Chapter 10
Energy Efficient Communication with Random Node Cooperation

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ABSTRACT

In this chapter, we focus on the energy efficient cooperative communication with random node cooperation for wireless networks. By "random," we mean that the cooperative nodes for each communication event are randomly selected based on the network and channel conditions. Different from the conventional deterministic cooperative communication where cooperative nodes are determined prior to the communication, here the number of cooperative nodes and the cooperation pattern may be random, which is more practical given the random nature of the channels among the source nodes, relay nodes, and destination nodes. In addition, it is more robust to the dynamic wireless network environment. Starting with a thorough literature survey, we then discuss the challenges for random cooperative communication systems. Afterwards, two examples are presented to illustrate the design methodologies. In the first example, we analyze a simple scheme for clustered wireless networks, where cooperative communication is deployed in the long-haul inter-cluster transmissions to improve the energy efficiency. We quantify the energy performance and emphasize its difference from the conventional deterministic ones. In the second example, we consider the cross-layer design between the physical layer and the medium access control (MAC) layer for the one-hop random single-relay networks. We unify the power control and the relay selection at the physical layer into the MAC signaling in a distributed fashion. This example clearly shows the strength of cross-layer design for energy-efficient cooperative systems with random node collaboration. Finally, we conclude with discussions over possible future research directions.

DOI: 10.4018/978-1-60566-665-5.ch010

INTRODUCTION

In energy-constrained wireless networks, such as wireless sensor networks, energy is normally non-renewable and is thus of paramount importance in the network design and operation. It is well known that multi-input multi-output (MIMO) techniques based on antenna arrays can dramatically reduce the required transmission energy in wireless fading environments under a certain throughput constraint due to spatial diversity. However, many wireless devices, for example, wireless sensor nodes, are usually limited in size such that it is impossible to mount multiple antennas at one node. Consequently, the traditional MIMO techniques can not be used in such networks to save energy. Nevertheless, it has been found that cooperative communication schemes, where multiple nodes collaborate on forming virtual antenna arrays, can be deployed to improve energy efficiency.

In this chapter, we focus on energy efficient cooperative communications with random node cooperation for wireless networks. By "random", we mean that the cooperative nodes for each communication event are randomly selected based on the network and channel conditions. Different from the conventional deterministic cooperative communication where cooperative nodes are determined prior to the communication, here the number of cooperative nodes and the cooperation pattern may be random, which is more practical given the random nature of the channels among the source nodes, relay nodes, and destination nodes. The random nature of cooperators incurs many new design challenges over those in the deterministic cooperative communication. In this chapter, we elaborate on these issues. Two typical examples are given to illustrate the general methodology and analysis techniques for random cooperative systems. We emphasize on the system energy efficiency to show the benefits of random cooperation for energy constrained wireless networks.

The rest of the chapter is organized as follows. We first introduce the related background with a thorough literature survey over cooperative communication. Then, we discuss in depth the design challenges for random cooperative schemes. After that, we give two design examples. The first example is for clustered wireless networks, where nodes in one cluster randomly participate in the long-haul inter-cluster communication to improve the overall energy efficiency. We will highlight the analysis of the system energy efficiency and clearly show its difference from the conventional deterministic ones. In the second example, we discuss the cross-layer design between the physical layer and the medium access control (MAC) layer for the one-hop random single-relay networks. We unify the power control and the relay selection at the physical layer into the MAC signaling in a distributed fashion. This example clearly illustrates the strength of cross-layer design for random cooperative systems. We conclude with some observations and a discussion of future research directions.

BACKGROUND

A large amount of research work has been done recently investigating various cooperative relay schemes. Generally speaking, these schemes can be classified into the following two categories: amplify-and-forward schemes and decode-and-forward schemes. For the first category, cooperative nodes do not decode their received packets, they just amplify and relay the received signal to the destination. Schemes such as those in [Sendonaris et al., 2003, Ochiai et al., 2005] belong to this category. In [Sendonaris et al., 2003, Ochiai et al., 2005], the source and cooperative nodes adjust the phase of their transmissions such that their signal can add coherently at the destination (i.e., distributed beamforming). Amplify-and-

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