Int. J. Communications, Network and System Sciences, 2010, 3, 612-619
doi:10.4236/ijcns.2010.37082 Published Online July 2010 (http://www.SciRP.org/journal/ijcns/).

Techniques of Transmitting Beamforming to Control the Generated Weights

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Received April 16, 2010; *revised May* 25, 2010; *accepted June* 29, 2010

Abstract

In this paper, we consider the limited feedback Transmitting Beamforming for (multiple in single out) MISO systems. In conventional techniques, all vectors of a large codebook (CB), used for the feedback of the quantized channel state information (CSI), are broadcasted to all users, in a guard period which is followed by data burst periods. Instead of transmitting a large number of codevectors, we thought to divide the CB into several sub-codebooks (SC) and the broadcast would be based on the switch between them. Accordingly, a good performance can be provided while minimizing the required feedback channel capacity applying some proposed techniques such as "the switched Sub Codebook (SSC)" and "the Fairness SSC (FSSC)". To minimize the quantization error, we propose two other techniques. The first is based on making Transmit SSC vectors controlled by a rotation weight (RW) to obtain almost a zero correlation between the SSC vectors used for the selected spatial channels. The second is based on introducing "the Schmidt algorithm" to construct an orthonormal weights using the generated weights. These two proposed techniques increase the probability of the selection of the worst case user on his best codevector to make zero the angle between his couple codevector and channel response. To analyze and validate the performance of these proposed techniques, simulation results are presented.

Keywords: MISO, Beamforming, Limited Feedback, CSI, SSC, FSSC, RW-FSSC, SSC-Schmidt Algorithm

1. Introduction

In the last few years, Multiuser MISO systems also named as (Space Division Multiple Access) SDMA based on Limited Feedback Transmitting Opportunistic Beamforming (OBF) have been a lot of interests in recent research studies. The goal is to provide high system spectral efficiency [1] while reducing the complexity. Due to the constraint of narrowband of the feedback channel, transmitting OBF on the broadcast channel with limited feedback has been widely studied in the literature as [2-4] and references therein.

Moreover, transmitting OBF is provided in the literature as a more practical design that ameliorates the performance of SDMA [5] and [6]. Each user selects the correspondent beamformer from the Beamforming CB. Therefore, we found many techniques to formulate the Beamforming CB vectors, for example: random orthonormal beamforming CB as proposed in [7-9] or transmitting beamforming based on grassmannian line packing as described in [10] and [11].

This SDMA design can be combined with multiuser scheduling [5] and [6]. Therefore BS uses an algorithm to select the best pair index of user-CB vector that increases the system capacity such as: Max-rate [4] or sub-optimal algorithms as proposed in [12] where a selection is based on the best pair of user-beam vectors. In [13], an algorithm is proposed, known as semi-orthogonal user selection scheme. This algorithm is based on upper bounded techniques where the value of the SINR and the value of the error quantization are compared to predefined thresholds which are defined in [2-4].

Up to the moment, the generated CB vectors are transmitted to all users and then select the best pair CB vector-user. After investigating these studies, we thought to reduce the complexity by introducing new techniques based on a score that measure frequency of access by using vectors in SC. Moreover, the second formulation of OBF CB vectors named Grassmanian method is the most prac-

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tical and near to the reality but the components of the OBF CB vectors are with non zero correlation. Consequently, the correlation between OBF CB vectors and the selected user channel is not null. Then, the interference level would be increased and then the system throughput decreases. Therefore, we thought to minimize the probability to make errors.

In this paper, we propose four new techniques of transmitting OBF at which the first technique is based on SSC applied to the Max-Rate scheduler with limited feedback system. The components of CB composed by $N = 2^B$ vectors would be divided into n_D SC. In [2-4], the N components of the CB vectors are transmitted to all users at each time slot. This number is reduced in this proposal to N/n_D components of the CB that would be transmitted to all users. Then, we minimize the complexity and respect the bandwidth of the feedback channel.

Besides, for the goal of providing fairness among users, we propose the second technique that is based on fairness SSC (FSSC). This proposal is the continuity of the SSC technique when we investigate and improve the SSC by introducing the proportional fair principle (PF) to switch the specific SC.

Moreover, we intend to meet the performance of the FSSC and to reduce the interference level at user receivers. Whereby, the correlation between OBF CB vectors is compared to predefined thresholds to make the specific rotation that minimize this correlation. Then, we put the threshold to a given value and at each transmission the value of correlation is controlled and compared to this threshold.

After this, we thought to use from the beginning an orthonormal weights in transmitting OBF in order to reduce the interference level at user receivers. Whereby, the correlation between OBF CB vectors is converge to zeros by applying the Schmidt algorithm and construct the new orthonormal OBF weights that give a zeros correlation between the generated OBF CB vectors.

The remainder of this paper is organized as follows. Section 2 describes the system and channel models. In Section 3, we present an overview of the design of different CB proposed in the literature. In section 4, we present an overview of the CSI quantization. In section 5, we describe the different steps of the proposed techniques of transmitting OBF: SSC, FSSC, RW-FSSC and SSC-Schmidt algorithm. In section 6, we present the Max-Rate scheduler. In section 7, we analyze the system capacity of the proposed techniques and give the closed form of capacity. In section 8, we present a selection of simulation results.

2. System Model

We consider a MISO system with M_t antennas at the base station (BS) and K users when each is equipped with one receive antenna. Each user has her own rate β_k. It is assumed that slow power control is employed to equally share the total transmitted power P_t on all transmit antennas at the BS. Users symbols are loaded on transmit antennas using Beamforming, *i.e.* the BS assigns a Beamforming vector to each of up to M_t selected active users.

The Beamforming vectors $\{W_i\}_{i=1}^{M_t}$ are obtained using a generated orthogonal unitary beamforming vectors as defined in [7-9] or using grassmannian line packing codebook as described in [2-4]. To solve the problem of limited resources allocated to the feedback channel, users estimate their CSI and feedback them in a quantized form on B bits to the BS through an uplink limited capacity feedback (LCFB) channel. We denote by $N = 2^B$ the number of CB vectors which is defined by $CB = \{W_1, W_2, ..., W_N\}$. At each time slot, the number of components that would be used in optimal side of the transmission is equal to the number of transmit antennas M_t.

It is assumed that transmit signals experience path loss, log-normal shadow fading, and multi-path fading. The CSI is measured by the vectors which represent the short term fading CSI on all branches from the BS to the k^{th} user assumed to be constant during a time slot. According to the slow power control, 1) each entry of the vector h_k is an independent and identically distributed complex Gaussian random variable $CN(0;\, 1)$ representing the short term fading; 2) the CSI experiences flat fading during each time slot, and varies independently over time slots.

We denote by $h_k(t)$ the $M_t \times 1$ channel vectors, $W_i(t)$ the $M_t \times 1$ CB, $s(t)$ the $M_t \times 1$ transmitted symbol, $n_k(t)$ the additive white Gaussian noise (AWGN) vector with distribution $CN(0;\, N_0/2)$ for each element, and $y_k(t)$ the received signal. Then, the received signal for the considered multi-user MISO system in the time slot t is represented by

$$y_k(t) = \sqrt{\frac{P_t}{M_t}} \sum_{i=1}^{M_t} h_k^H(t) W_i(t) s_i(t) + n_k(t) \qquad (1)$$

According to Equation (1), the received signal for user k when using the W_i CB vector can be:

$$y_{k,i}(t) = \sqrt{\frac{P_t}{M_t}} h_k^H W_i s_i + \sqrt{\frac{P_t}{M_t}} \sum_{j=1..M_t, j\neq i} h_k^H W_j s_j + n_k \qquad (2)$$

Hence, the corresponding expression of the signal to interference plus noise ratio $SINR$ for the k^{th} user and the i^{th} CB vector is expressed as follows:

$$SINR_{k,i} = \frac{\left|h_k^H w_i\right|^2}{\sum_{j=1..M_t, j\neq i} \left|h_k^H w_j\right|^2 + \frac{M_t}{P_t}} \qquad (3)$$

To evaluate the sum capacity, we need the statistical distribution of the $SINR_{k,i}$.

2.1. The Statistical Distribution of the Signal to Interference Plus Noise Ratio

To simplify the Equation (3), we let $a_i = \left|h_k^H w_i\right|^2$; i = 1, ..., M_t. The *SINR* on the i^{th} CB vector for user k given in the Equation (3) can be rewritten as

$$SINR_{k,i} = \frac{a_i}{\sum_{j=1..M_t, j\neq i} a_j + \frac{M_t}{P_t}} \quad (4)$$

Consequently,

$$SINR_{k,i} = \frac{a_i}{\sum_{m=1}^{i-1} a_m + \sum_{m=i+1}^{M_t} a_m + \frac{M_t}{P_t}} \quad (5)$$

Then,

$$SINR_{k,i} = \frac{a_i}{b_i + c_i + \frac{M_t}{P_t}} \quad (6)$$

where $b_i = \sum_{m=1}^{i-1} a_m$ and $c_i = \sum_{m=i+1}^{M_t} a_m$.

Although, the random variables a_i are of independent χ^2 distribution with two degrees of freedom. Note that the $SINR_{k,i}$ with different k are independent. Then the cumulative distribution function (CDF) of the largest SINR for user k denoted $SINR_{k,i}$ can be calculated in terms of the joint probability density function (PDF) of the largest one of M_t i.i.d χ^2 random variables, denoted by $f_{b_i,a_i,c_i}(x,y,z)$, as [14]

$$F_{SINR_{k,i}}(x) = \int_0^\infty \int_0^{(M_t-i)w/(i-1)} \int_0^{x\left(M_t/P_t + z + w\right)} f_{b_i,a_i,c_i}(w,y,z)\,dydzdw \quad (7)$$

After taking derivative with respect to x, the PDF of $SINR_{k,i}$ is given by

$$F_{SINR_{k,i}}(x) = \int_0^\infty \int_0^{(M_t-i)w/(i-1)} f_{b_i,a_i,c_i}\left(w, x\left(M_t/P_t + z + w\right), z\right) dzdw \quad (8)$$

It was further shown in [14] that the joint PDF $f_{b_i,a_i,c_i}(x,y,z)$ is available in closed form, after some modifications as given by

$$\begin{aligned} f_{b_i,a_i,c_i}(x,y,z) &= M_t \binom{M_t-1}{i-1} \frac{\left[w-(i-1)y\right]^{i-2}}{(i-2)!(M_t-i-1)!} \times \\ & e^{-w-y-z} U\left(w-(i-1)y\right) \times \\ & \sum_{j=0}^{M_t-i} \binom{M_t-i}{j} (-1)^j (z-jy)^{M_t-i-1} U(z-jy), \\ & y \succ 0; w \succ (i-1)y; z \prec (M_t-i)y. \end{aligned} \quad (9)$$

where U(.) denoted the Heaviside unit step function.

Remark:

If the largest *SINR* of the user k is the first component of the CB vectors then i = 1 and the correspondent CDF is as given in [15]

$$F_{SINR_{k,1}}(x) = \int_0^\infty \int_0^{x\left(M_t/P_t + z\right)} f_{a_1,b}(y,z)\,dydz \quad (10)$$

And

$$f_{SINR_{k,1}}(x) = \int_0^\infty \left(M_t/P_t + z\right) \int_0^\infty f_{a_1,b}\left(x\left(M_t/P_t + z\right), z\right) dz \quad (11)$$

It was further shown in [15] that the joint PDF is available in closed form, as given by

$$\begin{aligned} f_{a_1,b}(y,z) &= \frac{M_t}{(M_t-2)!} e^{-y-z} \times \\ & \sum_{j=0}^{M_t-1} \binom{M_t-1}{j} (-1)^j (z-jy)^{M_t-2} U(z-jy) \end{aligned} \quad (12)$$

After replacing this expression in (24), the PDF of the largest *SINR* of the user k ($SINR_{k,1}$) can be written as

$$\begin{aligned} f_{SINR_{k,1}}(x) &= \sum_{j=0}^{M_t-1} \frac{(M_t-1)M_t}{(M_t-1-j)!\,j!} \int_0^\infty \left(\frac{M_t}{P_t} + z\right) \times \\ & \left((1-jx)z - jx\frac{M_t}{P_t}\right)^{M_t-2} \times e^{-(1+x)z - x\frac{M_t}{P_t}} \\ & U\left((1-jx)z - jx\frac{M_t}{P_t}\right) dz \end{aligned} \quad (13)$$

3. Conventional Codebook Design

According to the considered system model, we can give a description of the CB vectors design. At each time slot, M_t symbols of users are multiplied by M_t random orthonormal vectors w_i $M_t \times 1$ for i = 1, ..., M_t. Where w_i's are generated according to an isotropic distribution [9] and [10] or are computed according to formulation described in [7]. This random orthonormal vectors are used to define a random CB. This CB vectors are generated with zero correlation which is near to the reality since it require that the chanal is known at both transmitter and receiver.

Moreover, we found in some prior work such as in [2] and [3] the term of CB vectors with none zero correlation such as grassmannian CB vectors defined in [8]. Relying to previous approaches a good beamforming is specifically using a grassmannian. Therefore, in this work, we can use this technique to generate CB vectors with none zero correlation.

4. CSI Quantization

Due to constraint of the bandwidth of feedback channel, each user just feeds back its maximum *SINR* quantized in *B* bits and the index of the corresponding codebook vector. In [2] and [3], the random vector quantization (RVQ) method is applied for quantizing the CSI. The CB vectors $\{W_i\}_{i=1}^{M_t}$ are obtained using a generated orthogonal unitary beamforming vectors as defined in [7-9] or using grassmannian line packing codebook as described in [2-4,12]. At each time slot, each user identified by *k* select his 'best' vector from the CB. For that, a quantization CB vector is selected as:

$$i_s = \arg\max_{\{W_j\}_{j=1}^{M_t}} \left| h_k^H \times W_j \right| \tag{14}$$

The quantization error is expressed as:

$$\delta = \sin^2\left(\angle\left(W_{i_s}, H\right)\right) \tag{15}$$

In the literature, it is often assumed for simplicity that the feedback is without errors. Then, the quantization error δ should be converges to zero.

5. The Proposed Techniques of Transmitting OBF

5.1. Design of SSC

For transmitting OBF, the CB vectors are used randomly such as in [2-4]. At each time slot, all of *N* components of CB are transmitted to all users. This is clearer in the previous step of quantization of CSI. Therefore, we propose an idea that based on dividing the *N* components of CB vectors into n_D SC to minimize the number of components to be transmitted to all users at each time slot.

Then, we define how to switch to a given SC at each time slot to increase the system capacity and give equal opportunity among users to the channel accesses. The switching is based by investigating user scores based on the historic use of each SC at a number of previous time slots. This would provide fairness among users.

The switching step is defined as follow:

1) The initialized matrix ($Score = zeros(K, n_D)$) is updated at each time slot and would be used in the following time slot:

$$Score(k_s, i_s) = Score(k_s, i_s) + 1 \tag{16}$$

where k_s is the index of each user among the M_t served users and i_s is the index of each CB vector among the M_t selected CB vectors of the SSC satisfying Equation (14).

2) At each time slot, we search the index of the user that has the worst capacity to give fairness among users

$$k^* = \min_k (C) \tag{17}$$

3) After, we search the index of the switched SC vector that satisfies the following expression

$$i^* = \max_i \left(Score\left(k^*, i\right)\right) \tag{18}$$

4) Finally, we update the matrix of Scores and compute the system capacity.

The most obvious benefit is to take consideration of the historic use of the CB vectors that will be represented by a score based on the user access frequency.

5.2. Design of FSSC

5.2.1. Fairness Criteria

In SSC, the idea to give fairness is derived and the selected score is that has the user with the worst capacity $\left(\min_{k\in K}(C)\right)$. If we apply this, we can assume that the number of users to have the worst capacity can be large. Then, the selected user is chosen randomly and the same user can be chosen many times. Therefore, in our proposal design, the most obvious goal is to give fairness among users. And accordingly, we thought to an idea in basis on max-min schedulers introduced in previous work such as proportional fairness in [7] when all users have the equal chance to be served.

Now, we can suppose that each user has her own rate β_k and we propose in this technique to select the index of the SC that has the minimum of the user's capacity's divided by the proportional component α_k when α_k is expressed in the following sub section in (20). Then, we can assume that to select user with using $\left(\min_{k\in K}\left(C_k/\alpha_k\right)\right)$ should be given most chance to users who can be served at the following time slot. Accordingly, the probability to choose the same user many times is minimized and this probability converges to zero. Moreover and according to the most aim of our proposal, we can talk about the index of Jain for fairness defined in [16] and expressed as follows

$$j = \frac{\left(\sum_{k=1}^{K} C_k(t)\right)^2}{K\sum_{k=1}^{K}\left(C_k(t)\right)^2} \tag{19}$$

where $C_k(t)$ is the system capacity of k^{th} user and *K* is the total number of users. We are going to present and to discuss this term in the simulation results to validate our scheme and their results.

5.2.2. FSSC Algorithm

The fairness switching algorithm is described as follows:

1) Initialization:

a) Let β_k the rate of user k.

b) Let the proportional components α_k as

$$\alpha_k = \beta_k \Big/ \sum_{i=1}^{K} \beta_i \quad (20)$$

c) The score matrix is defined in the previous subsection.

2) The Score matrix is updated at each time slot and should be used in the following time slot (the same in (16)).

3) At each time slot, we search the index of the user that has the worst of the capacity divided by α_k to give fairness among users

$$k^* = \left(\min_{k \in K} \left(\frac{C_k}{\alpha_k} \right) \right) \quad (21)$$

4) After, we search the index of the fairness switched SC vector that satisfies the following expression

$$i^* = \max_i \left(Score\left(k^*, i\right) \right) \quad (22)$$

5) Finally, we update the matrix of Scores and compute the system capacity.

The most obvious benefit is the use of an access control based on PF constraint to provide the fairness access channel among users.

5.3. Design of RW-FSSC

In the literature, it is often assumed for simplicity that the feedback is without errors. Then, the quantization error expressed in (15) should converge to zero i-e the probability to make errors should be converge to zero. But in reality, the use of grassmanian method to generate the OBF CB vectors when the components of OBF CB vectors are with not zero correlation should be make errors. Consequently, the correlation between OBF CB vectors using to select the user channel is not null. Therefore, we thought to control this value, compared with the value of threshold and make the rotation weight (RW).

The RW is consisting of the applying a rotation on the best codevector to make zero the angle between the couple codevector and channel response. Then, the RW increases the probability of the selection of the worst case user and if this user is selected he would be assigned the best possible symbol rate.

The RW is consisting of three cases at which the value of the angle between the couple codevector and channel response defined as θ is compared with a specific values of thresholds that described as follows:

1) Let θ_{max} the threshold: it is the maximum angle between the couple codevector and channel response and W_r the OBF codebook vectors after rotation.

2) Let $\theta = \angle\left(W_i, H\right)$

3) if $|\theta| \le \frac{\theta_{\max}}{4}$ Then $W_r = W_i$

4) else if $-\theta_{\max} \le \theta \le -\frac{\theta_{\max}}{4}$ Then

$$W_r = W_i^{'} \times \exp\left(-j \times \frac{\theta_{\max}}{2} \right)$$

5) else if $\frac{\theta_{\max}}{4} \le \theta \le \theta_{\max}$ Then

$$W_r = W_i^{'} \times \exp\left(j \times \frac{\theta_{\max}}{2} \right)$$

6) else if $\theta > \theta_{\max}$ Then SNR = 0

5.4. Design of the Method that Introduce the Schmidt Algorithm

5.4.1. Schmidt Algorithm

***Theorem:* (*Process of Gram-Schmidt*)**

Let $\{a_1, ..., a_N\}$ a family of vectors linearly independent.

Then it exists a family of orthonormal vectors $\{q_1, ..., q_N\}$ when for all $i = \{1, ..., N\}$, we have

$Vect\ \{a_1, ..., a_i\} = Vect\ \{q_1, ..., q_i\}$.

According to the process of Gram-Schmidt and to the SSC technique, we thought to introduce the Schmidt algorithm to construct a new orthonormal OBF CB vectors using the generated OBF CB vectors using one of the conventional CB designs and that used in the following step to select the user channel.

5.4.2. Steps of this Proposal Technique

On the first hand, we use one of the conventional CB design such as random orthonormal CB that have an isotropic distribution or the grassmanian method.

1) We denote by $\{W_i\}_{i=1}^{N}$ the generated OBF CB vectors

2) We apply the Schmidt algorithm and we obtain the new orthonormal OBF CB vectors W_1

And after, we use this new orthonormal OBF CB vectors W_1 to quantize the CSI and use the SSC transmit technique.

6. Max-Rate Scheduling

To maximize the system capacity, the technique of scheduling to share resources among active users is studied and applied. In this section, we describe the main idea of the Max-rate scheduling to select users. Accordingly, the selected M_t users to be served at each time slot experiences peak level signal to interference plus noise ratio (*SINR*) expressed in (3). This can be expressed as:

$$k_s = \arg\max_k \left(SINR_{k,i_s} \right) \quad (23)$$

where i_s is the index of the CB vectors selecting with the proposed technique of transmitting beamforming at the correspondent time slot. We use the Max-rate scheduling because it gives the optimal performance and the aim is to investigate the resources with the most efficiently.

7. Capacity Analysis

According to the step of [14], the exact sum capacity expression for such scheme under consideration can be written as

$$C = M_t \int_0^\infty \log_2(1+x) f_{SINR}(x)dx \quad (24)$$

Based on the mode of assignment of one of the proposed techniques, we can assume that the largest *SINR* of different users are i.i.d and the correspondent PDF is given by

$$f_{SINR}(x) = KF_{SINR_{k,1}}(x)^{K-1} f_{SINR_{k,1}}(x) \quad (25)$$

where $F_{SINR_{k,1}}$ and $f_{SINR_{k,1}}$ are the CDF and the PDF of the largest *SINR* for a particular user, given in (11) and (24) respectively. Then, the capacity can be written as

$$C = M_t \int_0^\infty \log_2(1+x) KF_{SINR_{k,1}}(x)^{K-1} f_{SINR_{k,1}}(x)dx \quad (26)$$

8. Simulation Results

In this section, the performances of the Max-rate scheduler with limited feedback are evaluated using the SSC, FSSC, the RW-FSSC and SSC-Schmidt algorithm to control the generated CB (for grassmannian CB vectors) [8] in terms of system capacity. The number of active users K used for these simulations varies from 1 to 30; the number of SC n_D is equal to 2, the time moving window T is of 200 and the feedback bits B is of 3.

In **Figure 1**, we compare the sum capacity performances of the "SSC" and the RBF techniques (random Max-rate scheme with LF such as in [2-5]).

Figure 2 illustrates the performance of the FSSC design in terms of system capacity. These results are compared to the SSC technique.

Figure 3 plots the index of jain for fairness of these two techniques versus the number of active users K when the value of SNR = 20 dB. This figure shows the fairness degree of the capacity in FSSC and SSC techniques. We can conclude that FSSC and SSC provide respectively a quasi optimal (~1) and near optimal fair degree. This is explained by the number of users that have the same worst capacity can increase with the number of users.

Figure 4 shows the performance of the RW-FSSC in terms of system capacity. These results are compared to the FSSC technique. **Figure 5** shows the simulation results of the system capacity of the SSC applying the Schmidt algorithm and SSC versus the number of active users.

In **Figures 1, 2, 4** and **5**, the simulation results of the

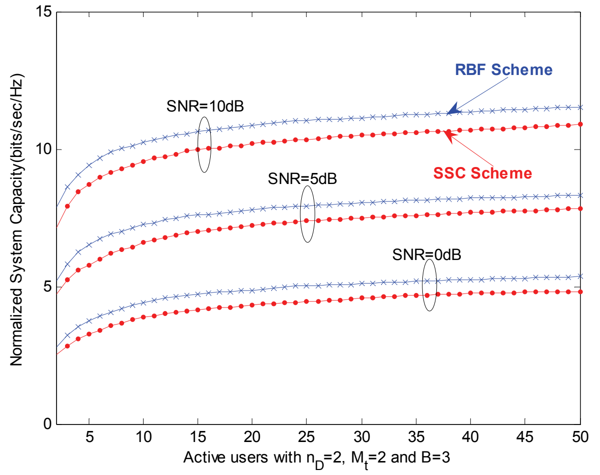

Figure 1. System capacity of the SSC and OBF techniques vs. number of active users.

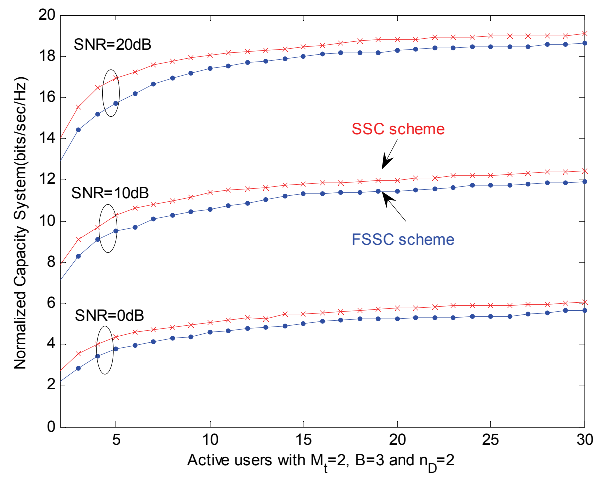

Figure 2. System capacity of the FSSC technique vs. number of active users.

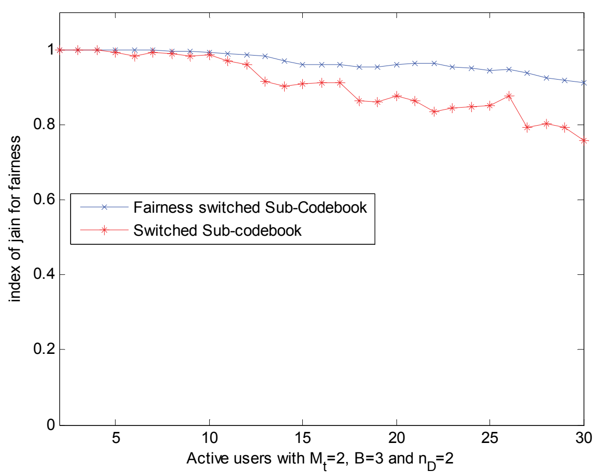

Figure 3. The index of jain for fairness.

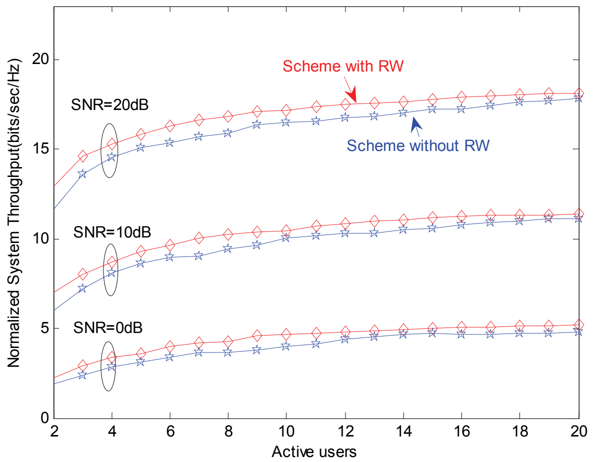

Figure 4. System capacity of RW-FSSC vs. number of active users with variation of the average SNR.

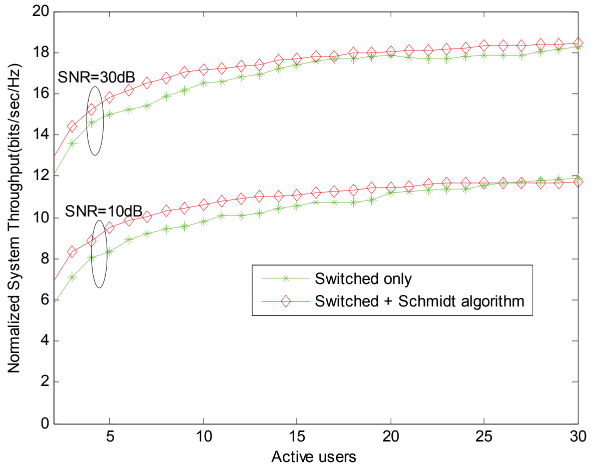

Figure 5. System capacity of SSC-Schmidt algorithm vs. number of active users with variation of the average SNR.

system capacity of the proposed techniques are plotted with different values of average SNR. Since, we can see that the system capacity applying the proposed techniques is nearly independent of the number of active users K. As can be seen from these figures, the difference between the curves of the transmit techniques is very small. In addition to that, the results of the proposed techniques are in good concordance and the system capacity grows as the average SNR increases.

9. Conclusions

The system capacity of limited feedback using OBF CB vectors and applying one of the new proposed techniques for Max-rate technique has been analyzed in this paper to deal with the performance of the coherent transmitting OBF. The transmit antenna are assigned to different up to M_t users at each time slot to increase system capacity.

According to the simulation results, we can conclude that the FSSC technique for Max-rate give fairness among users for a lot of number of users and a good performance. Moreover, we can conclude that the techniques to control the generated weights applied the FSSC for Max-rate minimize the probability to make error and give fairness among a number of users and a good performance while reducing the complexity of generating the OBF CB vectors as SSC technique. Accordingly, we can see that the system capacity can be improved using our proposed techniques.

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