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Energy-efficient forwarding in wireless sensor networks

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Abstract

For maximizing the energy efficiency in a wireless network, we propose two forwarding schemes termed single-link and multi-link energy-efficient forwarding that tradeoff delivery ratios against energy costs. Multi-link forwarding improves the network performance substantially by addressing multiple receivers at once during the packet forwarding process. If the first forwarding node does not receive a packet correctly, other nodes may act as backup nodes and perform the forwarding instead. By means of mathematical analyses, we derive how the energy efficiency of a forwarding path can be computed and how a forwarding tree is established. Routing cycles are explicitly taken into account and prevented by means of sequence numbers. Simulations and real-world experiments provide a comparison to other reference strategies, showing a superior performance of our forwarding scheme in terms of energy efficiency.

Keywords: Energy efficiency; Multi-link forwarding; Opportunistic routing; Wireless sensor networks

1. Introduction

Many recent experimental studies have shown that, especially in the field of sensor networks where low-power radio transmission is employed, wireless communication is far

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from being perfect [5,9,26,29]. Thus, widely used communication models corresponding to binary links with either full connectivity or none at all are not realistic. Instead of modeling only a connected and a disconnected region as in the *unit disk graph* model, more realistic loss models consider a transitional region with a widely varying degree of packet loss [6, 25,33]. Although for a sender–receiver pair the packet reception tends to decrease with growing distance, there might be some cases where more distant nodes have smaller loss ratios than do nearby ones. Thus, exploiting nodes located in the transitional region might improve the efficiency of a forwarding strategy significantly [7,23]. In terms of energy, it might be more efficient to establish longer paths that experience few packet losses instead of shorter ones that cause many transmissions until packets have reached their destinations.

In this paper, we will explore the efficiency of different forwarding strategies, which can be used by sensor nodes to report data to a predefined network sink. For such many-to-one communication, many routing algorithms rely on distance-based forwarding, where the number of hops serves as a distance metric [16,17,20,22,27]. However, since the energy consumption and the connectivity between nodes depend on the link quality, it is not obvious which neighbor should forward packets in order to be energy-efficient. If each node simply selects the node with the lowest hop counter, it is likely that the end-to-end path will exhibit high packet losses, leading to a poor efficiency due to many retransmissions.

Several experimental studies have explored this problem with different routing schemes [7,23,25,26]. While most of the existing work focuses either on minimizing the expected number of transmissions or tries to maximize end-to-end delivery, we concentrate on *energy efficiency* in order to trade off packet delivery ratios and energy consumption. By means of mathematical analyses, simulations and an implementation, we investigate a broad framework of distance-vector-based forwarding strategies for static wireless sensor networks. Furthermore, we propose two forwarding schemes, namely *single-link energy-efficient forwarding* and *multi-link energy-efficient forwarding*. While single-link forwarding sends a packet to only one forwarding node, multi-link forwarding exploits the broadcast characteristics of the wireless medium by addressing a packet to several nodes at once, from among which a forwarding node is selected afterwards. This will often improve the energy efficiency significantly, because if the first forwarding node does not receive a packet correctly, other nodes may act as backup nodes and perform the forwarding instead.

In the next section, we first outline the related work. Section 3 then describes our packet reception and energy model that is motivated by experimental studies; it is later used in the simulations. This section also gives information about the assumptions made and the performance metrics we focus on. In Section 4, we present the single-link and multi-link energy-efficient forwarding strategies. Considering the case of finite retransmissions, we present a mathematical analysis for both strategies. By means of simulations, we compare the performance of all forwarding strategies in Section 5. Results from real-world experiments are presented in Section 6. Section 7 concludes the paper.

2. Related work

Several routing protocols for sensor networks concentrate on energy-related issues, which surely are important and challenging aspects [1,8]. For many-to-one communication