Chapter 18
Cooperative Broadcast in Large-Scale Wireless Networks

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ABSTRACT

This chapter studies the cooperative broadcasting in wireless networks. We especially focus on multi-stage cooperative broadcasting in which the message from a source node is relayed by multiple groups of cooperating nodes. Interestingly, group transmissions become beneficial in the case of broadcasting as opposed to the case in traditional networks where receptions from different transmitters are considered as collision and disregarded. Different aspects of multistage cooperative broadcasting are analyzed in the chapter: (i) coverage behavior; (ii) power efficiency; (ii) error propagation; (iv) maximum communication rate. Whenever possible, performance is compared with multihop broadcasting where transmissions are relayed by a single node at each hop. We consider a large-scale network with many nodes distributed randomly in a given area. In order to analyze such networks, an important methodology, the continuum limit, is introduced. In the continuum limit, random networks are approximated by their dense limits under sum relay power constraint. This method allows us to obtain analytical results for the analysis of cooperative multistage broadcasting.

INTRODUCTION

In distributed ad hoc networks, most network protocols require multicast or broadcast of certain control messages. These messages generally constitute a significant portion of network traffic, and they may cause performance bottlenecks. Several authors have studied how to optimally transmit broadcast

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information to minimize the total number of transmissions or the energy consumption in large wireless networks (e.g., see Williams & Camp, 2002).

Under traditional multi-hop broadcasting, each node receives signals from its nearest neighbor, and messages propagate over hops formed by single nodes. In this case, receptions from different transmitters are considered as collision even if they correspond to the same source message. Hence, networks with high number of nodes suffer from multiple retransmissions and waste resources (Tseng, Ni, Chen & Sheu, 1999; Korkmaz, Ekici & Ozguner, 2007).

In wireless networks, transmitted packets are heard not only by their intended recipients but also by other neighboring nodes. This is known as the broadcast property of wireless medium and it is the main motivation for cooperative schemes. In this chapter, we study cooperative broadcasting which takes advantage of the broadcast nature of the wireless medium by including all receivers in the relaying process. In broadcasting, the goal is to send a source message to the entire network in the most efficient way. In contrast with multi-hop broadcasting, cooperative broadcasting brings in several advantages: (i) increased connectivity and coverage; (ii) improved power efficiency; (iii) bounded error propagation for uncoded transmission; (iv) improved communication rate.

The advantages of cooperation for broadcasting applications have been recognized in many works. Different cooperative strategies are proposed in order to improve energy efficiency (Hong & Scaglione, 2003; Maric & Yates, 2004; Hong & Scaglione, 2006; Sirkeci-Mergen & Scaglione, 2007; Sirkeci-Mergen & Scaglione, 2006), network lifetime (Maric & Yates, 2005), network coverage (Sirkeci-Mergen, Scaglione & Mergen, 2006; Sirkeci-Mergen & Scaglione, 2004; Sirkeci-Mergen & Scaglione, 2005), and communication rate (Sirkeci-Mergen & Gastpar, 2007; Khisti, Erez & Wornell, 2006);

In (Hong & Scaglione, 2003; Maric & Yates, 2004; Hong & Scaglione, 2006), the authors investigate the energy efficiency of cooperative transmissions over multihop networks for different setups. In the basic formulation, they assume that the receiving nodes combine the receptions from all nodes that transmitted previously to harvest energy and, in turn, benefit from transmit diversity. In addition, the nodes transmit based on a predetermined schedule and power allocation policy such that total power consumption of the network is minimized. In (Hong & Scaglione, 2003; Maric & Yates, 2004; Hong & Scaglione, 2006), it was shown that for a given transmission schedule, the optimal power allocation can be formulated as a constrained optimization problem which can be solved in polynomial time by utilizing linear programming tools. On the other hand, the authors also showed that finding the optimal scheduling that leads to the minimum total power consumption is an NP-complete problem and thus, it is not computationally tractable in general. Both works proposed heuristic methods to determine the optimal schedule.

In (Khisti, Erez & Wornell, 2006), authors characterize the broadcast capacity for slowly fading channels in wireless relay networks. The authors consider a model where an outage is declared if any of the receivers fails to decode the source message, and the broadcast capacity is defined as the maximum data rate at which the outage probability converges to zero as the number of nodes goes to infinity. They showed that the broadcast capacity converges to $C = log\,(1+ P/N_0)$, where P is the sum power constraint on the network and N_0 is the noise power. This result is obtained under the assumption that there is i.i.d. (independent and identically distributed) Rayleigh fading between nodes, but there is no signal attenuation with distance. The achievability result is based on a two-phase cooperative broadcasting scheme.

The multistage cooperative broadcasting, which is the main focus of this chapter, is introduced and analyzed by Sirkeci-Mergen & Scaglione in various publications. A closely related scheme is *opportunistic large arrays* proposed in (Scaglione & Hong, 2003) in which the nodes transmit based on their

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