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A recharging distance analysis for wireless sensor networks☆

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ABSTRACT

Efficient energy consumption is a challenging problem in wireless sensor networks especially close to the sink node, known as the energy hole problem. Various policies for recharging battery exhausted nodes have been proposed using special recharging vehicles. The focus in this paper is on a simple *recharging policy* that permits a recharging vehicle, stationed at the sink node, to move around and replenish any node's exhausted battery when a certain *recharging threshold* is violated. The minimization of the *recharging distance* covered by the recharging vehicle is shown to be a facility location problem, and particularly a 1-median one. Simulation results investigate various aspects of the recharging policy – including an enahnced version – related to the recharging threshold and the level of the energy left in the network nodes' batteries. In addition, it is shown that when the sink's positioning is set to the solution of the particular facility location problem, then the recharging distance is minimized irrespectively of the recharging threshold.

1. Introduction

Recharging wireless sensor nodes has recently attracted significant research attention (see e.g., [1–3]) as an alternative way to tackle the difficult problem of prolonging network's lifetime. This is made possible due to recent technological advances in wireless battering charging, e.g., through wireless energy transfer [4,5]. Since their early appearance almost two decades ago [6,7], wireless sensor networks have seen an exceptional growth and recent technological advancements have permitted the creation of small and low cost devices capable of sensing a wide range of natural phenomena and wirelessly transmitting the corresponding data.

Given that nodes of these networks are typically small devices supplied with tiny batteries and while being wireless, generally operate in the absence of an infrastructure, they depend on the energy supplied by their limited batteries. Therefore, even though energy consumption is of key importance in wireless networks, it becomes more intense in their sensor counterparts [8] mostly due to the *energy hole* problem [9]. In particular, sensor nodes also act as relays for data generated by other nodes that need to reach the *sink*, i.e., the particular node that is responsible to collect all sensed information. Consequently, nodes that are close to the sink have to relay a large amount of *traffic load*, and therefore their energy consumption is increased compared to other nodes of less intense traffic load.

In this paper, the increased energy consumption, due to the *energy hole* problem, is tackled by the implementation of a recharging vehicle able to move within the network when a request is applied by one or more sensor nodes in need for a battery replenishment. The vehicle remains stationed at the sink node when inactive, and moves according to shortest path's branches upon a energy request. A simple *recharging policy* is introduced under which a request is sent to the sink node to initiate a recharging process if the battery level of a sensor node is below a fixed *recharging threshold*. As it is shown in the paper, the *recharging distance*, i.e., the distance covered by the recharging vehicle under this recharging policy, corresponds to a facility location problem and particularly to a 1-median one [10]. This is an important contribution, since it relates battery replenishing problems in wireless networks to facility location problems.

Simulation results validate the analytical findings and show that when the sink is located at the solution of the 1-median problem formulated here, then the distance covered by the recharging vehicle is minimized. For the simulation purposes, geometric random graphs [11] are considered as suitable for representing wireless sensor network topologies [12], even though the analytical findings can be applied to any other topology type. The effect of the

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