A User-Driven Deployment Plan of Dynamic Charging Systems for EVs

Duc Minh Nguyen

I. Introduction

When we design a sustainable future, most of us will agree upon the crucial role of green transportation. Electric vehicles (EVs) will revolutionize cities around the world by reducing our reliance on fossil fuels, cutting down on polluting emissions, improving public health, and creating economic growth.

To facilitate the application of EVs worldwide, it is necessary to develop charging infrastructure for EVs. Existing solutions include plug-in charging stations. However, charging stations alone may not be sufficient in metropolitan cities due to the long charging time, potentially failing to meet the charging demand during rush hours. Therefore, a promising complementary charging solution is dynamic charging, i.e., electrified roads that charge EVs completely wirelessly while driving. These charging roads can benefit several EVs at the same time while alleviating the anxiety of having to stop and charge. The technology behind dynamic charging has been thoroughly studied in several institutes around the world such as KAIST (South Korea) [1], the University of Auckland (New Zealand) [2], Oak Ridge National Laboratory (United States) [3], and its samples have also been demonstrated by Qualcomm Halo [4] and Witricity [5]. Given this prosperous future of dynamic charging technology, it is essential that we understand the efficient deployment methods and their significance at a large scale, e.g., city level. In the literature, even though efforts have been made to exploit charging facilities, such as improving EVs routing [6], modeling the impact of dynamic charging deployment is still a new research area.

In previous work [7], we presented an initial effort to modeling and analyzing dynamic charging deployment at a city level. We assumed a uniform deployment of charging roads and derived two metrics: i) the distribution of the distance to the nearest charging road, and ii) the probability of passing through at least one charging road, in a random trip, which could then be applied to several urban cities.

II. Problem Statement & Methodology

In this work, we extend our knowledge and take an important step towards an even better understanding of dynamic charging systems deployment in metropolitan cities. We begin with an observation that the trips in populous cities are not uniformly distributed. Indeed, they are directly correlated with the population density, road network density, and socioeconomic interactions within the city. Thus, we adopt a model that describes the traffic density as following a power-law distribution in terms of the distance from the city center. Not only has this model been widely used in the literature [8], but upon analyzing the 2019 New York City (NYC) taxi trip records data [9], we also find that the number of taxi pickups/drop-offs follows the same distribution, as shown in Fig. 1. Therefore, we propose that the charging roads are deployed following the distribution of traffic density, and investigate metrics such as the total trip distance traveled on charging roads, denoted as D_c, so as to provide urban planners and city policy-makers with meaningful tools to build deployment plans of dynamic wireless charging infrastructure, such as to decide how densely they need to deploy dynamic charging to ensure coverage at a certain level of confidence. For example, in Fig. 2, the distribution of D_c on a 7 kilometer-trip across the center of cities with different road densities is shown. We utilize stochastic geometry for our analysis, as it is a powerful statistical tool that enables computing the proposed metrics averaging over all random trips. To support our analysis even further, we present our findings when applying the metrics to NYC, using 6-month taxi trip records data in 2019 [9] and the street networks data from OpenStreetMap [10]. Using these datasets, we simulate the scenario that dynamic charging systems are actually deployed in NYC, as depicted in Fig. 3, where each road is equipped with charging capability at a probability that is a decreasing

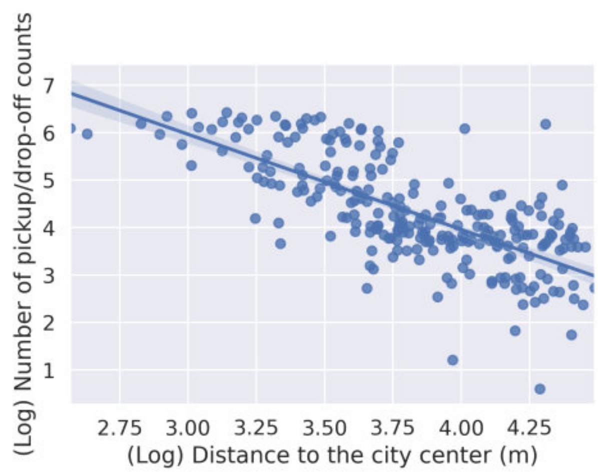


Fig. 1: Scatter plot of the taxi zones in New York city fitted with a linear regression model and 95% confidence interval

The author is with Computer, Electrical and Mathematical Science and Engineering Division, King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia (email: ducminh.nguyen@kaust.edu.sa).

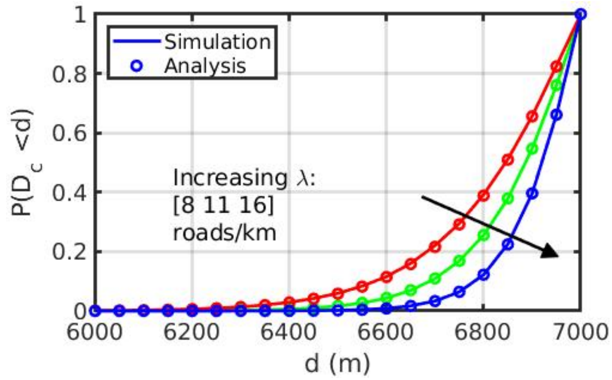
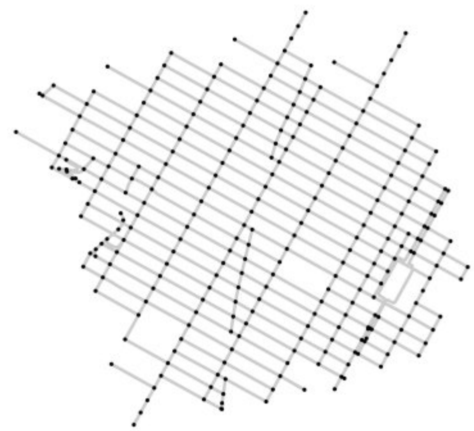
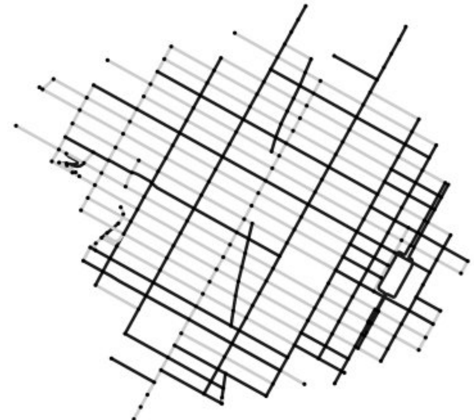


Fig. 2: The probability $\mathbb{P}(D_c < d)$ on a 7 km trip across the center of cities with different road densities, i.e., λ, when the source and destination roads are parallel and source road is not charging and destination road is charging

function of its distance from the city center. Then, we analyze the taxi trip records dataset to compute and aggregate our proposed metrics to compare with our analytical results. To the best of our knowledge, our work is one of the pioneer researches aiming at understanding the impact of dynamic charging deployment for EVs in urban cities. Thus, we believe that it contributes positively to the application of EVs and a future of sustainable transportation.



(a) Road systems without dynamic charging



(b) Road system with dynamic charging

Fig. 3: The road systems within 1.5 km from Times Square, Manhattan, NYC, before and after deploying dynamic charging

References

[1] S. Y. Choi, B. W. Gu, S. Y. Jeong, and C. T. Rim, "Advances in wireless power transfer systems for roadway-powered electric vehicles," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 3, no. 1, pp. 18–36, 2015.

[2] J. T. Boys and G. A. Covic, "The inductive power transfer story at the University of Auckland," *IEEE Circuits and Systems Magazine*, vol. 15, no. 2, pp. 6–27, 2015.

[3] O. C. Onar, J. M. Miller, S. L. Campbell, C. Coomer, C. P. White, and L. E. Seiber, "Oak Ridge national laboratory wireless power transfer development for sustainable campus initiative," in *2013 IEEE Transportation Electrification Conference and Expo (ITEC)*, June 2013, pp. 1–8.

[4] "Qualcomm demonstrates dynamic electric vehicle charging," https://www.qualcomm.com/news/releases/2017/05/18/qualcomm-demonstrates-dynamic-electric-vehicle-charging, accessed: 2021-02-04.

[5] "Witricity acquires Qualcomm Halo," https://witricity.com/witricity-acquires-qualcomm-halo, accessed: 2021-02-04.

[6] J. Eisner, S. Funke, and S. Storandt, "Optimal route planning for electric vehicles in large networks," in *Twenty-Fifth AAAI Conference on Artificial Intelligence*, 2011.

[7] D. M. Nguyen, M. A. Kishk, and M.-S. Alouini, "Modeling and analysis of dynamic charging for evs: A stochastic geometry approach," *IEEE Open Journal of Vehicular Technology*, vol. 2, pp. 17–44, 2021.

[8] R. Li, L. Dong, J. Zhang, X. Wang, W.-X. Wang, Z. Di, and H. E. Stanley, "Simple spatial scaling rules behind complex cities," *Nature Communications*, vol. 8, no. 1, pp. 1–7, 2017.

[9] N. Taxi and L. C. (TLC), "TLC trip record data," 2019, available from https://www1.nyc.gov/site/tlc/about/tlc-trip-record-data.page. Accessed: 2021-02-04.

[10] OpenStreetMap contributors, "Planet dump retrieved from https://planet.osm.org ," https://www.openstreetmap.org , 2017.