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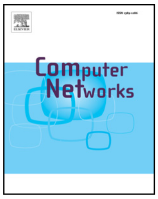

Optimal charger placement for wireless power transfer[☆]

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ABSTRACT

As a promising technology to achieve perpetual operation of battery-powered wireless sensor devices, wireless power transfer has attracted much attention recently. In wireless power transfer, the charger enables the energy to be wirelessly transmitted to the rechargeable sensor devices that are hungry for energy. Previous works mainly focus on maximizing the charging utility or minimizing the charging delay. This paper concerns two more practical issues of placing wireless chargers, the first one aims at minimizing the deployment cost of chargers while satisfying the overall requirement for charging levels, and the second one aims at maximizing the total charging levels subject to a deployment cost budget constraint. We investigate the above two optimal charger placement problems under two typical scenarios in which omni chargers and directional chargers are used, respectively. To resolve these two problems under the two charging models, we first prove their NP-hardness and then propose four approximation algorithms with proven performance guarantees. Finally, we conduct extensive simulation experiments to validate our designs, and the experimental results demonstrate that the proposed algorithms significantly outperform the baselines.

1. Introduction

The past few decades have witnessed an intensive interest in using wireless sensor networks to monitor the physical world [2]. A wireless sensor network contains lots of battery-driven wireless sensor devices, and therefore, prolonging the system lifetime is always a critical task. Recently researchers have paid much attention to extending the wireless sensor network lifetime, where battery replacement [3] and energy harvesting [4,5] are two typical approaches. In real-world applications, however, battery replacement is very costly and time-consuming, and it needs to turn off the sensor device for a short term. So battery replacement is not suitable for the large-scale deployment of wireless sensor networks [6,7]. Energy harvesting sensor devices are powered by ambient energy, such as solar and wind energy [5,8]. These environmental energy sources are not stable in nature and hard to predict precisely, and therefore, the energy harvesting approach is not beneficial to energy-hungry sensing tasks.

With the recent breakthrough in wireless power transfer technology [9,10], researchers have attempted to employ wireless chargers to provide power to wireless sensor devices. As a promising way of prolonging the sensor network lifetime, wireless charging has attracted more and more interest in a few years. In the wireless power transfer for target sensor network, one significant task is to effectively deploy wireless chargers according to some strategies such that the system performance can be optimized or improved.

Most of the existing works are designed around charging utility maximization [11–13], that is, they focus on deploying a certain number of wireless chargers to maximize the total charging power for the target sensor network area. However, we argue that such a charging utility maximization may experience excessive charging which is sometimes unnecessary. In most cases, we only need to ensure that the charging power is greater than the minimum power to maintain network operation. Besides, these works define the charging utility on real numbers to represent the total charging power of the network. In local energy scheduling, the sensor device often evaluates its charging levels as integers, instead of reals, in order to achieve efficient decision making [8,14]. There-

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(5) Effect of charging angle (φ_c): For the directional charging case, we study how the charging angle affects the performance of EnumLPD and RLMA. Fig. 9 shows the total charging levels of the two algorithms when the charging angle increases from 90° to 330° with an incremental step of 15°. It can be seen that EnumLPD outperforms RLMA at any given charging angle, the gap of total charging levels between the two algorithms is between 31% and 39% in all of the experiments.

Here we give a more detail comparison between our EnumGreedy algorithm and its baseline algorithm AA. AA is an $\frac{1}{2}(1-1/e)$-approximation algorithm with time complexity $\mathcal{O}(mn^3)$, and EnumGreedy achieves an approximation ratio of $(1-1/e)$ with time complexity $\mathcal{O}(mn^6)$, which means that EnumGreedy will achieve a better result than AA especially in the worst case, even though it costs more time. However, we can hardly see a visible difference between the two algorithms in Fig. 7, the reason is that all values in Fig. 7 is the average of 100 runs, and thus we can not see the "worst case". To describe the difference between the two algorithms EnumGreedy and AA, we show the largest gap between algorithms EnumGreedy and AA in 100 runs in Fig. 10. We can see that the difference between the two algorithms is more visible, especially in Fig. 10(a), the total charging levels achieved by EnumGreedy are about 6.5% larger than that of AA when the number of sensor devices is 320.

7. Conclusion

In this paper, we study the optimal wireless charger placement problem with respect to the deployment cost. We study the problem from two different aspects, the first is the cost-minimum charger placement problem and the second is the charging level-maximum charger placement problem. We consider the two problems under two different charging models, i.e., omni charging and directional charging. Correspondingly, we propose four problems for the two aspects under two charging models. We prove the NP-hardness of the proposed problems, and design approximation algorithms for each problem. Extensive simulation experiments validate the effectiveness of our algorithms. In the future, we will extend our study to 3D wireless power transfer.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Xingjian Ding: Conceptualization, Methodology, Writing - original draft. **Yongcai Wang:** Writing - review & editing, Formal analysis. **Guodong Sun:** Writing - review & editing, Validation. **Chuanwen Luo:** Software, Investigation. **Deying Li:** Supervision, Project administration, Writing - review & editing. **Wenping Chen:** Software. **Qian Hu:** Visualization.

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.comnet.2020.107123

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