

Demo: An Energy Synchronized Charging Protocol for Rechargeable Wireless Sensor Networks

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ABSTRACT

Different from energy harvesting which generates dynamic energy supplies, the mobile charger is able to provide stable and reliable energy supply for sensor nodes, and thus enables sustainable system operations. While previous mobile charging protocols either focus on the charger travel distance or the charging delay of sensor nodes, in this work we propose a novel Energy Synchronized Charging (ESync) protocol, which simultaneously reduces both of them. Observing the limitation of the Traveling Salesman Problem (TSP)-based solutions when nodes energy consumptions are diverse, we construct a set of nested TSP tours based on their energy consumption rates, and only nodes with low remaining energy are involved in each charging round. Furthermore, we propose the concept of energy synchronization to synchronize the charging requests sequence of nodes with their sequence on the TSP tours.

Categories and Subject Descriptors

C.2.2 [Computer-Communication Networks]: Network protocols

General Terms

Design, Testbed

Keywords

Mobile Charging, Energy Synchronization, Nested TSP Tours

1. INTRODUCTION

To address the energy constraints of sensor nodes, the concepts and implementations of adopting mobile chargers to replenish nodes energy supply in rechargeable sensor networks have attracted a lot of attentions in the re-

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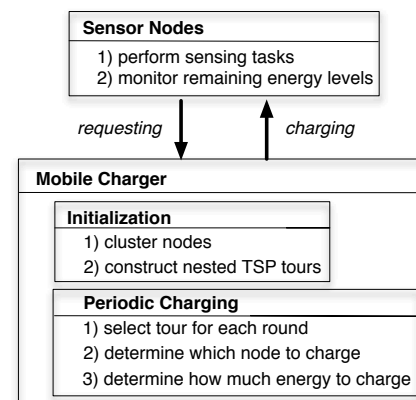


Figure 1: An overview of the proposed ESync charging protocol.

search community recently [3]. Different from traditional energy harvesting sensor networks, where the harvested energy is dynamic in both the spatial and temporal dimensions, the mobility-assisted energy replenishment provides a stable and reliable energy supply for sensor nodes and thus enables truly sustainable operations of sensor networks. Due to the limited mobility of the charger, the scheduling of charging tasks for sensor nodes in the network plays a critical role in achieving a high charging efficiency. The Traveling Salesman Problem (TSP)-based charging protocols are a family of classic solutions to the mobile charging problem, with which in general, the mobile charger periodically carries out the charging process following a pre-optimized tour [4]. As a result, the charging of nodes can be accomplished with a short charger travel distance and thus a short time duration.

However, the limitation of TSP-based solutions is that when nodes energy consumptions are diverse, it may lead to the unnecessary visits of energy-sufficient nodes. This not only increases the charger travel distance when performing the charging tasks of sensor nodes, but also prolongs the waiting time before the energy-hungry nodes can be charged. To address this issue, we investigate the on-demand mobile charging scenario where nodes are charged only when necessary in our recent work [1]. Specifically, sensor nodes send

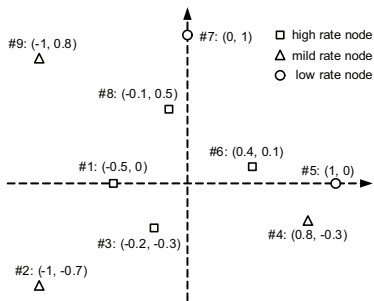


Figure 2: Nodes deployments.



Figure 3: Overview of the experiment settings.

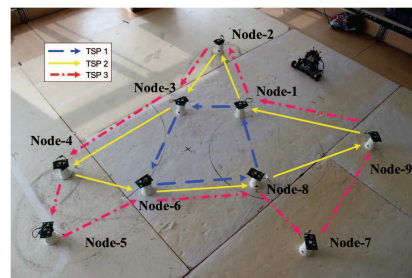


Figure 4: Nodes clustering and tour construction.

out charging requests to the mobile charger when their energy levels are low, and the charger replenishes their energy supply according to those received requests. We aim to design a novel mobile charging protocol that is able to leverage on the advantages of existing designs while minimizing the impact of their limitations.

2. ESYNC DESIGN

The most significant feature in our design in [1] is synchronizing the energy supply of sensor nodes based on a set of nested TSP tours. Upon achieving such energy synchronization, we can realize the ideal mobile charging paradigm that *the charger can simply travel according to the TSP tours to reduce its travel distance, and whenever a sensor node runs short of energy, the charger will happen to be traveling towards it.*

At the macro-level of the mobile charging process, to leverage the advantage of the TSP-based solutions while minimizing the impact of their limitations when node energy consumptions are highly diverse, we construct a set of nested TSP tours based on the energy consumption rates of sensor nodes. Then for each round of the charging process, a novel tour selection algorithm is designed to only involve the energy-hungry nodes into the charging schedule during that round. At the micro-level focusing on the charging schedule during individual rounds, observing that nodes charging requests sequence may significantly degrade the charging performance, we propose the concept of energy synchronization among nodes to proactively match nodes charging requests sequence to the selected TSP tour in each charging round, which is achieved by carefully selecting the node to be charged next and controlling the amount of energy charged to individual nodes. As a result, both the charger travel distance and the charging delay of sensor nodes are reduced. Figure 1 presents an illustrative view of our design from the aspects of both the charger and sensor nodes.

3. EVALUATION

In our experiment, we randomly deploy 9 sensor nodes in an open field of $3 \times 3 m^2$, and a LEGO Ministorms NXT robot with an average travel speed of $0.1 m$ per second is adopted as the mobile charger. The locations of these nodes are shown in Fig. 2. Figure 3 shows our experiment settings. These 9 sensor nodes are organized into 3 clusters based on their energy consumption rates (i.e., $\{1, 3, 6, 8\}$, $\{2, 4, 9\}$, and $\{5, 7\}$), and 3 nested TSP tours are constructed accordingly, as highlighted in Fig. 4. Sensor nodes send out charging requests to the charger when their energy supply is depleted, and the charger performs these charging tasks according to ESync.

We evaluate the performance of ESync and compare it with two classic baselines: TSP and Nearest-Job-Next [2]. For TSP, the charger travels and charges nodes following the TSP tour, and its travel is independent of whether the charging request from the node has been received. For Nearest-Job-Next, the charger always selects the geographically nearest requesting node as the next node to charge. Both the two baselines adopt the full charging of nodes throughout the charging process.

A mobile charging process of 15 minutes is performed in each experiment, and the requests charging latency and charger travel distance during these charging processes are recorded for evaluation. Our experiment results show that the charger travel distance resultant by ESync is about 30% and 20% shorter than those obtained by TSP and Nearest-Job-Next, and the request charging latency is reduced by about 50%.

4. DEMONSTRATION DESCRIPTION

In this demo, we will demonstrate and explain the detailed experiment settings and the ESync-based mobile charging process. The demo will also highlight the core idea of our design, i.e., the *energy synchronization*, by visualizing the evaluation process of the remaining energy level of sensor nodes and how it is synchronized with the travel of the charger. A video about this demo can be found at <http://youtu.be/2em2cJZDdMU>.

5. ACKNOWLEDGMENTS

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