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Analysis and scheduling of practical network coding in OFDMA relay networks

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ABSTRACT

Network coding has become a prominent approach to improve throughput of wireless networks. However, most of work in the literature concentrates mainly on 802.11-like random access networks. New technologies such as OFDMA (orthogonal frequency division multiple access), offer new opportunities for employing network coding. This paper considers how to apply the practical network coding scheme in OFDMA relay networks via cross-layer optimization. Specifically, we aim to explore the following questions: (1) When and how can wireless nodes select relay paths in the presence of network coding? (2) How can an OFDMA relay system assign network resource such as subcarrier and power for all the transmitting nodes? (3) What are the impacts of OFDMA system parameters on the network coding gain? To answer these questions, two efficient coding-aware relay strategies are presented to select forwarding paths with fixed and dynamic power allocation. In order to exploit the network capacity in slow frequency selective fading channels, we formulate optimization frameworks and propose channel-aware coding-aware resource allocation algorithms for an arbitrary traffic pattern. Our studies show that the network coding (i.e. XOR) gain depends on the nodes' powers, traffic patterns etc. Especially, OFDMA relay network with dynamic power possesses both ***coding gain*** and ***power gain***. Extensive simulations are performed to verify our analysis and demonstrate the throughput improvement of our proposals in the presence of XOR coding.

1. Introduction

In the past few years, OFDMA networks such as WiMax and 3G LTE have been brought into commercial deployment. It can support various bandwidth-intensive services such as interactive games, VoIP, peer-to-peer streaming that involve bidirectional traffic. However, the capacity of an OFDMA cell is still limited by communication distance, as many other wireless communication systems. Deploying dense base stations (*BS*) can mitigate the capacity loss caused by large-scale fading, but at the expense of high deployment and management costs. An efficient way is to make use of inexpensive relays to forward traffic between a base station and mobile/portable subscribers (*SS*). When bidirectional flows pass through a relay station (*RS*), the needed resource can be potentially saved if network coding is introduced.

The practical XOR coding scheme [2] demonstrates throughput enhancement in 802.11 networks, which uses a single common frequency. However, very limited research concentrates on applying network coding in "*OFDMA relay networks*", where the fractional frequency band, namely *subcarrier*, is the allocable resource. To the best of our knowledge, Zhang et al. [11] initially study the performance of XOR operation in the base station to encode packets for subscribers in the OFDMA cell. Practical network coding can reduce traffic load in a relay station so that a number of orthogonal "subcarriers" can be saved

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for other applications. An illustration of coding structure is shown in Fig. 1, where the relay node can encode bidirectional flows using one subcarrier instead of two subcarriers. Although the OFDMA system shares the same coding structure with the 802.11 ad hoc networks, they are fundamentally different in the coding operation, the coding gain and the scheduling methods. Previous studies (e.g. [2]) identify that this coding structure has a XOR coding gain of 4/3 in 802.11 wireless networks. While in an OFDMA *relay* system, we analytically show that the coding gain depends on the traffic pattern, nodes' powers and channel gains. We also have an interesting observation on the effects of network coding when a node's power can be dynamically allocated. In the relay station, XOR operation not only reduces the traffic loads, but also shifts the saved power on other transmitting subcarriers, resulting in an additional ***power gain***.

Unlike the distributed random access scheme of IEEE 802.11, the orthogonal frequency band of an OFDMA relay network is allocated by the base station. Intuitively, if a *RS* transmits a set of bidirectional traffic that can be encoded together, the *BS* assigns less subcarriers to the *RS*. Thus, the network can support a larger traffic matrix with coding-aware relaying. A fundamental question is how to allocate network resource (e.g. subcarrier and power) to optimize the network throughput for an arbitrary traffic pattern when network coding is enabled. This problem, though very important, has not been studied in the literature. Authors in [10] proposed an adaptive resource allocation scheme to optimize OFDMA downlink throughput with fairness constraints. Based on their work, we propose channel-aware and coding-aware scheduling algorithms to scale up the OFDMA system throughput.

Another important question is how to select routing in the presence of multiple relays. We illustrate this problem in Fig. 2 with bidirectional flows between the *BS* and the *SS*. Without network coding, the uplink and the downlink may choose different relay paths based on their individual benefits. For example, the *BS* prefers RS_1 while the *SS* is inclined to select RS_2. When network coding is considered jointly with route discovery, the uplink and the downlink flows may traverse the same path, e.g. $BS - RS_2 - SS$, that can bring potential XOR-coding gain and improve resource usage.

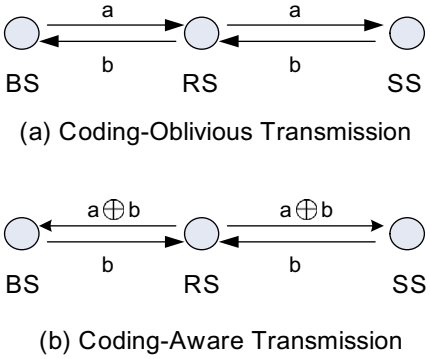

Fig. 1. XOR for OFDMA relay network in reducing number of subcarriers.

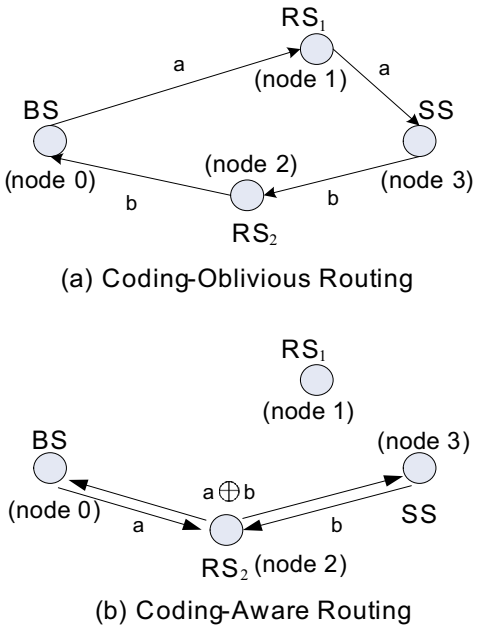

Fig. 2. XOR route selection.

The major contributions of our paper are:

- Two coding-aware routing strategies are presented to facilitate XOR-coding in OFDMA relay networks with fixed and dynamic power allocations.
- We formulate optimization frameworks to perform resource allocation (e.g. subcarrier, power) for OFDMA relay networks in the presence of network coding.
- We propose channel-aware coding-aware scheduling algorithms to maximize system throughput for an arbitrary traffic pattern.
- We investigate the impact of transmission power, channel gain, traffic pattern on the network coding gain, and find (a) the throughput gain of XOR-coding depends on the transmission powers of wireless nodes; (b) dynamic power allocation brings both *coding gain* and *power gain*.

The rest of this paper is organized as follows. In Section 2, we describe the basic characteristics of an OFDMA relay system. Section 3 presents the XOR-coding scheme and the coding-aware routing strategies. In Sections 4 and 5, coding-aware channel-aware scheduling algorithms are proposed with fixed and dynamic power allocation, respectively. We compare the end-to-end throughput of the coding-aware algorithms with those of the coding-oblivious algorithms in Section 6. Literature survey is presented in Section 7 and Section 8 concludes.

2. System description

In OFDMA mechanism, the frequency band is divided into a set of orthogonal narrow band subcarriers. Although OFDMA has many desirable characteristics, its performance is still limited by transmission distance, as many