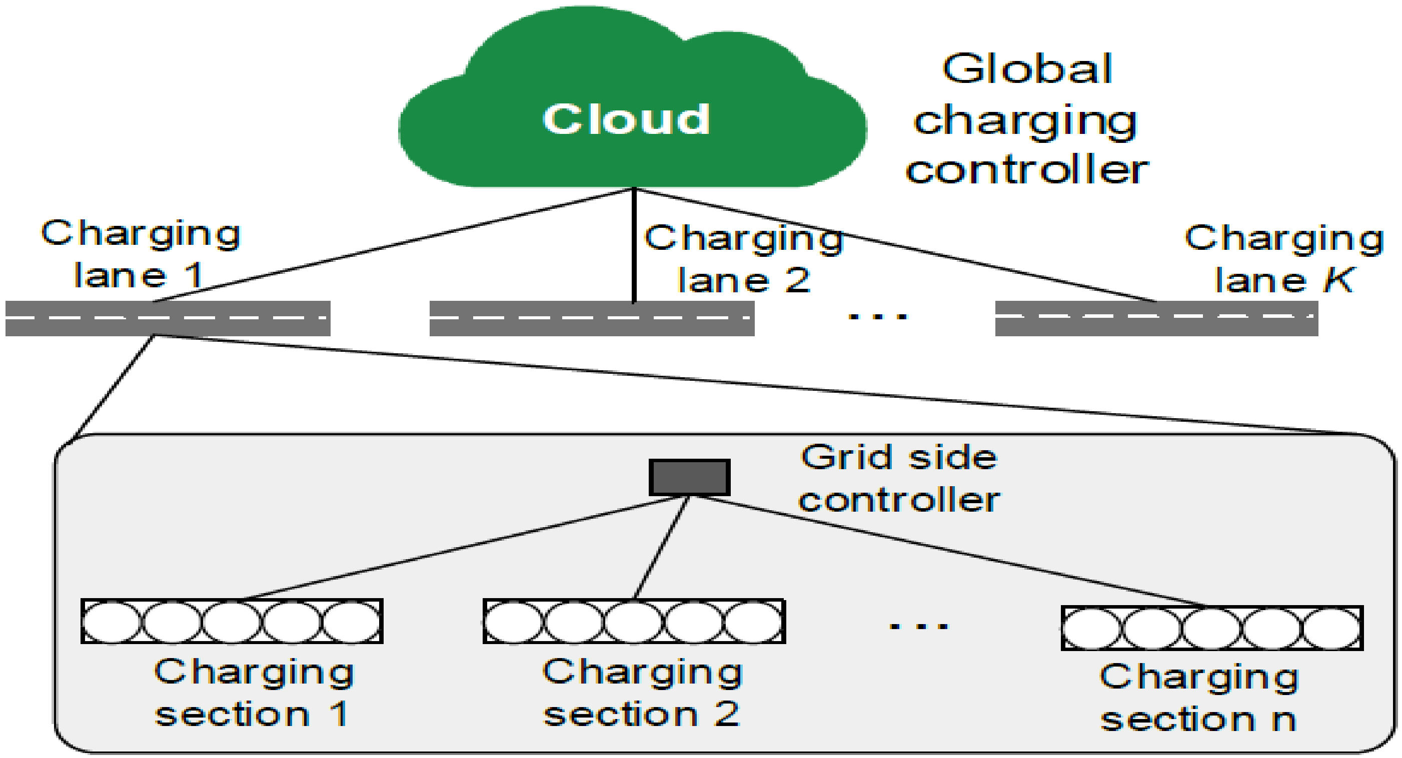
Range Anxiety ✓

Charge vehicles in motion

- Long Queue ✓
- Time-Consuming ✓
- Range Anxiety ✓
- Maintain SoC ✗

Background & Motivation

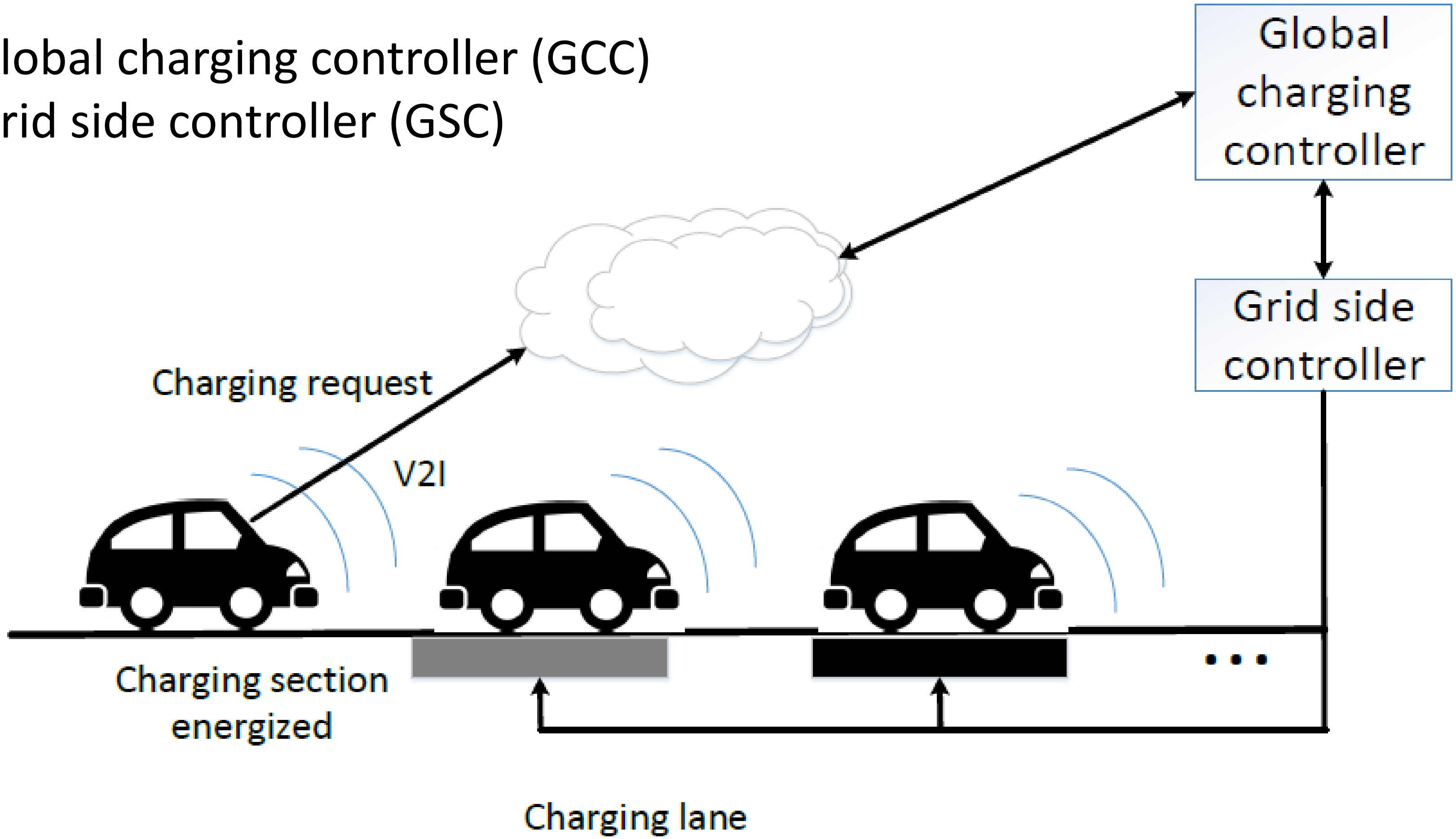
The wireless power transfer (WPT) system architecture



Introduction

The wireless power transfer (WPT) system architecture

Global charging controller (GCC)
Grid side controller (GSC)

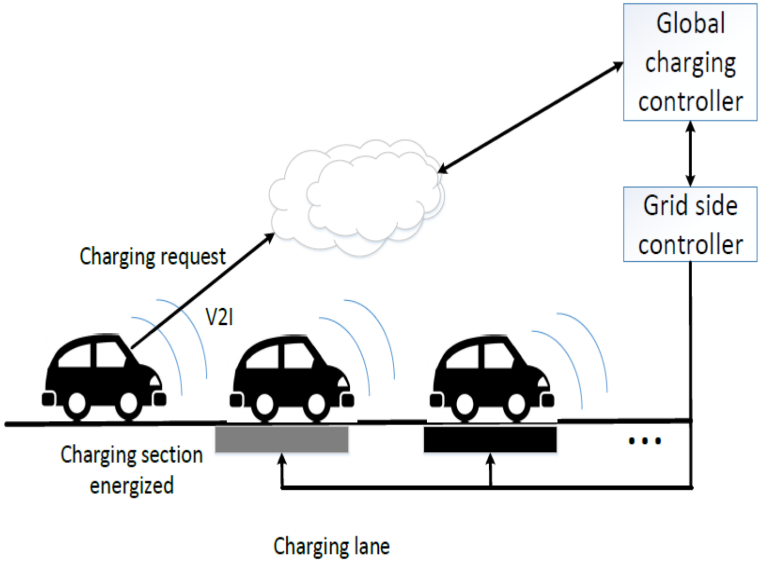


Introduction

The scenario we consider

1. We consider a WPT system in a highway scenario where vehicles follow a similar velocity.

2. When there are multiple vehicles on a charging lane simultaneously, the charging infrastructure needs to meet the needs of all the vehicles at the same time.



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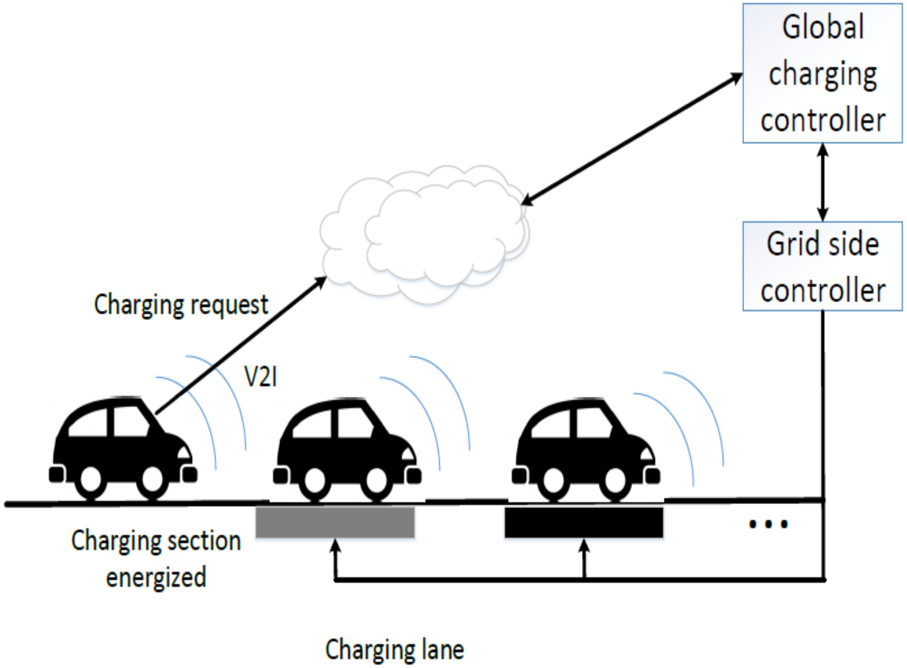
Introduction

Challenge



When the infrastructure cannot fulfill the demands from all EVs on a charging lane, how to allocate the limited power to the EVs so that they have sufficient power to arrive at the next charging lane or their destinations?

Introduction

Challenge

There has been no effort devoted to handling this challenge

Introduction
Related work

Study on the WPT systems and EV techniques

1. Analyze the existing technologies in the WPT systems
   - [Li, JESTPE 2015]
2. Examine the technical aspects and charging topology of in-motion wireless power charging of EVs
   - [Onar, APEC 2011]

Implementation of the WPT systems for EVs

1. Design of optimized core structure and electric components
   - [Shin, Trans. IE 2014]
2. General design requirements and analysis of WPT systems
   - [Yilmaz, ITEC 2012]
3. Dynamic models to identify the maximum pickup
   - [Lee, Trans. PE 2015]

Introduction

Three problems to be formulated

i. SOC-B: balancing the state of charge (SOC) of the EVs
ii. Power-B: balancing the amount of stored power of the EVs
iii. Power-M: minimizing the total power charged

Solution

1. i)-ii) are convex: use the subgradient method to solve the problems.
2. iii) is a linear programming problem: can be solved by the simplex method. We also design a greedy algorithm to solve the problem.

Power Distribution Scheduling

EV Traffic Model we consider

1. A discrete time system where time = *1, 2, …*

2. n charging sections c_1, c_2, …, c_n in a charging lane

3. m heterogeneous EVs {1, 2, …, m} based on the EVs' current stored energy in the batteries

4. The maximum capacity of the GSC is A

5. The maximum power that each charging section j can provide is a_j

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Power Distribution Scheduling

The SOC-B problem: balancing the SOCs of the EVs

Goal: to distribute the power to each charging section *j* in each time slot *t*, $x_j(t)$, to guarantee all the EVs can finish their trips and the SOCs of all the EVs are balanced when they leave the charging lane.

Power Distribution Scheduling

The SOC-B problem: balancing the SOCs of the EVs

Problem formulation

Objective function: minimize the variance of SOCs

Constraints:

1) the sum of the allocated power of all the charging sections ≤ the maximum power provided by the GSC;
2) the power allocated to each charging section *j* cannot exceed the maximum power provided by charging section *j*;
3) the SOC of each EV should be enough to move to the next charging section or the destination;

The problem is **convex**.

Solution: The subgradient method

Power Distribution Scheduling

The Power-B problem: Balancing the amount of the stored power of the EVs

Objective: to balance the absolute amount of stored power of all the Evs when the EVs leave the charging lane.

Problem formulation

Objective function: minimize the variance of energy stored

Constraints: has the same constraints as the problem to balance the SOCs of EVs.

The problem is **convex**.
Solution: The subgradient method

Power Distribution Scheduling

The Power-M problem: minimizing the total power charged

Objective: to minimize the total power charged by all the charging sections in the charging lane.

Problem formulation

Objective function: minimize the total power charged by all the charging sections in the charging lane.

Constraints: has the same constraints as the previous two problems.

The problem is a linear programming (LP) problem, and hence can be solved directly using the **simplex method**.

Power Distribution Scheduling

The Power-M problem: minimizing the total power charged

Greedy algorithm

for each charging section j at time slot t do

if charging section j is the last charging section

then charge each EV i with power

$$x_j(t) = \max\{p'_{\text{req},i} + P^j_{\text{trac},i} - z_i(t), 0\}$$

// Provide enough power to reach the destination

else charge each EV i with power

$$x_j(t) = \max\{p'_{\text{th},i} + P^j_{\text{trac},i} - z_i(t), 0\}$$

// Provide enough power to reach the next charging section

Theorem: The greedy algorithm can achieve the optimal solution.

Experiment

Simulation settings

1. Both MatLab and Simulation for Urban MObility (SUMO);
2. The number of EVs is varied from 10 to 50;
3. The number of charging sections is set to 10;
4. Each EV's SOC is set randomly in [0.4, 0.8] when entering a charging lane;
5. 3 types of EVs were considered (Nissan Leaf, Toyota Prius, and Chevy Volt);
6. The power capacity of the GSC is randomly chosen from [40-100]Kw;
7. The simulation takes 20 times;

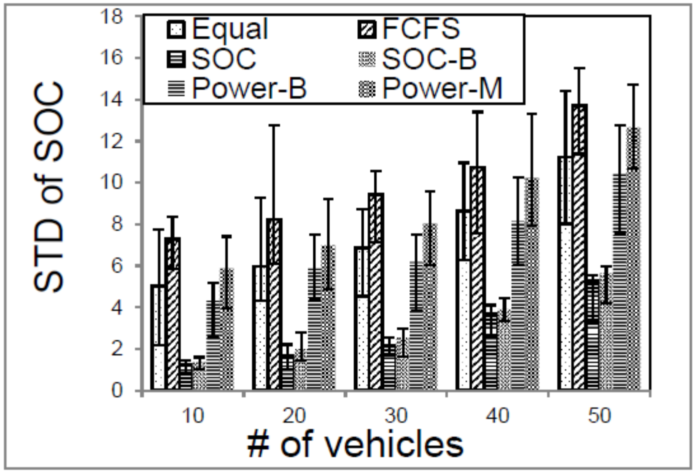
Compared methods

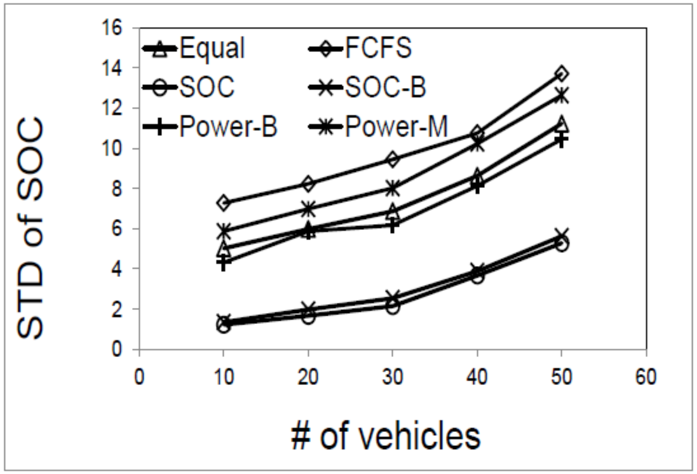
1. Equal sharing method (Equal).
2. First come first serve method (FCFS).
3. State of charge method (SOC).

Experiment

Simulation results

Balancing the SOCs of the EVs





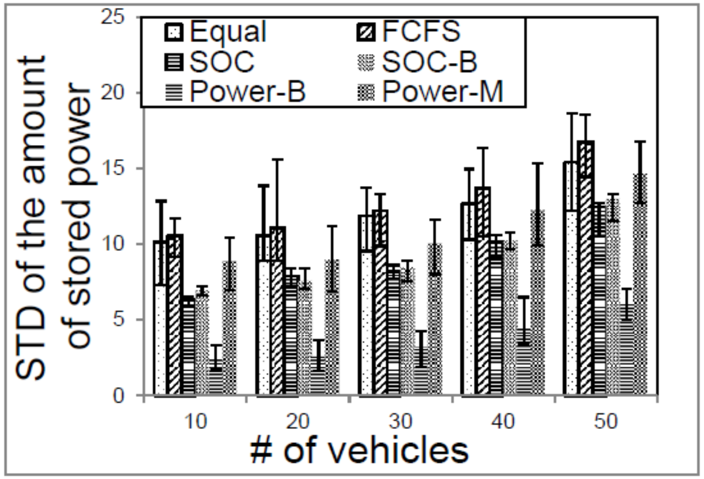
Observation: the standard deviation of SOC follow

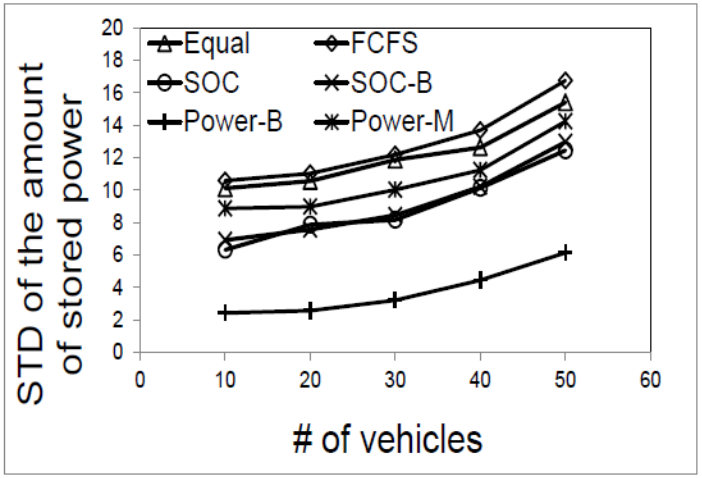
SOC ≈ SOC-B < Power-B < Equal < Power-M < FCFS

Experiment

Simulation results

Balancing the Amount of the Stored Power of the EVs





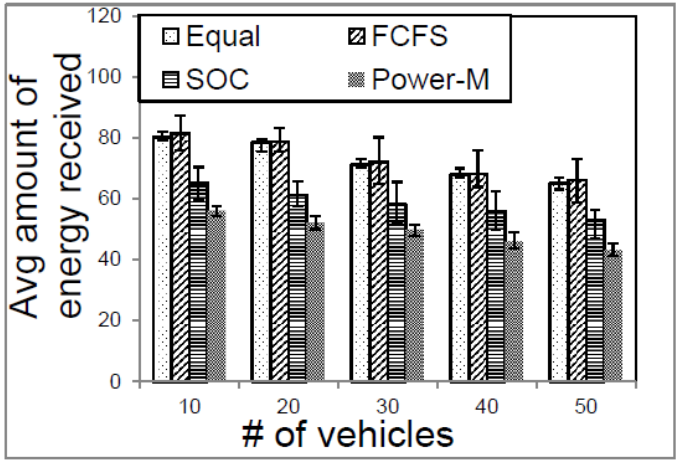
Observation: the standard deviation of EVs' stored power follows

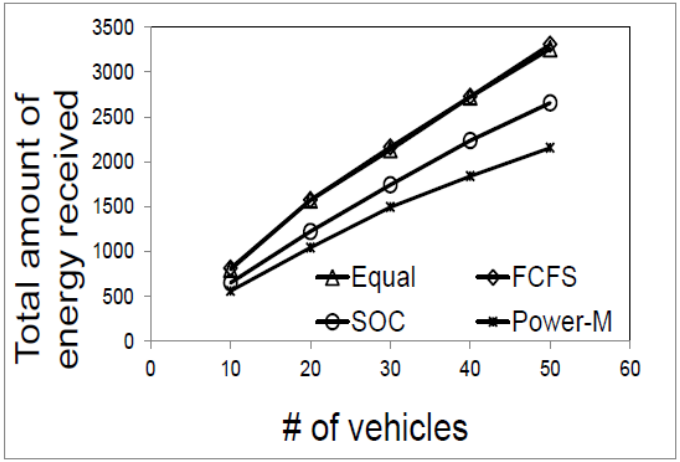
Power-B < SOC ≈ SOC-B < Power-M < Equal < FCFS

Experiment

Simulation results

Minimizing the Amount of Total Power Charged





Observation: Fuel consumption follows:

Power-M < SOC < Equal ≈ FCFS

Conclusions

1. We studied the power distribution scheduling problems, SOC-B, Power-B, and Power-M, to enable the EVs to receive enough power to reach their destinations and meanwhile achieve a goal.

2. We showed SOC-B and Power-B are convex, which can be solved using the subgradient method. We also designed a greedy algorithm to achieve the optimal solution for Power-M.

3. We conducted extensive experiments to confirm that our solutions are effective in achieving their goals.

Future work

We will consider different velocities and velocity variation of vehicles in general roads

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QUESTIONS ?

Thank you!

Questions & Comments?

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