Lifetime maximization routing with network coding in wireless multihop networks

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Abstract In this paper, we consider the lifetime maximization routing with network coding in wireless multihop networks. We first show that lifetime maximization with network coding is different from pure routing, throughput maximization with network coding and energy minimization with network coding. Then we formulate lifetime maximization problems in three different cases of (i) no network coding, (ii) two-way network coding, and (iii) overhearing network coding. To solve these problems, we use flow augmenting routing (FA) for the first case, and then extend the FA with network coding (FANC) by using energy minimized one-hop network coding. After that, we investigate the influence of parameters of FANC, evaluate the performance of FANC with two-way and overhearing network coding schemes and compare it with that without network coding under two different power control models, namely, protocol and physical ones. The results show that the lifetime can be improved significantly by using network coding, and the performance gain of network coding decreases with the increase of flow asymmetry and the power control ability.

Keywords network coding, lifetime maximization, linear programming, flow augmenting routing, wireless multihop networks


1 Introduction

In energy constrained wireless multihop networks, replacing or recharging batteries of nodes is often inconvenient or even impossible, and their lifetime is limited by the available energy of network nodes. Thus, lifetime maximization has been an interesting research topic and a variety of methods for this purpose have been proposed until now, for instance, using transmitting power control [1], scheduling with periodical sleep [2], load-balancing with multi-path routing [3–5], etc. Research (e.g., [6]) has shown that given communication demands in a wireless multihop network, the lifetime of the network depends on the selection of routing paths [6]. Due to the rapid development of energy constrained wireless sensor networks, lifetime maximization routing has been investigated extensively but mostly without considering network coding [4,6–8].

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Network coding that was first proposed by Ahlswede et al. in [9] has been proved to be able to effectively improve the throughput [9–12] and energy efficiency [13,14] of both wired and wireless networks. A lot of research has been done in various aspects of network coding, such as coding approaches [15–19], practical implementation of inter-session network coding [10] and opportunistic routing with network coding [20], network optimization with network coding in both multicast [13,21–23] and unicast [12,14,24,25], and the performance bound of network coding [26,27].

The basic idea of network coding is to equip routers with processing and coding ability besides forwarding, and to utilize spatial redundancy among nodes (for inter-session network coding) and time redundancy among packets (for intra-session network coding) to reduce the occupied network resources. Since wireless signal is inherently broadcast and lots of spatial redundancy can be exploited for network coding, much research has been done to improve the network throughput with network coding in wireless networks [10,18,19,22]. Intuitively, network coding can also be utilized to decrease the number of transmissions, and thus save the power of some bottleneck nodes and prolong the lifetime of the wireless multihop network. However, although network coding can effectively improve throughput [10–12] and increase energy efficiency [13,14] of wireless networks, it is still unknown how much the lifetime can be extended by using network coding, how to design network coding for lifetime maximization and what factors affect the improvement ratio.

In this paper, we investigate the lifetime maximization routing with network coding in wireless multihop networks. To this end, we first give the formulation of three problems for lifetime maximization with 1) no network coding, 2) two-way network coding, and 3) overhearing network coding. Then we propose flow augmenting routing with network coding (FANC) and local energy minimized one-hop network coding to solve these problems. After that, we evaluate the performance of FANC and compare it with that without network coding in two different power control models.

The rest of the paper is arranged as follows. In Section 2, we introduce related work in details. In Section 3, we give preliminary definitions and notations, such as network model, power control models, one-hop network coding, and network lifetime. Then, we give problem formulation of lifetime maximization for three different cases in Section 4. After that, we propose the flow augmenting routing with network coding (FANC) and local energy minimized one-hop network coding in Section 5. And we evaluate the performance of FANC and compare it with the case without network coding in Section 6. Finally, we conclude the paper in Section 7.

2 Related work

Due to the fast development of energy constrained wireless networks, network lifetime has become an important issue, and thus a variety of methods have been proposed to prolong network lifetime in different protocol layers. Transmission power control is proposed to save energy in physical layer [1]. Scheduling with periodical sleep is often used to reduce listening power cost in MAC layer [2,28]. In the routing layer, the lifetime optimization problem is solved with subgradient method in [4], and a heuristic flow augmenting routing algorithm is proposed to find multi-path routing for lifetime extension in [3].

Since network coding was firstly proposed by Ahlswede et al. in [9], a lot of network coding schemes have been proposed for both intra- and inter-session network coding. For intra-session NC, linear network coding is proposed in [15,16], and proved to be sufficient to achieve the rate region of multicast. For inter-session NC, linear programming with poison-antidote method is utilized to find the suboptimal network coding approach in [24,25]. Recently, simplified but efficient pairwise inter-session network coding (PINC) is developed, which is defined by the constraints between two paired routing paths [17]. However, in these two inter-session network approaches, finding optimal network coding is exponentially complicated with the number of nodes and nodes' degrees. As to practical implementation of network coding, COPE [10] is the first that applies opportunistic one-hop network coding to an 802.11 based wireless ad hoc network, and achieves significant throughput gain. Due to the scalability and low overhead of COPE, we adopt it as the network coding scheme in this paper.

Network coding provides a new dimension for enhancing network performance, thus network optimiza-