Optimizing Multiuser Multimedia Transmission Through Power Allocation in SLNR-precoding-based MISO Downlink Systems

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***Abstract*—Transmission of the multimedia video streaming has been an important topic in wireless communications. As a metric of video quality at the application layer, peak signal-to-noise ratio (PSNR) is affected by the capacity at the physical layer which can be improved by power controlling and precoding. This paper investigates an optimal power allocation scheme which can maximize the sum PSNR of all users in an SLNR-precoding-based multiuser multiple input single output (MISO) system. The power allocation problem can be transformed into a convex optimization problem when the system works in the high signal to interference plus noise ratio (SINR) region. Performance of the proposed power allocation scheme is evaluated through computer simulation. Results show that, when the system works in the high SINR region, performance improvement in terms of sum PSNR through power allocation is neglectable while the effects of different precoding schemes on the sum PSNR performance are obvious.**

***Index Terms*—Power allocation, signal to leakage noise ratio (SLNR) precoding, multiuser multimedia transmission.**

I. INTRODUCTION

The development of mobile internet has greatly influenced the way of acquiring information and brought a huge challenge to wireless communications. More and more demands on Quality of Service (QoS) have been emerging, which depend not only on the wireless communication speed but also on the information content to be transmitted. Transmission of multimedia video over such mobile internet is of increasing importance in both business and research fields. For multimedia video streaming, peak signal-to-noise ratio (PSNR) is an important metric for video quality measurement [1], which is a function of the distortion of the reconstructed video at the receiver measured with mean square error (MSE). This distortion comes from some aspects such as video compression and packet loss distortion. Considering one or part of these factors, many distortion models are proposed and discussed [2], [3], [4].

The performance at the application layer is always affected and limited by parameters at the physical layer, for instance the channel capacity, which limits transmission data as well as the coding rate. As a function of coding rate, the distortion of signals seen from the application layer will thereby be limited by system capacity. This tells that performance at the application layer can be enhanced through some physical layer improvements under cross layer frameworks. At the physical layer, some techniques are used to improve the capacity performance, such as multiple antenna technique [5], cooperative communication technique [6], and some joint design based on these techniques [7]. These schemes have the potential of increasing the video quality at the application layer from the cross layer point of view, such as [8].

In the recent years, multiple antenna technique is generally accepted as a key technique which can improve system capacity. It is also a fact that employing multiple antennas, especially in the multi-user system, cause inter-stream and inter-user interference. To improve such kinds of interference and combat the channel fading, precoding is proposed [9], [10], [11]. Sadek et al. proposed a precoding scheme in the multi-user (MU) multiple input multiple output (MIMO) system by means of defining a novel concept signal to leakage and noise ratio (SLNR) [12]. SLNR precoding scheme is an important precoding because of its advantages, for example, there exists no number limit of the transmit antennas and meanwhile, this is a precoding scheme that deals with not only the interference from the other users but also the additive noise at the receiver. Therefore, SLNR precoding has been paid much attention and studied considering some other physical layer techniques, like space time coding [12], multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) [13]. Power allocation in the precoding-based system is often designed for the objective such as improving the QoS performance of the cell-edge users [14] and improving the sum rate performance [15], [16], most of which are to achieve performance gains at the physical layer. This may not lead an optimal performance at the application layer.

For the multiuser multimedia transmission, the sum PSNR of all users, equivalent to the average PSNR of all users for a certain user number, is an important system level measurement for the wireless video transmission. In this paper, for the multiuser multi-input single-output (MU-MISO) SLNR-precoding-based system, to improve the quality of the video transmission, we propose an optimal power allocation scheme which can maximize the sum PSNR of all users and discuss

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the effects of the power controlling together with the different precoding schemes on the sum PSNR performance.

The rest of this paper is organized as follows. Section II introduces the system model and formulates the corresponding power allocation problem. In section III, the proposed power allocation problem is investigated. Simulation results are presented to evaluate the effects of different power allocations and different precoding schemes in terms of sum PSNR performance in section IV. Then, the conclusions are drawn in Section V.

Notation: $\mathbf{V}^{\mathrm{H}}$ and $\mathbf{V}^{-1}$ denote the conjugate transpose and inverse transformation of matrix $\mathbf{V}$, respectively. $\mathbf{I}$ is the the identity matrix with the corresponding dimension. The absolute value of scalar v and the norm of the matrix $\mathbf{V}$ are represented by $|v|$ and $\|\mathbf{V}\|$, respectively. $\times$ denotes the Cartesian product.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. Physical Layer Model

We focus on the multiuser multi-input single-output (MU-MISO) downlink where there exist a base station equipped with N_t antennas, and a set of mobile terminals, denoted as $\mathcal{K}$ with K elements. Due to the limit of size, each mobile terminal is equipped with only one antenna. Before transmitting, the single-stream data of each user is processed through precoding. Then, the transmitted signal $\mathbf{x}$ can be represented as

$$\mathbf{x} = \sum_{k\in\mathcal{K}} \mathbf{w}_k s_k, \tag{1}$$

where s_k is the symbol transmitted by user k and $\mathbf{w}_k \in \mathbb{C}^{N_t\times 1}$ is the corresponding normalized precoding vector designed based on the equal power allocation among users, i.e. $\mathrm{E}[\|\mathbf{w}_k\|^2] = 1$ for every $k \in \mathcal{K}$. Without loss of generality, for every user, the average power of the symbol to be transmitted is of unit norm, i.e. $\mathrm{E}[|s_k|^2] = 1$. Then, the total power P_t can be computed as $\mathrm{E}[\|\mathbf{x}\|^2] = \mathrm{E}[\mathbf{x}^H\mathbf{x}] = K$.

Then, the corresponding power allocation is proposed to further improve the system performance on the basis of the precoding vectors designed. After power allocation, equation (1) can be rewritten as

$$\mathbf{x} = \sum_{k\in\mathcal{K}} \sqrt{p_k}\mathbf{w}_k s_k. \tag{2}$$

where p_k represents the power allocated to user $k \in \mathcal{K}$ and the minimum power allocated to each user is denoted as P_{min}, i.e. $p_k \geq P_{min}, \forall k \in \mathcal{K}$. The total transmission power $\mathrm{E}[\mathbf{x}^H\mathbf{x}] = \sum_{k\in\mathcal{K}} p_k$ should be constrained as follows

$$\sum_{k\in\mathcal{K}} p_k \leq P_t. \tag{3}$$

In this paper, we assume that full channel state information (CSI) is available at the base station. The wireless channel is modeled as a block fading channel considering both the large scale loss and small scale loss. $\hat{\mathbf{h}}_i \in \mathbb{C}^{1\times N_t}, i \in \mathcal{K}$ denotes the small scale loss caused by multipath effect and is represented as a vector containing N_t independent identically distributed complex gaussian variables with zero mean together with unit variance. In addition, the large scale loss is modeled by path loss and expressed as $d_i^{-\alpha}$, where the d_i is the distance from base station to mobile user i and α is the corresponding path loss exponent. Then, the channel vector $\mathbf{h}_i$ can be shown as

$$\mathbf{h}_i = d_i^{-\alpha/2}\hat{\mathbf{h}}_i, \tag{4}$$

and the received signal at user $i \in \mathcal{K}$ can be represented as

$$\mathbf{y}_i = \mathbf{h}_i\mathbf{x} = \mathbf{h}_i\sqrt{p_i}\mathbf{w}_i s_i + \mathbf{h}_i \sum_{k\in\mathcal{K}/i} \sqrt{p_k}\mathbf{w}_k s_k, \forall i \in \mathcal{K}. \tag{5}$$

The precoding applied at the base station is SLNR precoding proposed in [12], which is designed by maximizing the notion SLNR defined. For the system studied in this paper, the SLNR precoding $\mathbf{w}_i$ for user $i \in \mathcal{K}$ can be obtained through solving the normalized eigenvector corresponding to the maximum eigenvalue of the matrix defined in (6)

$$(\sigma_i^2\mathbf{I} + \sum_{k\in\mathcal{K}/i} \mathbf{h}_k^{\mathrm{H}}\mathbf{h}_k)^{-1}\mathbf{h}_i^{\mathrm{H}}\mathbf{h}_i, \tag{6}$$

and readers are referred to [12] for more details about the SLNR precoding.

The signal to interference plus noise ratio (SINR) at receiver i can be expressed as

$$\mathrm{SINR}_i = \frac{\chi_i p_i |\mathbf{h}_i\mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k\in\mathcal{K}/i} p_k|\mathbf{h}_i\mathbf{w}_k|^2}, \forall i \in \mathcal{K}, \tag{7}$$

where χ_i represents the spreading coefficient[1] and the corresponding capacity for user i shows

$$C_i = B\log_2(1 + \frac{\chi_i p_i |\mathbf{h}_i\mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k\in\mathcal{K}/i} p_k|\mathbf{h}_i\mathbf{w}_k|^2}), \forall i \in \mathcal{K}. \tag{8}$$

where B is the bandwidth.

B. Application Layer Model

The video quality of user i (which is expressed as PSNR in this paper) can be represented as [2],

$$\mathrm{PSNR}_i = 10\log_{10}\frac{255^2}{D_i}, \forall i \in \mathcal{K}, \tag{9}$$

where the video distortion D_i for user i is often described and quantized by the mean square error (MSE) between the video sequence before transmitting and the reconstructed video sequence[2],[3]. In this paper, we assume there exists no distortion caused by packet loss together with bit error during the wireless transmission when the capacity at the physical layer can afford the output rate at the application layer, and only consider the distortion caused by the video encoder. This can be guaranteed by some advanced capacity approaching techniques. Then, the corresponding MSE is only affected by the output rate of the video encoder. Specifically, the MSE decreases as the output rate increases. In our formulated problem, the encoder distortion D_i for user $i \in \mathcal{K}$, as a

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[1] To make the model more general, we introduce a spreading coefficient χ_i for each user i. The model coincides with a narrow band system if $\chi_i = 1$ and with a wide band if $\chi_i \gg 1$.

function of the output rate of video encoder R_i, is modeled using the MSE-based distortion-rate (D-R) model in [3],

$$D_i(R_i) = \frac{a_i}{\exp(R_i/b_i) - 1}, \forall i \in \mathcal{K}, \tag{10}$$

where a_i and b_i are video-dependent coefficients that can be determined off-line through fitting based on experimental measurements or estimated on-line.

C. Problem Formulation

In this paper, our optimization objective is to maximize the sum PSNR of all users through adjusting the transmission power of each user, with the given precoding vectors and the full channel state information (CSI). Then, the optimization problem can be formulated as

$$\text{Given} : \mathbf{h}_i, \mathbf{w}_i, \chi_i, \sigma_i^2, a_i, b_i, P_t, P_{min}, B, \forall i \in \mathcal{K} \tag{11}$$

$$\text{Find} : p_i, R_i, \forall i \in \mathcal{K} \tag{12}$$

$$\text{Maximize} : \sum_{i \in \mathcal{K}} 10 \log_{10} \frac{255^2}{\frac{a_i}{\exp(R_i/b_i) - 1}} \tag{13}$$

$$\text{Subject to} : \sum_{i \in \mathcal{K}} p_i \leq P_t \tag{14}$$

$$p_i \geq P_{min}, \forall i \in \mathcal{K} \tag{15}$$

$$R_i \leq C_i, \forall i \in \mathcal{K}, \tag{16}$$

$$C_i = B \log_2\left(1 + \frac{\chi_i p_i |\mathbf{h}_i \mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k \in \mathcal{K}/i} p_k |\mathbf{h}_i \mathbf{w}_k|^2}\right), \forall i \in \mathcal{K}. \tag{17}$$

The constraint set defined in (16) means that the output rate parameter R_i at the application layer is limited by the channel capacity C_i because that the transmission rate below capacity is the necessary condition of the no error transmission at the physical layer.

III. SUM-PSNR OPTIMAL POWER ALLOCATION

The optimization problem formulated in (11)-(17) is a non-convex optimization problem. This makes the problem hard to obtain the globally optimal solution using the standard convex optimization techniques.

We can find that the PSNR_i defined in (9) is a monotonically increasing function of the encoding rate R_i[2]. Meanwhile, the achievable encoding rate at the application layer is bounded by the the corresponding capacity at the physical layer. Then, the maximum PSNR of a certain user can be achieved by substituting the capacity C_i into the PSNR function defined in (9). On the other hand, when the achievable capacity of every user is fixed, the video encoding rate R_i of each user i is independent with those of the other users. Therefore, the maximal sum PSNR of all users can be reached when the encoding rate of every user achieves the corresponding physical layer channel capacity at the same time. Mathematically, we denote the chosen encoding rate vector as $\mathbf{R} = [R_1, R_2, \cdots, R_K]$ and the possible set of the encoding rate as $\mathfrak{R} = [0, C_1] \times [0, C_2] \cdots \times [0, C_K]$. Then, the optimal sum PSNR of all users can be achieved as follows

$$\arg\max_{\mathbf{R} \in \mathfrak{R}} \sum_{i \in \mathcal{K}} \text{PSNR}_i(\mathbf{R}) = [C_1, C_2, \cdots, C_K]. \tag{18}$$

So, the optimization objective defined in (13) can be transformed into a function about the channel capacity, i.e.

$$\text{PSNR}_i = 10 \log_{10} \frac{255^2}{\frac{a_i}{\exp(C_i/b_i) - 1}}. \tag{19}$$

Meanwhile, many wireless systems can provide large spreading gain, such as the code division multiple access (CDMA) system[3]. These systems can be regarded as working in the high SINR region because the SINR at the receiver can take values much larger than one at a relatively high probability. Then, the capacity expression (8) can be written by ignoring the term 1 as

$$C_i = B \log_2\left(\frac{\chi_i p_i |\mathbf{h}_i \mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k \in \mathcal{K}/i} p_k |\mathbf{h}_i \mathbf{w}_k|^2}\right). \tag{20}$$

To transform the formulated problem defined in (11)-(17) into a convex optimization problem, with the help of Geometric Programming (GP) [17], the capacity can be expressed through substituting $\vartheta_i = \ln(p_i)$ for $\forall i \in \mathcal{K}$ into (20), i.e.

$$\begin{aligned} C_i =& B \ln\left(\frac{\chi_i e^{\vartheta_i} |\mathbf{h}_i \mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k \in \mathcal{K}/i} e^{\vartheta_k} |\mathbf{h}_i \mathbf{w}_k|^2}\right) / \ln(2) \\ =& B[\ln(\chi_i |\mathbf{h}_i \mathbf{w}_i|^2) + \vartheta_i - \ln(\sigma_i^2 + \sum_{k \in \mathcal{K}/i} e^{\vartheta_k} |\mathbf{h}_i \mathbf{w}_k|^2)] / \ln(2) \\ =& [\underbrace{\ln(\chi_i |\mathbf{h}_i \mathbf{w}_i|^2) + \vartheta_i}_{(*)} \underbrace{- \ln(e^{\ln \sigma_i^2} + \sum_{k \in \mathcal{K}/i} e^{\vartheta_k} |\mathbf{h}_i \mathbf{w}_k|^2)]}_{(**)} \frac{B}{\ln(2)}. \end{aligned} \tag{21}$$

The term (**) is a concave function with $\vartheta_1, \vartheta_2, \cdots, \vartheta_K$ and the term (*) is a linear function with $\vartheta_1, \vartheta_2, \cdots, \vartheta_K$. Then, C_i has been transformed into a concave function about $\vartheta_1, \vartheta_2, \cdots, \vartheta_K$. So, we have the following proposition.

Proposition 1. PSNR_i *is a concave function with variables* $\vartheta_1, \vartheta_2, \cdots, \vartheta_K$*, for* $\forall i \in \mathcal{K}$.

Proof: The first and second order derivatives of PSNR_i defined in (19) with respective to C_i can be computed as

$$\text{PSNR}_i^{(1)}(C_i) = \frac{10}{b_i \ln(10)} \left(1 + \frac{1}{(\exp(C_i/b_i) - 1)}\right), \tag{22}$$

and

$$\text{PSNR}_i^{(2)}(C_i) = -\frac{10}{b_i^2 \ln(10)} \frac{\exp(C_i/b_i)}{(\exp(C_i/b_i) - 1)^2}, \tag{23}$$

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[2] This can be proved by the property of its first order derivative. In addition, intuitively, as the output rate of the video encoder increases, the MSE of the reconstructed video will decrease and the corresponding PSNR will be improved.

[3] In practical CDMA systems, the spreading codes can not be ensured perfectly orthogonal and so that this leads to that there still exists inter-user interference at a specific receiver. With the help of precoding and power controlling, the effects of the interference from the other users can be further eliminated.

respectively. Because the coefficient b_i is positive [3], the first order derivative is always positive and this ensures that PSNR_i is an increasing function with C_i. Meanwhile, the second order derivative is always negative and this leads the PSNR_i to be a concave function with C_i [18]. In addition, as described in the above paragraph, C_i is a concave function according to the variables $\vartheta_1, \vartheta_2, \cdots, \vartheta_K$. Due to the composition property of the convexity described by (3.10) in [18], PSNR_i can be judged as a concave function with the variables $\vartheta_1, \vartheta_2, \cdots, \vartheta_K$. ■

Then, the optimization problem formulated in (11)-(16) can be transformed into

$$\text{Given}: \mathbf{h}_i, \mathbf{w}_i, \chi_i, \sigma_i^2, a_i, b_i, P_t, P_{min}, B, \forall i \in \mathcal{K} \quad (24)$$

$$\text{Find}: \vartheta_i, \forall i \in \mathcal{K} \quad (25)$$

$$\text{Maximize}: \sum_{i\in\mathcal{K}} 10\log_{10}\frac{255^2}{\frac{a_i}{\exp(C_i/b_i)-1}} \quad (26)$$

$$\text{Subject to}: \sum_{i\in\mathcal{K}} e^{\vartheta_i} \le P_t \quad (27)$$

$$e^{\vartheta_i} \ge P_{min}, \forall i \in \mathcal{K} \quad (28)$$

$$C_i = B\log_2\left(\frac{\chi_i e^{\vartheta_i}|\mathbf{h}_i\mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k\in\mathcal{K}/i} e^{\vartheta_k}|\mathbf{h}_i\mathbf{w}_k|^2}\right), \quad (29)$$

which has been converted into a convex optimization problem, and the transformed problem defined in (24)-(29) can be solved by the standard convex optimization techniques. Consequently, the power variables $p_1, p_2, \cdots p_K$ can be obtained through $p_i = e^{\vartheta_i}, \forall i \in \mathcal{K}$.

IV. SIMULATION RESULTS AND ANALYSIS

In this section, we simulate a four-user SLNR-precoding-based MISO broadcasting downlink system. Without loss of generality, the distance from the base station to a specific user can be normalized and then, the relative distances of all users in our simulation are set as 1, 1, $\sqrt{2}$ and 1. To measure the path loss during signal transmission, the path loss exponent α is set to 4. The additive noise at each receiver is set to the same variance σ^2. Then, the sum PSNR performance of all users are evaluated and plotted versus the received SNR of the user with the normalized distance, i.e., $10\log(1/\sigma^2)$. The minimum power allocated to every user is set 0.2 in our simulation. The spreading gain of each user is set to 200 and the bandwidth B is 15KHz. In our simulation, the multimedia video will be transmitted only when the system works in the high SINR region [4]. In the simulations, two video sequences, *Foreman* (FM) and *Mother and Daughter* (MD) are considered representing drastic and light motion characteristics, respectively. The corresponding parameters for these two sequences are obtained by the pairs of training rate and distortion in [3]. In this paper, we simulate the scenarios with four transmit antennas and two transmit antennas respectively. The optimization problem defined in (24)-(29) is solved by `CVX` matlab package [19] [5]. All the results are averaged over 1000 independent simulations.

We compare the optimal sum PSNR power allocation proposed in Section III (denoted as PSNRopt scheme), with two other power allocation schemes for a performance evaluation: i) power allocation maximizing the sum capacity of all users (denoted as Capacityopt scheme), ii) equal power allocation (denoted as Equalpower).

In addition, three precoding schemes are considered for performance comparison: i) the signal to leakage and noise ratio (SLNR) precoding proposed in [12], ii) the zero-forcing (ZF) precoding referred in [12] and iii) no precoding (NP) process at the transmitter, which means the normalized diversity vectors $[\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}]$ and $[\frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}]$ are used at the transmitter in our simulation for the two transmit antenna scenario and four transmit antenna scenario, respectively.

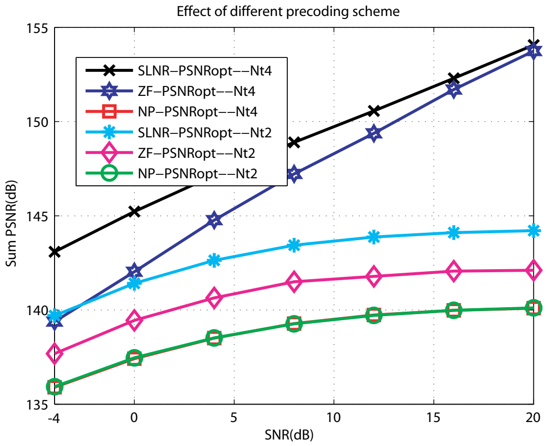

Figure 1. Effects of different precoding schemes when the sum PSNR optimal power allocation is used

In Fig. 1, we compare the sum PSNR performance based on the SLNR precoding with the performance based on the other precoding schemes referred above, when the sum PSNR optimal power allocation proposed is applied at the transmitter, for two and four transmit antennas respectively. In the simulation, the video transmitted to user 1, 2 is MD sequence and the video transmitted to user 3, 4 is FM sequence. From the figure, we can find the sum PSNR improvement provided by precoding is obvious and the corresponding effects differ from different precoding schemes. The sum PSNR performance provided by SLNR precoding is better than that supported by ZF precoding and the transmission without precoding corresponds to the worst performance. In addition, when precoding is used, more transmit antennas can provide better sum PSNR performance because of more capacity improvements.

When the number of the transmit antennas is larger than the number of interference users ($Nt = 4$) which leads to the precoding process efficient, the sum PSNR performance

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[4] In the simulation, we take the condition that the minimum SINR of all users before and after the power allocation is larger than 10 as the judgement whether the system works in the high SINR region.

[5] The optimization problem defined in (24)-(29) is not a standard form for the `CVX` matlab package but can be transformed into a solvable one through linear relaxation techniques. The readers can refer to more details in the Appendix.

based on the SLNR precoding outperforms the performance based on ZF precoding in the low SNR region. However, the differences between these two schemes becomes smaller as the SNR increases and looks much the same when the SNR approaches to 20 dB. The reason for this phenomenon is that the SLNR precoding is designed to combat the interference and additive noise simultaneously. In the low SNR region, the additive noise is an important factor which affects the SINR at the receiver to a great extent and the SLNR precoding plays a greater role compared with ZF precoding on both the capacity performance and the PSNR performance. But, in the high SNR region, the effects of the additive noise are tiny and can be ignored while the interference from the other users dominates the SINR. Then, the effects of ZF precoding on sum PSNR performance are close to the effects based on SLNR precoding. On the other hand, when the number of the transmit antennas is less than the number of interference users ($Nt = 2$), the effects of the precoding schemes are limited, especially for the ZF precoding, and then, the corresponding sum PSNR does not embody the trend above. But, from the figure, compared with the scheme without precoding, to apply precoding at the physical layer still plays a role on PSNR performance even when the number of the transmit antennas is not large enough.

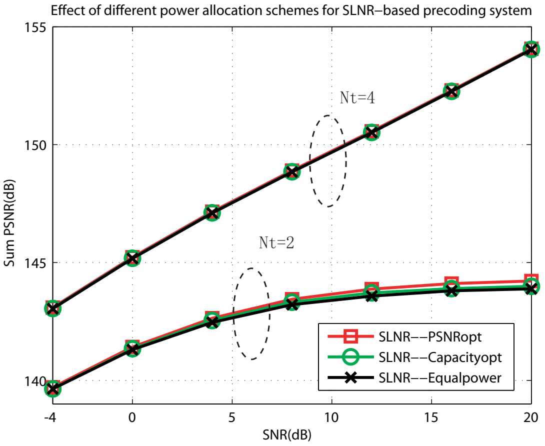

Figure 2. Effects of different power allocations in SLNR-precoding-based system

In Fig. 2, we evaluate the sum PSNR performance of different power allocations in the SLNR-precoding-based system, when MD sequence is transmitted to user 1, 2 and FM sequence is transmitted to user 3, 4. From the figure, we can find the optimal power allocation proposed in Section III makes tiny differences comparing with Capacityopt scheme and Equalpower scheme when the system works in the high SINR region. From the simulation results, we can obtain some interesting conclusions. In the SLNR-precoding-based MISO system, for the sum PSNR performance of all the transmitted video, the improvement provided by power allocation is tiny and neglectable when the system works in the high SINR region. It is unnecessary to use a cross-layer-based power allocation to maximize the sum PSNR or a single-layer-based power allocation to maximize the sum capacity at the physical layer and the equal power allocation can provide almost the same performance. This phenomenon can be partially explained from the following aspect. The improvements provided by power allocation to the capacity performance are limited when the system works in the high SINR region due to the monotonically decreasing gradient of the capacity curve. Meanwhile, in our formulated problem, when the capacity is substituted into the equation (10) and divided by a large positive number b, the effects of power allocations on the PSNR performance are further weakened compared with the effects on capacity.

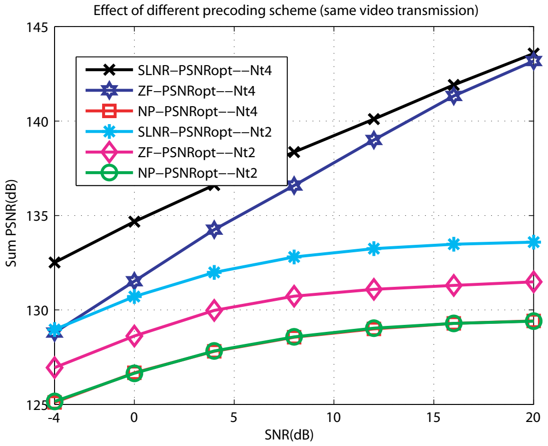

Figure 3. Effects of different precoding schemes when the same video sequence is transmitted

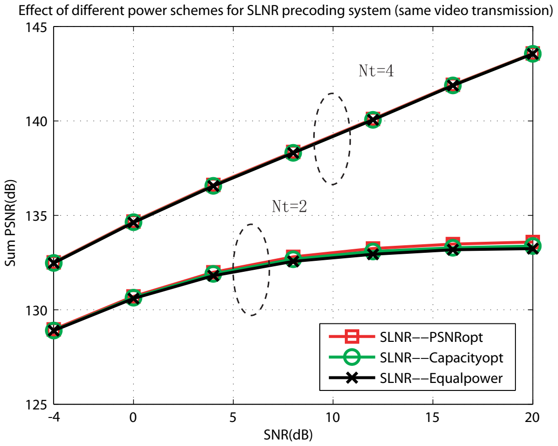

Figure 4. Effects of different power allocations when the same video sequence is transmitted

From Fig. 3 and Fig. 4, where FM video sequence is transmitted to all the users in the same simulation scenario as Fig. 1 and Fig. 2 respectively, the same conclusions can be obtained.

V. CONCLUSION

In this paper, we have investigated a power allocation scheme that can maximize the sum PSNR of all users in the SLNR-precoding-based MU-MISO system. When the system works in the high SINR region, the formulated problem can be transformed into a convex optimization through a series of monotonic analysis, geometric programming and composition property of convexity. Then, we evaluate the effects of the proposed power allocation and furthermore discuss the effects of precoding together with power allocation on the sum PSNR performance. Simulation results showed that different power allocations made a negligible difference about the sum PSNR performance when the system studied works in the high SINR region while different precoding schemes provided different improvements in terms of sum PSNR performance.

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APPENDIX

A. Linear relaxation for the formulated power allocation problem

We use the linear relaxation technique to transform the optimization defined in (24)-(29) into a solvable form for the `CVX` package. The objective of the formulated optimization is to achieve the maximum of the sum of concave functions $\mathrm{PSNR}_i(C_i)$ defined in (19). To this end, we use a large amount of tangents of the function (19) to describe and limit the upper bound of PSNR_i, i.e.

$$\mathrm{PSNR}_i \le \mathrm{PSNR}_i(C_i(t)) + \mathrm{PSNR}_i'(C_i(t))(C_i - C_i(t)), \quad \forall i \in \mathcal{K}, \forall t \in \{1, 2, \cdots T\}, \tag{30}$$

where PSNR_i' represents the derivative of PSNR for C_i and $C_i(t)$ with $t \in \{1, 2, \cdots T\}$ denotes the C_i corresponding to the tth tangent. These tangents are uniformly distributed in the feasible set $[C_i^L, C_i^U]$. C_i^L and C_i^U represent the lower bound and upper bound of C_i respectively. Then, $C_i(t)$ shows

$$C_i(t) = C_i^L + (t-1)\frac{(C_i^U - C_i^L)}{(T-1)}. \tag{31}$$

With the help of the constraints defined in (30), the objective function has been transferred into a linear function and the optimization problem can be transformed into

$$\begin{aligned}
\text{Given}: & \mathbf{h}_i, \mathbf{w}_i, \chi_i, \sigma_i^2, a_i, b_i, P_t, P_{min}, && (32)\\
& B, C_i^L, C_i^U, \forall i \in \mathcal{K} && (33)\\
\text{Find}: & \vartheta_i, \forall i \in \mathcal{K} && (34)\\
\text{Maximize}: & \sum_{i\in\mathcal{K}} \mathrm{PSNR}_i && (35)\\
\text{Subject to}: & \sum_{i\in\mathcal{K}} e^{\vartheta_i} \le P_t && (36)\\
& e^{\vartheta_i} \ge P_{min}, \forall i \in \mathcal{K} && (37)\\
& C_i = B\log_2\left(\frac{\chi_i e^{\vartheta_i}|\mathbf{h}_i\mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k\in\mathcal{K}/i} e^{\vartheta_k}|\mathbf{h}_i\mathbf{w}_k|^2}\right), && (38)\\
& (30). && (39)
\end{aligned}$$

This linear relaxation of PSNR will be more effective when more tangents are used within the scope of C_i because more tangents describe the PSNR curve more accurately and the corresponding power allocation obtained will be more closer to the actual optimal scheme. Then, based on the above transformation, the optimization problem defined in (32)-(39) can be solved by the `CVX` matlab package [19].

REFERENCES

[1] S. Khan, Y. Peng, E. Steinbach, M. Sgroi, and W. Kellerer, “Application-driven cross-layer optimization for video streaming over wireless networks,” *IEEE Communications Magazine*, vol. 41, no. 1, pp. 122–130, Janurary 2006.

[2] K. Stuhlmüler, A. Fäber, M. Link, and B. Girod, “Analysis of video transmission over lossy channels,” *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 6, pp. 1012–1032, June 2000.

[3] L. U. Choi, M. T. Ivrlač, E. Steinbach, and J. A. Nossek, “Sequence-level models for distortion-rate behaviour of compressed video,” in *2005 IEEE International Conference on Image Processing*, September 2005.

[4] X. Zhu, E. Setton, and B. Girod, “Congestion distortion optimized video transmission over ad hoc networks,” *EURASIP Signal Processing: Image Communication*, vol. 20, no. 8, pp. 773–783, September 2005.

[5] E. Telatar, “Capacity of multi-antenna gaussian channels,” *European Transactions on Telecommunications*, vol. 10, no. 6, pp. 585–595, November-December 1999.

[6] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior,” *IEEE Transactions on Information Theory*, vol. 50, no. 12, pp. 3062–3080, December 2004.

[7] L. Yu, J. Liu, and K. Long, “Analysis of Virtual MIMO-Based Cooperative Communication in Femtocell Networks ,” in *2011 IEEE Global Telecommunications Conference*, December 2011.

[8] Z. Guan, T. Melodia, and D. Yuan, “Optimizing cooperative video streaming in wireless networks,” in *2011 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks*, June 2011.

[9] M. Joham, W. Utschick, and J. A. Nossek, “Linear transmit processing in mimo communications systems,” *IEEE Transactions on Signal Processing*, vol. 53, no. 8, pp. 2700–2712, August 2005.

[10] V. Stankovic and M. Haardt, “Generalized design of multi-user mimo precoding matrices,” *IEEE Transactions on Wireless Communications*, vol. 7, no. 3, pp. 953–961, March 2008.

[11] H. Zhang, M. T. Ivrlač, J. A. Nossek, and D. Yuan, “On multiuser mimo multistream transmission,” *IEEE Transactions on Vehicular Technology*, vol. 58, no. 9, pp. 5336–5341, November 2009.

[12] M. Sadek, A. Tarighat, and A. H. Sayed, “A leakage-based precoding scheme for downlink multi-user mimo channels,” *IEEE Trans. Wireless Communications*, vol. 6, no. 5, pp. 1711–1721, May 2007.

[13] M. Sadek and S. Aissa, “Leakage based precoding for multi-user mimo-ofdm systems,” *IEEE Transactions on Wireless Communications*, vol. 10, no. 8, pp. 2428–2433, August 2011.

[14] U. Phuyal, S. C. Jha, and V. K. Bhargava, “Joint zero-forcing based precoder design for qos-aware power allocation in mimo cooperative cellular network,” *IEEE Journal on Selected Areas in Communications*, vol. 30, no. 2, pp. 350–358, February 2012.

[15] S. Feng, M. M. Wang, W. Yaxi, F. Haiqiang, and L. Jinhui, “An efficient power allocation scheme for leakage-based precoding in multi-cell multiuser mimo downlink,” *IEEE COMMUNICATIONS LETTERS*, vol. 15, no. 10, pp. 1053–1055, October 2011.

[16] X. Jin, Y. Yang, L. Tian, D. Pang, J. Shi, and E. Dutkiewicz, “QoS-Aware Optimal Power Allocation with Channel Inversion Regularization Precoding in MU-MIMO,” in *2009 IEEE International Conference on Communications*, June 2009.

[17] M. Chiang, C. W. Tan, D. P. Palomar, D. ONeill, and D. Julian, “Power control by geometric programming,” *IEEE Transactions on Wireless Comunications*, vol. 6, no. 7, pp. 2640–2651, July 2007.

[18] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge University Press, 2004.

[19] M. Grant and S. Boyd, “CVX: Matlab software for disciplined convex programming, version 1.21,” 2011, http://cvxr.com/cvx/.