Successive Optimization Transmission for high and low SNR stations in Wireless LAN Systems

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***Abstract*— Multiuser (MU) – multiple input multiple output (MIMO) techniques are attractive for increasing the downlink spectrum efficiency while requiring few antennas at each user station (STA). As practical precoding methods for multi-user MIMO systems, block diagonalization (BD) and successive optimization (SO) algorithms have been investigated using the metric of channel capacity. However, the throughput of SO algorithms has not been evaluated for wireless LAN systems. This paper focuses on the two-STA scenario where a close STA lies in the very near field of the access point (AP) while the distant STA lies farther from the AP; it proposes MU-MIMO transmission based on an SO algorithm that uses only the channel state information (CSI) of the close STA. The proposed method determines the transmission weight for the distant STA so as to nullify the close STA and reduces the inter-user interference at the distant STA by decreasing the transmission power for the close STA. Thus, the distant STA does not have to implement the CSI feedback function. Simulations compare zero forcing (ZF), BD, and proposed SO algorithms and confirm the conditions wherein the proposed method outperforms single user MIMO and multiuser MIMO based on ZF and BD algorithms.**

***Index Terms*—Multiuser MIMO, Power allocation, Successive optimization algorithm, wireless LAN.**

I. INTRODUCTION

Multiuser-multiple input multiple output (MU-MIMO) systems have attracted much attention as a promising way to increase the spectrum efficiency of the downlink [1][2]. Since data traffic is rapidly increasing, it is expected to accelerate the introduction of MU-MIMO techniques in actual systems. Thus, a wireless LAN (WLAN) system, IEEE802.11ac, has almost agreed to adopt downlink MU-MIMO as an optional feature [3]. Practical precoding methods for MU-MIMO systems include zero forcing (ZF) [4][5], block diagonalization (BD) [6][7], and successive optimization (SO) [6][8][9] algorithms. In ZF and BD algorithms, the transmission weights are designed so as not to interfere with any other stations (STAs) by using channel state information (CSI) for all STAs, while SO algorithms do not require CSI for all STAs. Thus it is expected that SO algorithms will yield higher MAC efficiency than ZF and BD algorithms.

While one of the STAs does not have to feed the CSI back to the access point (AP), the STA needs to compensate the inter-user interference. Our solution is to mitigate the inter-user interference at the low SNR STA by reducing the transmission power for the high SNR STA. To evaluate the transmission performance of the proposed method, we focus on the scenario of a close STA (high SNR) and a distant STA (low SNR). Thus, the proposed method compensates the inter-user interference at the distant STA by transmission power reduction for the close STA. The inter-user interference at the close STA is also reduced by determining the transmission weight for the distant STA so as to nullify the signal space of the close STA using the CSI for the close STA. Since the proposed method dispenses with CSI feedback from the distant STA, this ability provides several advantages. They include improving MAC efficiency, reducing the risk of losing the CSI feedback opportunity at the distant STA due to detection of the transmission of the other cell, and enabling MU-MIMO communication with the distant STA that does not have an MU-MIMO function such as CSI feedback. On the other hand, the proposed method does require a large SNR gap between the close and distant STAs. Computer simulations are conducted based on the IEEE802.11 TGac Draft D1.0.

This paper is organized as follows. Section II describes the MU-MIMO OFDM system for the scenario considered, and transmission schemes based on single user (SU-)MIMO, ZF, BD, and the proposed method. Section III details the computer simulation setup based on IEEE802.11TGac Draft D1.0 and the results are shown. Section IV summarizes the paper.

Throughout the paper, superscript H denotes Hermitian transposition. $[\mathbf{A}]_L$ is the function that chooses L column vectors from a matrix $\mathbf{A}$. $\mathbf{A}^{-1}$ denotes the pseudo inverse of $\mathbf{A}$. $\mathbf{I}_N$ is an $N \times N$ unit matrix.

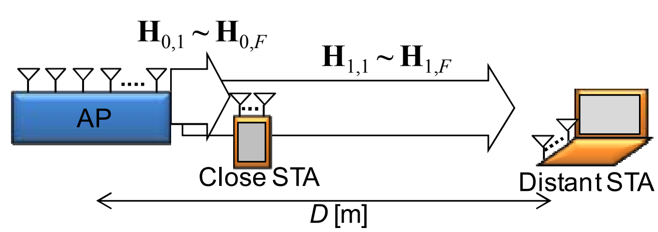

Fig. 1. MIMO OFDM system model

II. SYSTEM MODEL

MU-MIMO downlink transmission in OFDM systems is considered. Fig. 1 shows the system model; the AP communicates with the close STA and distant STA. The numbers of transmit antennas at the AP and receive antennas at each STA are assumed to be M_t and M_r, respectively. The downlink CSI for the close STA and distant STA at the i-th subcarrier are represented by channel matrices $\mathbf{H}_{0,i}$ and $\mathbf{H}_{1,i} \in \mathbb{C}^{Mr\times Mt}$, respectively, where the number of subcarriers in OFDM is F and $1 \le i \le F$. The elements of $\mathbf{H}_{0,i}$ and $\mathbf{H}_{1,i}$ are complex Gaussian with zero mean and their variances are defined as σ_0^2 and σ_1^2, respectively. Thus, when a single transmit antenna and single receive antenna are used (SISO channel), the SNR expectations at the close and distant STAs are expressed as σ_0^2/σ^2, and σ_1^2/σ^2, respectively. The SNR of the close STA is assumed to be much greater than that of the distant STA ($\sigma_0^2 >> \sigma_1^2$). The numbers of spatial streams for the close and distant STAs are L_0 and L_1, respectively. The received signal vectors at the close and distant STAs, $\mathbf{y}_{0,i}$ and $\mathbf{y}_{1,i} \in \mathbb{C}^{Mr\times 1}$, are given as

$$\begin{cases} \mathbf{y}_{0,i} = \mathbf{H}_{0,i}\mathbf{W}_{0,i}\mathbf{P}_{0,i}\mathbf{x}_{0,i} + \mathbf{H}_{0,i}\mathbf{W}_{1,i}\mathbf{P}_{1,i}\mathbf{x}_{1,i} + \mathbf{n}_{0,i}, \\ \mathbf{y}_{1,i} = \mathbf{H}_{1,i}\mathbf{W}_{1,i}\mathbf{P}_{1,i}\mathbf{x}_{1,i} + \mathbf{H}_{1,i}\mathbf{W}_{0,i}\mathbf{P}_{0,i}\mathbf{x}_{0,i} + \mathbf{n}_{1,i} \end{cases} \tag{1}$$

where $\mathbf{W}_{0,i} \in \mathbb{C}^{M_t\times L_0}$ and $\mathbf{W}_{1,i} \in \mathbb{C}^{M_t\times L_1}$, $\mathbf{x}_{0,i} \in \mathbb{C}^{L_0\times 1}$ and $\mathbf{x}_{1,i} \in \mathbb{C}^{L_1\times 1}$, and $\mathbf{n}_{0,i}$ and $\mathbf{n}_{1,i} \in \mathbb{C}^{M_r\times 1}$ are the transmission weights, transmission signal vectors, and noise vectors for the close STA and distant STA, respectively. The expectations of the element of the transmitted signal vectors and noise vectors are defined to be zero, and their variances are set to be one and σ^2, respectively. The j-th column vectors of transmission weights, $\mathbf{w}_{0,j,,i}$ and $\mathbf{w}_{1,j,i}$, satisfy $\|\mathbf{w}_{0,j,,i}\|^2 = \|\mathbf{w}_{1,j,,i}\|^2 = 1$. $\mathbf{P}_{0,i}$ and $\mathbf{P}_{1,i}$ are power allocation matrices for the close and distant STAs. $\mathbf{P}_{0,i}$ and $\mathbf{P}_{1,i}$ are diagonal matrices and their diagonal elements are expressed as the square roots of power coefficients, $\sqrt{p_{0,1}}$, ..., $\sqrt{p_{0,L_0}}$, and $\sqrt{p_{1,1}}$, ..., $\sqrt{p_{1,L_1}}$, respectively. We assumed that the transmission power is equally allocated to each subcarrier and the transmission power at each subcarrier is normalized to be one.

$$\sum_{j=1}^{L_0} p_{0,j} + \sum_{j=1}^{L_1} p_{1,j} = P_0 + P_1 = 1. \tag{2}$$

where P_0 and P_1 are the ratio of the transmit power allocated to the close and distant STAs. In this paper, we assumed that the transmission power within a STA is equally allocated to each data stream in all methods.

A. CSI feedback

Consider the VHT compressed beamforming report field [2] that is supported in IEEE802.11 standard and TGac Draft D1.0. V matrix in the compressed beamforming is obtained as the right singular vectors of channel matrices by using Singular Value Decomposition (SVD) as

$$\begin{cases} \mathbf{H}_{0,i} = \mathbf{U}_{0,i}\begin{pmatrix}\mathbf{\Sigma}_{0,i} & \mathbf{0}\end{pmatrix}\begin{pmatrix}\mathbf{V}_{0,i}^{(s)} & \mathbf{V}_{0,i}^{(n)}\end{pmatrix}^H \\ \mathbf{H}_{1,i} = \mathbf{U}_{1,i}\begin{pmatrix}\mathbf{\Sigma}_{1,i} & \mathbf{0}\end{pmatrix}\begin{pmatrix}\mathbf{V}_{1,i}^{(s)} & \mathbf{V}_{1,i}^{(n)}\end{pmatrix}^H \end{cases}, \tag{3}$$

where $\mathbf{U}_{0,i}$ and $\mathbf{U}_{1,i}$ are left singular vectors, $\mathbf{\Sigma}_{0,i}$ and $\mathbf{\Sigma}_{1,i}$ are diagonal matrices, and $\begin{pmatrix}\mathbf{V}_{0,i}^{(s)} & \mathbf{V}_{0,i}^{(n)}\end{pmatrix}$ and $\begin{pmatrix}\mathbf{V}_{1,i}^{(s)} & \mathbf{V}_{1,i}^{(n)}\end{pmatrix}$ are right singular vectors. The right singular vectors corresponding to the signal space are fed back to the AP by using compressed beamforming. In the compression method, the V matrix is transformed to angles, ψ and ϕ as follows.

$$\mathbf{V}_{0,i}^{(s)} = \begin{bmatrix} e^{j\phi_{11}} & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & e^{j\phi_{(Mt-1)1}} & 0 \\ 0 & \cdots & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \cos\psi_{21} & -\sin\psi_{21} & 0 & \cdots & 0 \\ \sin\psi_{21} & \cos\psi_{21} & 0 & \cdots & 0 \\ 0 & 0 & 1 & 0 & 0 \\ \vdots & \vdots & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \times \cdots$$
$$\times \begin{bmatrix} \cos\psi_{(Mt-1)1} & 0 & \cdots & 0 & -\sin\psi_{(Mt-1)1} \\ 0 & 1 & 0 & 0 & 0 \\ \vdots & 0 & \ddots & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ \sin\psi_{(Mt-1)1} & 0 & \cdots & 0 & \cos\psi_{(Mt-1)1} \end{bmatrix} \times \cdots \times \begin{bmatrix} \mathbf{I}_{L_0} \\ \mathbf{0} \end{bmatrix} \tag{4}$$

where $0 \le \psi \le \pi/2$ and $0 \le \phi \le 2\pi$. Next, N_B and $N_B + 2$ bits are allocated for ψ and ϕ, respectively. The AP obtains the right si ngular vectors for all subcarriers by using these angles.

B. Transmission schemes

- SU-MIMO

In SU-MIMO transmission, L_k column vectors of $\mathbf{V}_{k,i}^{(s)}$ corresponding to the higher singular values are used as the transmission weights, $\mathbf{W}_{k,i}$, where k identifies the close STA ($k = 0$) and the distant STA ($k = 1$). Since transmission is divided in the time domain for the close and distant STAs, the received signal in SU-MIMO is obtained as

$$\begin{cases} \mathbf{y}_{0,i} = \mathbf{H}_{0,i}\mathbf{W}_{0,i}\mathbf{P}_{0,i}\mathbf{x}_{0,i} + \mathbf{n}_{0,i}, \\ \mathbf{y}_{1,i} = \mathbf{H}_{1,i}\mathbf{W}_{1,i}\mathbf{P}_{1,i}\mathbf{x}_{1,i} + \mathbf{n}_{1,i} \end{cases} \tag{5}$$

The AP obtains $\mathbf{V}_{0,i}^{(s)}$ and $\mathbf{V}_{1,i}^{(s)}$ by using the feedback method in Eq. 4. The transmission power is allocated to each spatial stream. Thus, $p_{0,j} = \sqrt{1/L_0}$ and $p_{1,j} = \sqrt{1/L_1}$.

- ZF algorithm

The transmission weights in ZF are calculated by the pseudo inverse matrix of the aggregation matrix of $\mathbf{V}_{0,i}^{(s)}$ and $\mathbf{V}_{1,i}^{(s)}$ as

$$\begin{pmatrix}\mathbf{G}_{0,i} & \mathbf{G}_{1,i}\end{pmatrix} = \begin{pmatrix}\mathbf{V}_{0,i}^{(s)H} \\ \mathbf{V}_{1,i}^{(s)H}\end{pmatrix}^{-1}. \tag{6}$$

Transmission weight, $\mathbf{W}_{k,i}$, is obtained as $\left[\mathbf{G}_{k,i}\mathbf{\Gamma}_{k,i}\right]_{L_k}$, where $\mathbf{\Gamma}_{k,i}$ is a diagonal matrix whose diagonal elements normalize the norm of column vectors of $\mathbf{G}_{k,i}$ to be one. The transmission power is assumed to be equally allocated to the two STAs as $p_{0,j} = \sqrt{1/2L_0}$ and $p_{1,j} = \sqrt{1/2L_1}$.

- BD algorithm

The BD algorithm utilizes the null space of the other STA. The base vectors for the null space are calculated by QR decomposition as

$$\mathbf{V}_{k,i}^{(s)} = \begin{pmatrix} \mathbf{Q}_{k,i}^{(s)} & \mathbf{Q}_{k,i}^{(n)} \end{pmatrix} \begin{pmatrix} \mathbf{R}_{k,i} \\ \mathbf{0} \end{pmatrix}, \qquad (7)$$

where $\mathbf{R}_{k,i}$, $\mathbf{Q}_{k,i}^{(s)}$ and $\mathbf{Q}_{k,i}^{(n)}$ are the upper triangular matrix, unit vectors for the signal space and unit vectors for the null space, respectively. $\mathbf{Q}_{k,i}^{(s)}$ is identical to $\mathbf{V}_{k,i}^{(s)}$ and $\mathbf{Q}_{k,i}^{(n)}$ satisfies the relationship of $\mathbf{Q}_{k,i}^{(n)H}\mathbf{V}_{k,i}^{(s)} = \mathbf{0}$. SVD is then performed on the null space channel matrix, $\mathbf{H}_{0,i}\mathbf{Q}_{1,i}^{(n)}$, and $\mathbf{H}_{1,i}\mathbf{Q}_{0,i}^{(n)}$ as

$$\begin{aligned} \mathbf{H}_{0,i}\mathbf{Q}_{1,i}^{(n)} &= \overline{\mathbf{U}}_{0,i} \begin{pmatrix} \overline{\mathbf{\Sigma}}_{0,i} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \overline{\mathbf{V}}_{0,i}^{(s)} & \overline{\mathbf{V}}_{0,i}^{(n)} \end{pmatrix}^H \\ \mathbf{H}_{1,i}\mathbf{Q}_{0,i}^{(n)} &= \overline{\mathbf{U}}_{1,i} \begin{pmatrix} \overline{\mathbf{\Sigma}}_{1,i} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \overline{\mathbf{V}}_{1,i}^{(s)} & \overline{\mathbf{V}}_{1,i}^{(n)} \end{pmatrix}^H \end{aligned}, \qquad (8)$$

where $\overline{\mathbf{\Sigma}}_{k,i}$ is the $M_r \times M_r$ diagonal matrix and the diagonal elements of $\overline{\mathbf{\Sigma}}_{k,i}$ are the square roots of the null space eigenvalues, $\overline{\lambda}_{k,1}, \overline{\lambda}_{k,2}, \cdots, \overline{\lambda}_{k,Mr}$. $\overline{\mathbf{U}}_{k,i}$ and $\begin{pmatrix} \overline{\mathbf{V}}_{k,i}^{(s)} & \overline{\mathbf{V}}_{k,i}^{(n)} \end{pmatrix}$ are the left and right singular vectors, respectively. The transmission weight matrices for the close STA and distant STA, $\mathbf{W}_{0,i}$ and $\mathbf{W}_{1,i}$, are given as L_0 and L_1 column vectors of $\mathbf{Q}_{1,i}^{(n)}\overline{\mathbf{V}}_{0,i}^{(s)}$ and $\mathbf{Q}_{0,i}^{(n)}\overline{\mathbf{V}}_{1,i}^{(s)}$, respectively. The signal received at the close STA and distant STA is given by Eq. 1. When there is no error in CSI at the AP, Eq 8 is rewritten as

$$\begin{aligned} \mathbf{y}_{0,i} &= \mathbf{H}_{0,i}\mathbf{W}_{0,i}\mathbf{P}_{0,i}\mathbf{x}_{0,i} + \mathbf{n}_{0,i} \\ \mathbf{y}_{1,i} &= \mathbf{H}_{1,i}\mathbf{W}_{1,i}\mathbf{P}_{1,i}\mathbf{x}_{1,i} + \mathbf{n}_{1,i} \end{aligned}. \qquad (9)$$

Since the CSI at the AP includes error caused by the limited quantization bits and thermal noise, the inter-user interference is proportional to the CSI error. Although the calculation complexity of Eq. 9 overloads the AP, high throughput is expected. The transmission power is allocated to each stream as the same in ZF.

- Proposed SO algorithm

The AP gets the CSI feedback from only the close STA in the proposed method. The transmission weight for the close STA, $\mathbf{W}_{0,i}$, is obtained as L_0 column vectors of $\mathbf{V}_{0,i}^{(s)}$, the same as in SU-MIMO. The transmission weight for the distant STA, $\mathbf{W}_{1,i}$, is calculated as L_1 column vectors of $\mathbf{Q}_{0,i}^{(n)}$, in Eq. 6. When the CSI of the close STA at the AP is perfect, the received signals at the close and distant STAs are rewritten as

$$\begin{aligned} \mathbf{y}_{0,i} &= \mathbf{H}_{0,i}\mathbf{W}_{0,i}\mathbf{P}_{0,i}\mathbf{x}_{0,i} + \mathbf{n}_{0,i} \\ \mathbf{y}_{1,i} &= \mathbf{H}_{1,i}\mathbf{W}_{1,i}\mathbf{P}_{1,i}\mathbf{x}_{1,i} + \mathbf{H}_{1,i}\mathbf{W}_{0,i}\mathbf{P}_{0,i}\mathbf{x}_{0,i} + \mathbf{n}_{1,i} \end{aligned}. \qquad (10)$$

Since $\mathbf{W}_{0,i}$ is not orthogonal to $\mathbf{H}_{1,i}$, the inter-user interference exists at the distant STA. To mitigate this inter-user interference, the AP reduces the transmission power for the close STA, $\mathbf{P}_{0,i}$. The expectation of the inter-user interference at each receive antenna of the distant STA, I_1, is expressed as

$$I_1 = \sigma_1^2 \sum_{j=1}^{L_0} p_{0,j} = \sigma_1^2 P_0 \quad . \qquad (11)$$

where it is assumed that there is no correlation between $\mathbf{H}_{0,i}$ and $\mathbf{H}_{1,i}$. Thus, the inter-user interference can be mitigated by reducing I_1 by decreasing P_0. In this paper, the AP controls P_0 so as to make the inter-user interference, I_1, equal $\alpha\sigma^2$. Thus, the powers allocated to the close STA and distant STA, P_0 and P_1, are given as

$$P_0 = \frac{\alpha\sigma^2}{\sigma_1^2}, \quad P_1 = \sum_{j=1}^{L_1} p_{1,j} = 1 - \frac{\alpha\sigma^2}{\sigma_1^2}. \qquad (12)$$

The power allocated to the close STA decreases as the signal power at the distant STA increases. The allowable inter-user interference, $\alpha\sigma^2$, at the distant STA is determined by term α. When α is equal to one, the expectation of the inter-user interference power is the same as the noise variance, σ^2. Since the signal power at the close STA is significantly decreased, the required condition is indicated by $\sigma_0^2 >> \sigma_1^2$. The calculation complexity of the proposed method is less than that of the BD algorithm since Eq. 7 is not required.

C. Communication sequence

Fig. 2 shows transmission sequence models of SU-MIMO, ZF, BD, and the proposed method based on IEEE802.11 TGac Draft D1.0. We consider only downlink transmission and the saturated traffic situation. In SU-MIMO transmission, the AP first transmits a null data packet announcement (NDPA) and null data packet (NDP) for CSI estimation. The STA then lets the AP know the CSI via CSI feedback (CSI FB). By using CSI, the AP transmits to the close STA or the distant STA. In ZF and BD algorithm transmission, the AP receives CSI FB from the close and distant STAs after the transmission of NDPA and NDP. Data packets are then simultaneously transmitted to the close and distant STAs. In the proposed method, the transmission sequence is similar to that of the ZF and BD algorithm. However, the CSI FB from the distant STA is not required. $T_{D,0}$ and $T_{D,1}$ in the SU-MIMO scenario denote time durations of data symbols for the close STA and distant STA, respectively. T_D denotes the time duration of data symbols for the close STA and distant STA in MU-MIMO with ZF, BD and proposed method. It is assumed the close STA and distant STA have the same duration of data packets regardless of their throughput. Thus, MAC efficiencies of the close STA and distant STA in the SU-MIMO scenario, $\rho_{SU,0}$ and $\rho_{SU,1}$, that in ZF and BD, ρ_{MU}, and that in the proposed method, ρ_P, are given by

$$\rho_{SU,0} = \frac{T_{D,0}}{T_{SU}}, \quad \rho_{SU,1} = \frac{T_{D,1}}{T_{SU}}, \quad \rho_{MU} = \frac{T_D}{T_{MU}}, \quad \rho_P = \frac{T_D}{T_P}. \qquad (13)$$

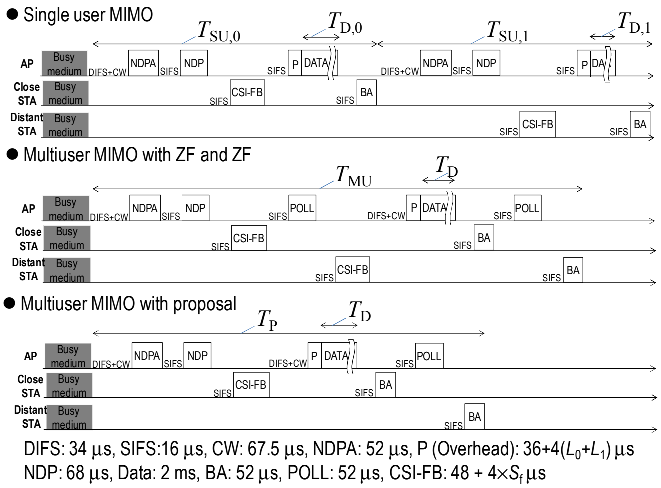

Fig. 2. Simplified transmission sequence model.

Table. I. Simulation parameters.

Bandwidth	80MHz
Number of data subcarriers	226
Length of data symbols	2 ms (500 OFDM symbols)
Length of OFDM symbol	4.0 μs
Tx and Rx antenna numbers	8 (Tx) and 4 (Rx)
Modulation schemes	QPSK, 16QAM, 64QAM, 256QAM
Coding rate	1/2, 2/3, 3/4, 5/6
Distance from the AP	20 cm (close STA), 10 m to 30 m (distant STA)
Noise variance	- 84 dBm
Quantization bit amount	12bit (DAC), 12bit (ADC)
Total transmission power	17 dBm

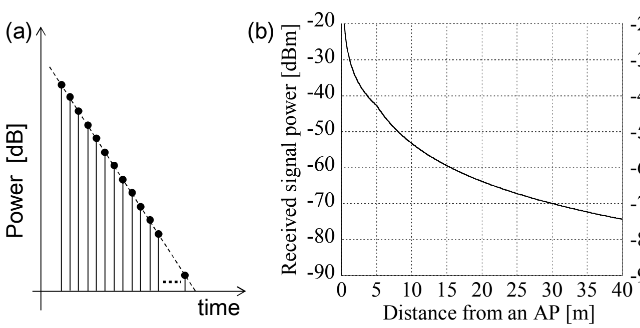

Fig. 3. Channel model.

III. Computer Simulations

Computer simulations were conducted to evaluate the transmission performance of the proposed method. Table I shows the simulation parameters. We considered an 80MHz bandwidth MIMO-OFDM system based on IEEE802.11 TGac Draft D1.0 [3]. Numbers of transmit antennas, receive antennas and data subcarriers were set to be eight ($M_t = 8$), four ($M_r = 4$), and 226 ($F = 226$). The close STA is assumed to be 30 cm from the AP, and the distance between the AP and distant STA, D, is varied from 15[m] to 40[m]. Modulation schemes of QPSK, 16QAM, 64QAM and 256QAM and convolutional coding were used and the AP selects the combination of modulation scheme and coding rate from 9 MCS indices indicated in [3]. To simplify the discussion of MAC efficiency, the time duration for data symbols, T_D, $T_{D,0}$, and $T_{D,1}$ was assumed to be 2 ms (500 OFDM symbols). Seven bits are reserved to feedback angles, ϕ and ψ in Eq. 4, N_B.. Thus, in an 8×4 MIMO channel, 352 bit ($22 \times N_B + 22 \times (N_B + 2)$) are needed for AP feedback in each subcarrier. The number of OFDM symbols for CSI feedback, S_f, depends on the uplink throughput. We select the MCS index of the uplink to maximize the throughput and to hold the PER under 10^{-2}. The transmissions using 256 QAM, coding rate of 5/6, and 4 spatial streams (corresponding to the close STA), and 16 QAM, coding rate of 1/2, and 4 spatial streams (corresponding to the distant STA for $D = 30$[m]) need 14 and 44 OFDM symbols for CSI feedback, respectively.

A. Channel model

Fig. 3(a) shows the delay profile in the time domain. We considered a simplified channel model that has 20 arriving waves; the powers of which are exponentially decreased. The channel delay spread was set to 50 nsec. The elements were assumed to be independent and identically distributed. The received power at the STA is shown in Fig. 3 (b). Fig. 3 (b) was based on the propagation model in [10]. Since the noise variance in the time domain was defined as – 84 dBm, the expected SNR of the close STA was 65.7 dB and those of the distant STA (D = 15, 20, 25, 30, 35, 40 [m]) were 24.6, 20.2, 16.8, 14.1, 11.7, and 9.7 dB.

B. Simulation Results

To evaluate the transmission performance of the proposed method, we used the system throughputs for SU-MIMO, ZF, BD, and proposed method as defined by

$$\begin{cases} C_{SU} = \frac{1}{2}\left(\rho_{SU,0} B_{SU,0}\left(1-\gamma_{SU,0}\right) + \rho_{SU,1} B_{SU,1}\left(1-\gamma_{SU,1}\right)\right) \\ C_{ZF} = \rho_{MU}\left(B_{ZF,0}\left(1-\gamma_{ZF,0}\right) + B_{ZF,1}\left(1-\gamma_{ZF,1}\right)\right) \\ C_{BD} = \rho_{MU}\left(B_{BD,0}\left(1-\gamma_{BD,0}\right) + B_{BD,1}\left(1-\gamma_{BD,1}\right)\right) \\ C_{P} = \rho_{P}\left(B_{P,0}\left(1-\gamma_{P,0}\right) + B_{BD,1}\left(1-\gamma_{P,1}\right)\right), \end{cases} \tag{14}$$

where $\gamma_{SU,k}$, $\gamma_{ZF,k}$, $\gamma_{BD,k}$, and $\gamma_{P,k}$ denote the respective packet error rates (PER) of SU-MIMO, ZF, BD, and proposed method; k identifies the close STA (k = 0) or the distant STA (k = 1). $B_{SU,k}$, $B_{ZF,k}$, $B_{BD,k}$, and $B_{P,k}$ denote bit rates calculated by the MCS index and spatial stream number, which are selected by round-robin search to maximize the system throughput in each method. When 256 QAM, 5/6 coding rate, and 4 spatial streams are used, the bit rate is calculated as 8 [bit] × (5/6) × 4 × 226/(4.0×10^{-6}) [μs] = 1.5 [Gb/s]. This paper does not consider retransmission of data packets.

Fig. 4 shows the system throughput of the proposed method versus α in Eq. 10 when the distances between the AP and the distant STA are 15m, 25m and 35m. We can see that optimum value for α depends on the SNR condition of the distant STA. In this paper, we show the throughputs of the proposal with α = 0 dB and that with α selection, which corresponds to the optimum value for α. Fig. 5 shows the system throughputs in the SU-MIMO, ZF algorithm, BD algorithm, and proposed methods. The proposed method with α = 0 dB outperforms SU-MIMO if D is greater than 25 [m]. Compared to ZF and BD algorithms, the proposed method is effective in the region where D is greater than 25 [m] and 30 [m], even though the distant STA does not feed the CSI back to the AP. The throughputs of the proposed method with α selection are greater than those with α = 0 dB when D is less than 35 [m]. It is found that α selection extends the effective region of the proposed method. Although these computer simulations consider static channels, the transmission performance of ZF and BD algorithm is thought to deteriorate if the distant STA experiences by the time varying channel, which is expected in an actual environment. Even in the static environment, the throughput of the proposed methods is 19% and 10 % greater than those of ZF and BD algorithms when D is 35m. Fig.6 shows the throughput of each STA for the ZF, BD and proposed methods. It is found that the throughput of the close STA in the proposed method with α = 0 [dB] decreases as the distance shortens. This decrease is caused by the reduction in transmission power for the close STA. On the other hand, the throughput of the close STA in the proposed method with α selection does not decrease regardless of D by allowing for the large inter-user interference at the distant STA. We can see that the proposed methods with α of 0 dB and with α selection offer a higher distant STA throughput and higher close STA throughput than those in ZF and BD algorithms, respectively.

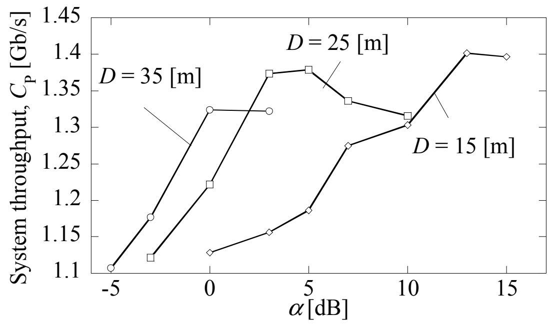

Fig. 4. System throughput of proposed method versus α.

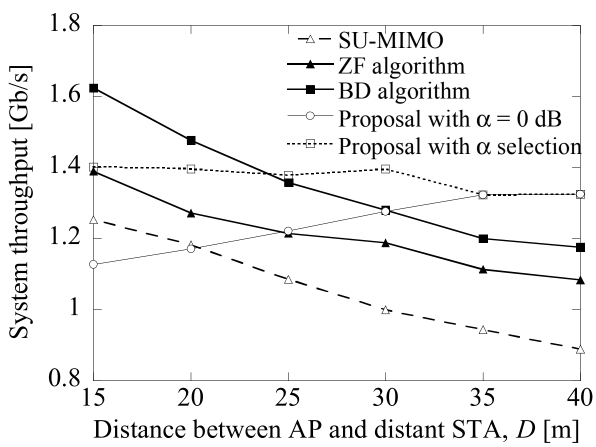

Fig. 5. Comparison of system throughputs of SU-MIMO, ZF, BD, and proposal.

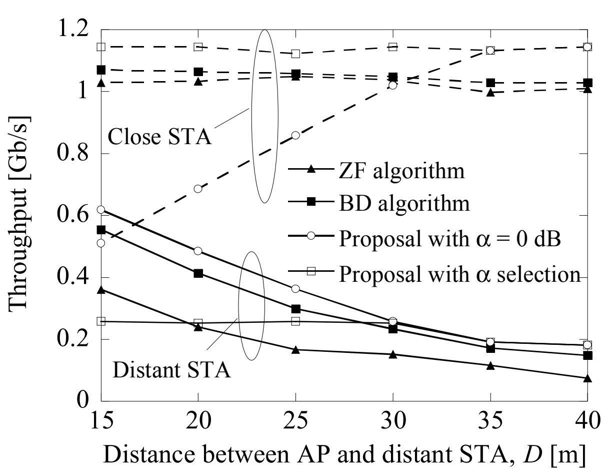

Fig. 6. System throughputs of the close STA and distant STA: ZF, BD, and proposal.

IV. CONCLUSION

A new MU-MIMO transmission scheme based on the successive optimization algorithm for wireless LAN systems has been presented for the scenario where there are two STAs, close and distant STAs. Since the transmission weights are calculated by using CSI from just the close STA, the distant STA does not have to feed its CSI back to the AP. This operation lightens the overload of the transmission weight calculation and increases MAC efficiency. Furthermore, the proposed method enables MU-MIMO transmission with the distant STA that does not support CSI notification. In the proposed method, the inter-user interference at the distant STA can be controlled by the term α. Computer simulations clarified the effective regions of the proposed method with α = 0 dB and α selection. It was found that the throughput of the proposed method is 19% and 10% higher than those of ZF and BD algorithms if the distant STA is 35m from the AP.

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