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ΔSNR-MAC: A priority-based multi-round contention scheme for MU-MIMO WLANs

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ABSTRACT

The performance of uplink multiuser MIMO (MU-MIMO) transmissions heavily depends on which users to transmit together. In WLANs where each user independently determines when to transmit by random access, the performance degradation occurs when a set of users for concurrent transmissions are not chosen properly. In this paper, we address this problem and propose ΔSNR-MAC protocol to enhance the uplink throughput in MU-MIMO WLANs. In ΔSNR-MAC, a set of users transmitting together are determined one after another through a multi-round contention where the number of rounds equals the number of antennas at the AP. In each round, given winning users that are already transmitting, each user calculates its SNR reduction amount due to the winning users. ΔSNR-MAC gives a higher priority to users with less SNR reduction amounts. To achieve this, each round consists of multiple stages where earlier stages are reserved for users with less SNR reduction amounts. In this way, users with the strong channel orthogonality can transmit together in a fully distributed manner. We theoretically analyze the throughput of ΔSNR-MAC and propose a parameter selection method to maximize the throughput. Our evaluation results confirm that ΔSNR-MAC improves the uplink throughput over existing schemes both in two- and three-antenna AP cases and achieves temporal fairness in mobile environments.

1. Introduction

With the proliferation of bandwidth-hogging mobile devices such as smartphones and tablet computers, there is an increasing demand for high wireless capacity. Multiple-Input and Multiple-Output (MIMO) has been devised as a promising technology to boost wireless capacity. To handle explosively increasing mobile traffic, most of the wireless systems have embraced the MIMO technology as a solution in their latest standards.

In Wireless Local Area Networks (WLANs), the recent advances have mainly come from the MIMO technology in the physical (PHY) layer. Specifically, the IEEE 802.11n standard has incorporated the single user MIMO (SU-MIMO) with up to four spatial streams, providing a maximum data rate of 600 Mbps [1]. As a next step, the downlink multiuser MIMO (MU-MIMO) has been included in the IEEE 802.11ac standard to further enhance throughput beyond gigabit-per-second [2]. Considering the direction of WLAN evolution, the uplink MU-MIMO is also expected to be available in future standards.

The performance of uplink MU-MIMO transmissions depends on a set of mobile users (STAs) transmitting together. In general, users with the strong channel orthogonality should transmit together to maximize performance. In cellular networks, base users (BSs) can easily control which

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users to transmit together through centralized scheduling. In existing user scheduling/grouping algorithms, each BS explicitly selects users for concurrent transmissions and assign their data rates accordingly [3,4]. However, such scheduling algorithms are not suitable for WLANs since random access is used in the medium access control (MAC) layer. In Distributed Coordination Function (DCF) [5], each user independently determines when to transmit while access points (APs) have no scheduling functionality. In this case, the performance degrades severely when users for concurrent transmissions are not chosen well, sometimes to levels worse than that without the MU-MIMO. In order to address this problem, we need a new contention scheme where users with the strong channel orthogonality are selected in a fully distributed manner.

In this paper, we propose ΔSNR-MAC protocol to enhance the uplink throughput in MU-MIMO WLANs. In ΔSNR-MAC, a set of users transmitting together are determined one after another through a multi-round contention where the number of rounds equals the number of antennas at the AP. In each round, given winning users that are already transmitting, each user calculates its SNR reduction amount due to the winning users. ΔSNR-MAC gives a higher priority to users with less SNR reduction amounts. To achieve this, each round consists of multiple stages where earlier stages are reserved for users with less SNR reduction amounts. In this way, users with the strong channel orthogonality can transmit together in a fully distributed manner.

The rest of this paper is organized as follows. The background and motivation are presented in Section 2. We provide the operation procedures of ΔSNR-MAC along with the implementation details in Section 3. The theoretical analysis of throughput is given in Section 4, and the parameter selection method is provided in Section 5. We provide the performance evaluation in Section 6, and an overview of related work in Section 7. We finally conclude this paper in Section 8.

2. Background and motivation

2.1. Uplink multiuser MIMO

In uplink MU-MIMO transmissions, multiple users are enabled to transmit together towards an AP. Fig. 1 shows an example where there are a two-antenna AP and three single-antenna users u_1, u_2, and u_3. When u_1 and u_2 transmit together, the received signal at the AP is given as

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{11} \\ h_{21} \end{pmatrix} x_1 + \begin{pmatrix} h_{12} \\ h_{22} \end{pmatrix} x_2 + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix}, \quad (1)$$

where $\boldsymbol{h_i} = (h_{1i}, h_{2i})$ is the uplink channel vector between u_i and the AP, x_i is the symbol transmitted by u_i, and n_i represents the Gaussian noise with variance N_0.

The AP decodes the symbols x_1 and x_2 by using *zero-forcing successive interference cancellation* (ZF-SIC). To decode a symbol, say x_2, first, the AP projects the received signal on a direction orthogonal to $\boldsymbol{h_1}$ as

$$\begin{aligned} y_{proj} &= (h_{21}, -h_{11}) \cdot (y_1, y_2) \\ &= (h_{21}h_{12} - h_{11}h_{22})x_2 + (h_{21}n_1 - h_{11}n_2), \end{aligned}$$

where $(\cdot)$ is the inner product. As shown in Fig. 1, this projection allows the AP to null out x_1 and decode x_2 without

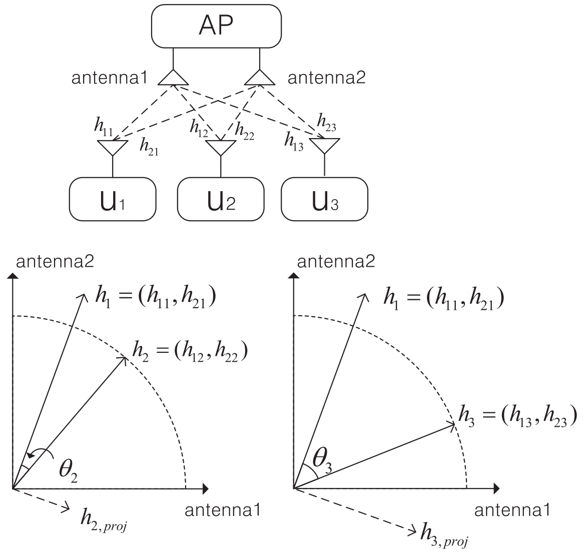

Fig. 1. Uplink MU-MIMO transmissions with ZF decoding. When the symbols are decoded in the order of x_2 (x_3) and x_1, the AP projects the received signal on the direction orthogonal to $\boldsymbol{h_1}$. Due to this projection, there is a reduction in the SNR of u_2 (u_3), which is determined by the angle between $\boldsymbol{h_1}$ and $\boldsymbol{h_2}$ ($\boldsymbol{h_3}$).

interference. The estimation $\hat{x}_2$ of x_2 is given by

$$\hat{x}_2 = x_2 + \frac{h_{21}n_1 - h_{11}n_2}{h_{21}h_{12} - h_{11}h_{22}}.$$

Since the noise after projection is scaled up, the SNR of u_2 decreases due to the projection. The SNR after projection $SNR_{2,proj}$ of u_2 is given by [7]

$$SNR_{2,proj} = \sin^2(\theta_2)\frac{||h_2x_2||^2}{N_0} = \sin^2(\theta_2)SNR_{2,orig}, \quad (2)$$

where θ_2 is the angle between $\boldsymbol{h_1}$ and $\boldsymbol{h_2}$, and $SNR_{2,orig} = ||\boldsymbol{h_2}x_2||^2/N_0$ represents the original SNR when u_2 transmits alone.

From (2), we can calculate the SNR reduction amount ΔSNR_2 (in dB) due to the projection as

$$\begin{aligned} \Delta SNR_2 &= 10\log_{10} SNR_{2,orig} - 10\log_{10} SNR_{2,proj} \\ &= -20\log_{10}\sin(\theta_2). \end{aligned} \quad (3)$$

Eq. (3) indicates that the SNR reduction amount depends only on θ_2, and is independent of the original SNR. This is because the channel after projection $\boldsymbol{h_{2,proj}}$ is determined by θ_2, as shown in Fig. 1. Specifically, there is an inverse relationship between θ_2 and ΔSNR_2, i.e., the larger θ_2 is, the smaller ΔSNR_2 is. Also, if $\boldsymbol{h_1}$ and $\boldsymbol{h_2}$ are orthogonal ($\theta_2 = 90^\circ$), the SNR of u_2 remains the same even after the projection.

After decoding x_2, the AP re-encodes[1] and subtract it from the received signal, and decode the other symbol x_1. Since there is no projection for x_1, the SNR of u_1 is simply $SNR_1 = ||\boldsymbol{h_1}x_1||^2/N_0$.

The above decoding process can be extended to an L-antenna case ($L \geq 3$) with L simultaneously transmitting

[1] We asssume that the AP can estimate $\boldsymbol{h_2}$ perfectly and thus regenerate $\boldsymbol{h_2}x_2$ without any estimation error.