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Coloring based Hierarchical Routing Approach

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Abstract

Graph coloring was exploited in wireless sensor networks to solve many optimization problems. These problems are related in general to channel assignment. In this paper, we propose to jointly use coloring for routing purposes. We introduce CHRA a coloring based hierarchical routing approach. Coloring is exploited to avoid interferences and also to schedule nodes transmissions to sink. We provide an analytical and experimental study assessing the performance of CHRA in terms of end-to-end delay and energy consumption. In particular, we find that CHRA performs better than LEACH, a well established hierarchical routing protocol.

Keywords: Wireless Sensor Network, Graph Coloring, TDMA scheduling, routing, optimization

1. Introduction

Context and motivation. Advances of wireless communication, micro-electro-mechanical systems (MEMS) and digital electronics have made wireless sensor networks (WSN) a popular research topic and promising technology for many fields. Indeed, WSNs have been envisioned in a large number of application domains [1, 2] like medical, military and environmental fields. WSNs are composed of a large number of autonomous nodes densely distributed within an area and sharing a wireless communication medium without the use of any infrastructure. Sensor nodes are made to operate autonomously to gather information about their environment and transmit it to a base station called sink. The intrinsic characteristics of sensor nodes like the limited transmission power, storage capacity and especially limited energy power impose several challenges. In fact, sensors are running on limited and typically non-renewable power supply since they are generally deployed in hostile or not reachable areas. In view of the scarcity of energy, prolonging sensors lifetime is a main design challenge of these networks. Besides, radio communication constitutes also one of the major sources of energy dissipation. In such environments, as nodes share the same medium access, collisions and interferences caused by simultaneous transmissions of neighbors become very frequent especially in a dense network. Packets retransmissions caused by these collisions contribute to the energy depletion of sensor nodes. Contention based mechanisms, like CSMA/CA [3], aim to reduce probability of collisions. However, control packets overhead, active sensing of the medium and backoff algorithm typically performed in this context, are inefficient in terms of energy consumption. Minimizing transmission delay and assuring

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fairness are other important challenges. With contention based MAC (Media Access Control) algorithms, it is hard to assure these properties due to the recourse to the backoff algorithm and nodes competition to access the channel. Channel assignment techniques like TDMA, can be well suited in minimizing energy consumption [4] since nodes can turn off their transmitters or receivers, unless they are expecting to receive or transmit a packet. In this context, classical problems from graph coloring theory can be mapped to channel assignment in wireless sensor networks [5, 6, 7, 8]. For example, attributing a slot time to sensors nodes is equivalent to the assignment of distinguished colors to these nodes while respecting scheduling constraints. Several researches have been interested into applying graph coloring theory in wireless networks. Most of algorithm are investigating the so called distance d (in terms of hops) coloring, with $d \geq 2$. The aim is to assign to interfering nodes distinguished colors in order to assure a conflict-free communication. However, most existing work dissociate between collision free coloring-based scheduling and energy efficient routing.

Contribution. The objective of this paper is to study the possible gains in applying graph coloring in the context of routing in wireless sensor network. We propose CHRA (Coloring based Hierarchical Routing Approach), a hierarchical routing approach based on node 2-hop coloring. Within CHRA, we tackle *both* channel access issues by a TDMA like protocol, and routing by exploiting a coloring based virtual infrastructure. In this respect, CHRA does not dissociate between the two phases but addresses them simultaneously. We contribute both an analytical and experimental analysis assessing the performance of CHRA under different network circumstances. We find that depending on the properties of the coloring different trade-offs can be obtained both in term of end-to-end delay and energy consumption. We notice that these two objectives are conflicting with one another since to increase energy conservation nodes could even not send data at all. In opposite, more communication is likely to ensure better delay at the price of consuming more energy. We experimented three heuristics to construct the coloring structure and highlight their impact on routing. Besides, and independently of the considered coloring, we study the performance of CHRA against LEACH [9] a widely used hierarchical protocol particularly known for saving energy and improving network lifetime. We find that CHRA outperforms leach and leads to lower energy consumption.

Related work overview. Routing protocols [10] in WSN can be divided into flat routing and hierarchical routing. With flat routing, all nodes have the same functionalities and execute the same tasks in the network. In this category, data transmission is performed hop by hop, e.g. [11, 12]. Flat routing is relatively not effective in large scale networks due to the limited energy resources. Hierarchical routing [13, 14, 15, 16, 17] consists in building a virtual infrastructure based on clustering. Nodes are organized into clusters, where cluster-heads (CH) and members have to perform different tasks. Low-Energy Adaptive Clustering Hierarchy (LEACH) [9], is one of the pioneering hierarchical routing approaches for WSNs. In LEACH, each round is composed of two phases, a set-up phase to form clusters and a steady phase to data transmissions. The set-up phase operates in a randomized manner in an attempt to elect different CHs and to distribute energy consumption over nodes. Many versions of LEACH are proposed forming the LEACH family, e.g., LEACH-C [18]. Other algorithms based on LEACH try to improve the clustering process such as HEED [19] where CHs are elected based on their energy level and these CHs send the aggregated data to the sink in a multi-hop manner rather than single-hop manner of LEACH. DWEHC [20] build on HEED by trying to generate a balanced distribution of CHs, but CHs transmit their data to the sink in a single hop fashion. None of these protocols have considered the use of coloring to jointly manage channel access and routing to the sink.

Outline. In Section 2, we provide an overview of our routing approach as well as an analytical study of its properties. In Section 3, we report our simulation results assessing the performance of our approach. Finally, in Section 4, we conclude the paper and discuss future research directions.

2. Coloring based Hierarchical Routing Approach

2.1. Rationale

Hierarchical routing [13, 14, 15, 16] is based on the idea of assigning different roles to nodes depending on their status. Generally speaking, the virtual infrastructure for such routing is obtained after a clustering