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Energy-efficient dynamic resource allocation with opportunistic network coding in OFDMA relay networks

Yu Chen *, Xuming Fang

Provincial Key Lab of Information Coding and Transmission, Southwest Jiaotong University, Chengdu, Sichuan 610031, PR China

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ABSTRACT

Network coding is significantly able to save system resources for wireless networks, and has been widely studied for the 802.11 wireless local area network and traditional cellular networks. The relay technology was introduced in 802.16j, 802.16m, and Long Term Evolution-Advanced (LTE-A) standards. Recently, the application of network coding to multi-hop wireless relay networks has been taken into consideration. Although the introduction of relay stations (RSs) may bring more energy consumption, it provides opportunities for network coding to save spectrum resources. Nevertheless, the benefits of network coding are diminished by high multiuser diversity based on orthogonal frequency division multiple access (OFDMA). For ensuring the superiority, network coding is performed opportunistically according to the channel state. Hence dynamic resource allocation (DRA) subject to rate constraints is combined with the idea of opportunistic network coding to minimize the total transmission power in a frame. A fixed set of discrete modulation levels in an OFDMA relay system is also considered. By taking the characteristic of a half-duplex decode-and-forward (DF) mode relay, a solution is proposed for the optimal problem of each subframe after separating power-aware relay selection. Simulation results show that DRA with opportunistic network coding can improve system energy efficiency. Further, it is more efficient for saving energy than DRA with static network coding compared solely to DRA.

1. Introduction

Orthogonal frequency division multiple access (OFDMA) is a key technology of the next generation. In an OFDMA system, a suitable frequency can be selected to implement user diversity. However, with the wide application of multimedia services, broader signal coverage, higher data transmission rates, and faster mobility are required in the next generation of mobile communication systems. With the existing cellular systems without relay stations (RSs), it has been difficult to satisfy the current service requirements. In order to not change the deployment of cellular systems, the relay technology was introduced in 802.16j, 802.16m, and Long Term Evolution-Advanced (LTE-A) standards to guarantee current services requirements.

With the emergence of "green communication" and "energy conservation and emission reduction", energy-saving in wireless networks becomes a challenge. Originally, relay station is introduced in the next generation network due to enhancing network coverage and improving boundary capacity. However the energy consumption in relay system is still severe. The energy-efficiency problem in the relay system is more complex comparing with the network without RSs, and it becomes a focus of the current research. Meanwhile, due to introduction of RSs, it also provides an opportunity for network coding applications.

Network coding was originally used in wired networks, however it is currently being applied to wireless

* Corresponding author. Tel.: +86 139 8220 9243.
E-mail addresses: cherry1593@163.com (Y. Chen), xmfang@swjtu.edu.cn (X. Fang).

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networks [1–3]. The network coding scheme mainly demonstrates throughput enhancement in 802.11 wireless local area networks [4,5], and shares a single common frequency band. The potential advantages of the network coding include resource (e.g. bandwidth and power) efficiency, computational efficiency, and robustness to network dynamics. In recent years, there has been research on applying network coding to OFDMA networks. In an ideal case where all downlinks have coding opportunities and the subcarriers have uniform channel gains for all mobile stations (MSs), a dynamic resource allocation (DRA) scheme with opportunistic network coding can save half of resources compared to traditional allocation schemes. However, the benefits of network coding are diminished by high multiuser diversity, because sharing the same subcarrier may result in underutilized bandwidth. In OFDMA networks without RSs, the cell should be covered by itself with a large amount of power. The channel gains of edge users and users near base station (BS) are quite different. Therefore, there is rare opportunity to perform network coding in OFDMA networks. However in an OFDMA relay network, RSs compensate the channel gains and enhance the signal strength for edge users, which provides more opportunities to perform network coding. If network coding is applied to an RS, some system resources could be opportunistically saved, then the energy consumption can be decreased. Currently, few research studies concentrating on network coding applications in OFDMA relay networks are being performed, and these works mainly contribute to system throughput maximization.

Normally, energy efficiency is defined as the number of bits per energy unit or bits/Joule. According to requirements of a determined transmit rate, reducing energy consumption means increasing energy efficiency. Hence the energy-saving problem can be regarded as an energy efficiency problem. Under a certain transmission rate, the number of bits transmitted in a frame and the duration time of a frame are determined. Then the energy-saving problem can be converted to a power-saving problem. That is to say, the energy-saving problem in a frame is equivalent to a power-saving problem. In this paper, by using opportunistic network coding for a fixed set of discrete modulation levels, subcarriers and bits are dynamically allocated to users to minimize transmit power of a frame in the system. RSs will perform network coding opportunistically after receiving the data from MSs and BSs. The optimal algorithm is a non-linear optimization with integer variables, and it is NP-hard. Thus this paper proposes a sub-optimal algorithm which separates relay selection and resource allocation. Subcarriers and bits are allocated after power-aware relay selection. The solution of DRA is implemented according to integer programming.

The rest of this paper is organized as follows. In Section 2, related work is summarized, and the system model and the formulation of joint optimization are presented in Section 3. Section 4 provides the proposed suboptimal algorithm to deal with the joint problem, a performance evaluation of the proposed algorithm is given in Section 5, and conclusions are drawn in Section 6.

2. Related work

Recently a great amount of literature has proposed solutions for resource allocation based on OFDMA networks. In order to increase cell throughput and improve spectral efficiency, subcarriers and power are dynamically allocated to users in [6,7]. To minimize the system total power, subcarriers, bits, and power are adaptively allocated with a fixed set of discrete modulation levels in [8]. Then, to reduce algorithm complexity, optimal solutions found by linear programming are studied in [9]. And network coding is already introduced in OFDMA networks for saving resource. In [10,11], a cross layer approach that explores the joint advantageous of network coding and dynamic subcarrier assignment in an OFDMA network is proposed. In the papers, MSs in the cells exchange their data with each other through the network coding-aware BS.

In OFDMA relay networks, the research regarding DRA with network coding mainly concentrates on increasing the gain of system capacity. In [12,13], joint subchannel and power allocation problems were studied in OFDMA relay cellular networks where RSs can perform network coding with downlink and uplink sessions of an MS. However, they did not consider a practical duplexing scheme for the transmission of network coded data. All RSs should operate in a full duplex mode in [12,13], which should be able to transmit and receive data simultaneously, but this is impractical in real networks. Hence, a network coding-based relay OFDMA frame structure is proposed in [14], which is a modification of the second approach supported by IEEE 802.16j frame structure standard. And in [15,16], all RSs are considered in half-duplex mode. In [15], time-varying channel states of wireless links were researched, wherein the power allocated to each channel was fixed. Subchannels are allocated to each wireless link opportunistically, and network coding can be performed opportunistically at RSs. Whether or not to perform network coding and which sessions will be encoded at each RS are determined upon time-varying channel states of wireless links. Then a stochastic optimization problem was proposed to maximize the average weighted sum-rate for both downlink and uplink sessions. In [16], the bidirectional communication between two terminals with the help of a relay is considered. The allocation of the transmission time and of the rates in both directions can be asymmetric. Hence, the sum-rate through two steps can be maximized by optimizing time and rate allocation.

However, there is little research regarding the DRA with opportunistic network coding in OFDMA relay networks to minimize energy consumption of a system, and the resource allocation schemes with network coding in relay networks are merely based on a continuous modulation set. Therefore, in this paper, for a fixed set of discrete modulation levels, joint optimization of relay selection and resource allocation with opportunistic network coding subject to rate constraints is considered to minimize the total transmission power in a frame. This paper also proposes a sub-optimal algorithm, in which each user selects its own the transmission mode. Then, taking advantage of the half-duplex decode-and-forward (DF) mode relay, we propose an