International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.8, No.6 (2015), pp.155-166
http://dx.doi.org/10.14257/ijsip.2015.8.6.17

Energy Efficient Feedback Design for Coordinated Multi-Point Transmission in Downlink

Yi Wang[1], Yanjun Hu[1] and Yiqing Zhou[2]

1 Key Laboratory of Intelligent Computing & Signal Processing, Ministry of Education, Anhui University, Hefei, China
2 Institute of Computing Technology, Chinese Academy of Sciences, Beijing, China
E-mail: mesh_wy@163.com; yanjunhu@ahu.edu.cn; zhouyiqing@ict.ac.cn

Abstract

Coordinated multi-point (CoMP) has been raised to increase the average cell throughput and the cell-edge user throughput. However, the energy consumption of mobile stations (MSs) is a key problem restricting the wide application of CoMP systems. Considering the energy consumption of feeding back channel state information (CSI) by MSs and the influence of CSI accuracy on the throughput of system, it is proposed to measure the relationship between feedback energy consumption and throughput with energy efficiency feedback utility (EEFU) function which can adapt to different application scenes by adjusting utilization coefficient. The feedback utilization of two precoders in CoMP systems is analyzed respectively, including the optimization allocation of feedback bits with utility function. The complete EEFU optimized expression and the optimizing flow path satisfying the actual application demands of CoMP systems are then derived. The simulation results illustrate the practicability and necessity of the EEFU function and verify the performance of EEFU with different precoders.

Keywords: *CoMP, LTE, energy efficiency, precoder, CDI*

1. Introduction

With the rapid development of 3GPP standardization on LTE-Advanced, *coordinated multi-point* (CoMP)transmission technology receives more and more attention, which can reduce the inter-cell interference and improve the spectrum efficiency at the cell edge through the cooperation among adjacent base stations (BSs) [1]. CoMP can be generally divided into two categories, *i.e.*, CoMP*joint processing* (CoMP-JP) and CoMP*coordinated beamforming or scheduling* (CoMP-CB/CS). The former requires sharing the data and *channel state information* (CSI) among BSs to facilitate the joint precoding, while the latter can work when scheduling information and CSI of the serving cell are shared [2, 3]. Compared to CoMP-CB/CS, CoMP-JP can exploit the abundant spatial resources provided by the cooperating BSs, and provide higher spectrum efficiency [4]. Therefore, CoMP-JP is concerned in this paper. In the rest of the papers, CoMP-JP is CoMP for simplicity. And a multi-cell single-user CoMP system is focused to study the feedback energy efficiency, which is important for energy-limited *mobile stations* (MSs).

Precoding is always employed in the downlink CoMP to achieve good performance at MSs with low computation capability. MSs must feedback CSI to BSs if *frequency division duplex* (FDD) is considered. The system performance highly depends on the quality of CSI. Since the perfect CSI is impossible in practice, codebook based CSI is widely adopted, where only the space direction of the channel, namely *channel direction information* (CDI), is considered while

ISSN: 2005-4254 IJSIP

channel quality information (CQI) is obtained from long-term statistics or perfectly known at the cooperating BSs [5].

In point-to-point MIMO systems, a CDI codebook with fixed size could be used. The larger the codebook, the more precise the CSI and hence the better the performance of precoding [6]. In the CoMP considering multi-point transmission, the received signals at the MS from different BSs have different qualities since the channels between the MS and BSs are independent to each other. Hence, from each downlink between a BS and the MS, the corresponding space direction is different. Since the number of MSs change frequently, a large size global codebook, which is much more complex than the per-cell codebook, needs to be re-designed from time to time. This means that fix-sized global codebook is not suitable for the dynamic situations in CoMP and brings in enormous overhead [7]. Therefore, it is proposed that per-cell codebooks, which are also considered in this paper, should be designed for CoMP based on the limited feedback [8].

Note that CoMP is employed to improve the performance of cell-edge MSs, whose transmission power is much higher than those in cell-center due to the larger transmission distance. Moreover, in the practical LTE systems, the CSI feedback cycle is designed to be multiple of 5ms according to the radio frame structure, and it would be taken as a long-term feedback if the cycle is 20ms [9]. Therefore, when codebook based CoMP is employed in the downlink transmission for cell-edge MSs, the CSI feedback is quite frequent. Given the high transmission power of cell-edge MSs, the feedback energy consumption would be large. Since MSs are power-limited, it is necessary to design the energy-efficient feedback schemes for CoMP in downlink transmission.

In this paper, an *energy efficiency feedback utility* (EEFU) function is firstly defined as the system performance metric. Then, considering the macro-diversity CoMP where multiple BSs transmit signals to one cell-edge MSs, per-cell CSI feedback schemes are designed for different precoding algorithms, such as *maximum ratio transmission* (MRT), *minimum mean square error* (MMSE) and *zero forcing* (ZF). It is shown in simulation that the optimization of the EEFU function helps the CoMP networks under different precoders to make better use of the feedback energy of MS.

The rest of the paper is organized as follows. In Section 2, the system model is described. In Section 3, the allocation of feedback bits is optimized with the calculation of EEFU under several types of precoder. Simulation results are provided in Section 4, and the conclusion is given in the last section.

2. System Model

A downlink CoMP is considered in the heterogeneous networks consisting of macro BSs and pico BSs with different transmission powers. As shown in Fig. 1, the cooperation could be carried out among adjacent macro BSs and/or pico BSs. To focus on the precoding performance and feedback scheme of CoMP, it is assumed that the backhaul link has sufficient capacity. Thus, the cooperative BSs can share the transmission data and feedback information perfectly to realize joint processing and transmission.

Suppose there are N BSs in a CoMP cooperating set, and each BS, high or low power node ,is equipped with N_t antennas [10]. These cooperating BSs are combined to transmit data to the MS with a single antenna. Denote the small-scale fading channel from the BS to the MS as $\boldsymbol{h}_n \in \mathbb{C}^{1\times N_t}$, and the corresponding large-scale fading as α_n .Without loss of generality, assume that $\mathrm{E}\{\|\boldsymbol{h}_n\|_2^2\}=1$, where $\|\cdot\|_2$ is the Euclidian norm. The small-scale fading channels from BSs in the CoMP cooperating set to the MS is $\boldsymbol{h}=\left[\boldsymbol{h}_1,\cdots,\boldsymbol{h}_N\right]^T \in \mathbb{C}^{N\times N_t}$, while the large-scale fading is $\boldsymbol{\alpha} = diag\left(\alpha_1,\cdots,\alpha_N\right) \in \mathbb{C}^{N\times N}$, where $diag(.)$ is the diagonal matrix taking only the diagonal terms of a matrix.

Assuming that the feedback bits from the MS to BS n is B_n, a random vector quantization (RVQ) codebook $\mathbf{C}_n$ of size 2^{B_n} is used, where $\mathbf{C}_n = \left\{\mathbf{c}_1, \mathbf{c}_2, \cdots, \mathbf{c}_{2^{B_n}}\right\}$. The quantized CDI of the per-cell channel $\boldsymbol{h}_n$ is given by

$$\boldsymbol{h}_n = \underset{\mathbf{c}_l:1\le l\le 2^{B_n}}{\arg\max} \left\|\boldsymbol{h}_n \mathbf{c}_l\right\|_2 \qquad (1)$$

where $\mathbf{c}_l \in \mathbf{C}_n$.

Denote the precoding matrix of the MS as $\boldsymbol{W} = \left(\boldsymbol{W}_1,\cdots,\boldsymbol{W}_N\right) \in \mathbb{C}^{N_t\times N}$. The transmission power matrix is $\boldsymbol{P} = \arg\left(\sqrt{P_1},\cdots,\sqrt{P_N}\right) \in \mathbb{C}^{N\times N}$. s_n is the independent information symbol with unit power from the MS to the BS, $\mathrm{E}\{s_n s_n^*\} = 1$, and the signal transmitted is denoted as a vector $\boldsymbol{s} \in \mathbb{C}^{N\times 1}$. The receiving signal of the MS is given as

$$\boldsymbol{y} = \boldsymbol{\alpha h W P s} + \boldsymbol{n} \quad (2)$$

where $\boldsymbol{n} \in \mathbb{C}^{N\times 1}$ is the noise.

Linear precoding is considered in this paper due to its low complexity, such as MRT, ZF and MMSE. The target of MRT precoding is to maximize the received SNR at MS under the power constraints, but it neglects the effect of interference. On the other hand, ZF precoder mainly eliminates the co-channel interference. As for MMSE precoder, it minimizes the mean square error between the source signal and received signal through the combined optimization design of precoding and decoding matrix. In CoMP systems, if a central unit controls the transmission of BSs, the noise will have greater impact on the system since the inter-cell interference is turned into desired signals [11].

In ZF precoding, the precoding vector $\boldsymbol{W}$ is the null space of other user's channel matrix and orthogonal with other channel direction vector [12]. It has been shown that in realistic cellular scenarios, ZF precoding matrix can be simplified as CDI [13]. Therefore, in following contents, MRT and MMSE precoding are considered and ZF precoding is included in MRT.

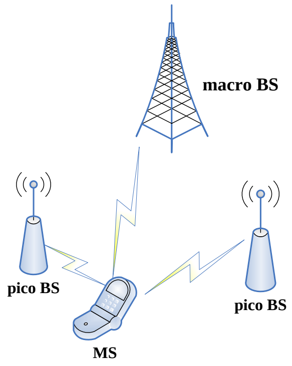

Figure 1. CoMP in a Heterogeneous Network

3. Energy Efficient Feedback Design

In this section, the EEFU function for CoMP is proposed at first, then the EEFU for two linear precoding methods, MRT and MMSE, are analyzed, including the optimization scheme and corresponding flow path of utility maximization.

3.1. EEFU Function for CoMP

Since CDI is fed back from the MS to BS frequently, it is closely related to the MS power consumption. Besides the power needed for feedback, a major power consumption is caused by the signal processing at the MS [14]. Considering these two kinds of energy, *energy efficiency* (EE) of the MS is defined as

$$f_{\mathrm{EE}}=\frac{f_{SE}}{P_{tot}}=\frac{\log_2(1+\gamma)}{P_{sp}+P_{fb}} \tag{3}$$

Where f_{SE} is the *spectrum efficiency* (SE), P_{tot} is the energy consumption and γ is the downlink SNR at the MS. Since the single user CoMP is concerned, there is no interference. P_{sp} consists of static energy $P_{sp,st}$ and dynamic processing energy $P_{sp,dy}$[15]. $P_{fb}=P_b\sum_{n=1}^{N}B_n$, where P_b is the energy of each feedback bit.

Considering the importance of EE and SE to MSs in CoMP systems, an adaptive coefficient should be employed to balance them. Hence, the unified EEFU function is defined as

$$f(B_{sum},\mu)=\frac{\log_2(1+\gamma)}{(P_{sp}+P_{fb})^{\mu}} \tag{4}$$

Where B_{sum} is the total number of feedback bits from the MS. According to the system requirement, the utility coefficient μ could be adjusted to optimize EE and SE:

1) whenμ=0, the system is only interested in SE, and the cost of feedback energy consumption can be ignored;
2) whenμ=1, the system is quite sensitive to the MS energy and feedback energy consumption;
3) when0<μ<1, the system concerns both the SE and power consumption at the MS. Usually, the system should select a parameter μ between 0 and 1.

It can be seen that the unified EEFU can be optimized over the total power consumption by taking a derivation over P_{tot}.

$$f'(B_{sum},\mu)=\left(\frac{f_{SE}}{P_{tot}{}^{\mu}}\right)'=\frac{P_{tot}{}^{\mu-1}\left(f_{SE}{}'P_{tot}-\mu f_{SE}P_{tot}{}'\right)}{P_{tot}{}^{2\mu}} \tag{5}$$

When $\mu=0$, the derivation of SE equals to $f'(B_{sum},0)>0$, so the demand of SE will be met with increasing feedback bits. Considering $f_{SE}{}'P_{tot}-f_{SE}P_{tot}{}'\le f_{SE}{}'P_{tot}-0\cdot f_{SE}P_{tot}{}'$, if $f'(B_{sum},1)>0$, $f'(B_{sum},\mu)>0$and the EE and SE will present increasing trends in accordance with the bits regardless of μ. If $f'(B_{sum},1)<0$, the EEFU will change from increasing to decreasing trend when μ increases from 0 to 1.When$\mu$is relatively small, it reflects more about the condition of SE. On the contrary, more attention will be paid to energy conservation along with large μ. Furthermore, In order to guarantee that the system outage probability is not too high, SE shall at least reach the minimum limit R_{ou}, *i.e.* ,$f(B_{k,sum},0)\geqslant R_{ou}$.

3.2. EEFU for CoMP based on MRT Precoding

Assume that MRT precoding is employed at the cooperating BSs, where the precoding vector shall be CDI. Then, the received signal can be expressed as in (2) with the precoding matrix given by

$$\boldsymbol{W}=\left(\boldsymbol{h}_1^H,\boldsymbol{h}_2^H,\cdots,\boldsymbol{h}_N^H\right) \tag{6}$$

where$(.)^H$ is the conjugate transpose of a vector or a matrix. Then the received SNR of the MS is shown as follows

$$\gamma=\mathrm{E}[\frac{\left\|\sum_{n=1}^{N}\sqrt{P_n}\alpha_n\boldsymbol{h}_n\boldsymbol{h}_n^H\right\|_2^2}{\sigma^2}]=T_1\mathrm{E}\left[\left\|\sum_{n=1}^{N}\beta_n\boldsymbol{h}_n\boldsymbol{h}_n^H\right\|_2^2\right] \tag{7}$$

where$\sigma^2$is the noise power, $T_1=1/\sigma^2$ and $\beta_n=\sqrt{P_n}\alpha_n$.

Assume that the per-cell quantized method is employed. Note that form (1), the phase $\angle\left(\boldsymbol{h}_i\boldsymbol{h}_i^H\right)$ distributes evenly in $[0,2\pi]$ and is independent with each other for different *i*. Therefore, (7) can be rewritten as

$$\gamma=T_1\sum_{n=1}^{N}\mathrm{E}[\|\beta_n\|_2^2]\,\mathrm{E}[\left\|\boldsymbol{h}_n\boldsymbol{h}_n^H\right\|_2^2] \tag{8}$$

According to [16], CDI quantization distortion is given by

$$\mathrm{E}[\left\|\boldsymbol{h}_n\boldsymbol{h}_n^H\right\|_2^2]=1-\frac{N_t-1}{N_t}2^{-\frac{B_n}{N_t-1}} \tag{9}$$

Substituting (8) and (9) into (4) gives

$$f(B_{sum},\mu)=\frac{\log_2(1+T_1\sum_{n=1}^{N}\mathrm{E}[\|\beta_n\|_2^2](1-\frac{N_t-1}{N_t}2^{-\frac{B_n}{N_t-1}}))}{(P_{sp}+P_{fb})^{\mu}} \tag{10}$$

The concavity and convexity for the above equation of both two variables cannot be estimated easily, and both the numerator and denominator will increase with the number of feedback bits. However, it can be seen that when the total bits $B_{k,sum}$ is fixed, there will be at least one bit allocation method which will maximize the unified EEFU. Considering that the number of feedback bits would be limited in practice, the maximization of the unified EEFU can be carried out as follows.

1) Given B_{sum}, the allocation scheme for maximization the unified EEFU worked out as follows.

The object function of the allocation scheme is the numerator of (10) which can be simplified with *Karush-Kuhun-Tucker* (KKT) condition as follows:

$$\begin{aligned}&min \quad g_1(B)=\sum_{n=1}^{N}\|\beta_n\|_2^2 2^{-\frac{B_n}{N_t-1}}\\&s.t. \quad \sum_{n=1}^{N}B_n=B_{sum},\ n=1,2,\cdots,N\end{aligned} \tag{11}$$

Thus, we could obtain the solution to B_n from solving Lagrange function as

$$B_n = round\left[(N_t - 1)[\log_2 \frac{\|\beta_n\|_2^2}{N_t - 1} - \log_2 \lambda]^\dagger\right] \quad (12)$$

where $[x]^\dagger = \max(0, x)$, $\lambda = \lambda_1 / \ln 2$, round is the nearest integer function. λ can be further obtained

$$\lambda = \frac{\|\beta_n\|_2^2}{(N_t - 1)2^{\frac{B_n}{N_t - 1}}} = \left(\frac{\prod_{n=1}^{N}\|\beta_n\|_2^2}{(N_t - 1)^N 2^{\frac{B_{sum}}{N_t - 1}}}\right)^{\frac{1}{N}} \quad (13)$$

2) Given the optimized bits allocation for each possible B_{sum}, the one which can maximize (10) will be selected.

$$f_{opt}(B_{sum}, \mu) = \max \frac{\log_2(1 + T_1 \sum_{n=1}^{N} \mathrm{E}[\|\beta_n\|_2^2](1 - \frac{N_t - 1}{N_t} 2^{-\frac{B_n}{N_t - 1}}))}{(P_{sp} + P_{fb})^\mu}, B_{sum=1,2,\cdots,\infty} \quad (14)$$

3.3 EEFU for CoMP based on MMSE Precoding

According to (2), the receiving signal of the MS can be obtained from the joint optimization of precoding matrix $\boldsymbol{W}$ and decoding matrix $\boldsymbol{G} \in \mathrm{C}^{N \times N}$ under the MMSE criterion

$$\hat{\boldsymbol{s}} = \boldsymbol{G}\boldsymbol{y} = \boldsymbol{G}(\boldsymbol{\alpha}\boldsymbol{h}\boldsymbol{W}\boldsymbol{P}\boldsymbol{s} + \boldsymbol{n}) \in \mathrm{C}^{N \times 1} \quad (15)$$

Where $\boldsymbol{W}$ and $\boldsymbol{G}$ are obtained as

$$\{\boldsymbol{W}, \boldsymbol{G}\} = \arg\min_{\{\boldsymbol{W}, \boldsymbol{G}\}} \mathrm{E}\left[\|\hat{\boldsymbol{s}} - \boldsymbol{s}\|_2^2\right] \quad (16)$$

The small-scale fading channel $\boldsymbol{h}$ can also be written as

$$\boldsymbol{h} = \boldsymbol{c}\boldsymbol{h} + \boldsymbol{d}\boldsymbol{q} \quad (17)$$

where $\boldsymbol{h} \in \mathrm{C}^{N \times N_t}$ is the channel after quantization and $\boldsymbol{q} \in \mathrm{C}^{N \times N_t}$ is the quantized error vector that is orthogonal with $\boldsymbol{h}$. Moreover, it can be obtained that

$$\boldsymbol{c} = [\cos\theta_1, \cos\theta_2, \cdots, \cos\theta_N] \in \mathrm{C}^{1 \times N}$$

$$\boldsymbol{d} = [\sin\theta_1, \sin\theta_2, \cdots, \sin\theta_N] \in \mathrm{C}^{1 \times N} \quad (18)$$

where $\cos\theta_n = \|\boldsymbol{h}_n \boldsymbol{h}_n\|_2$ measures the accuracy of the quantization.

According to (16), the optimum precoding and decoding matrix could be obtained as follows:

$$\boldsymbol{W} = \left(\boldsymbol{h}^H \boldsymbol{\alpha}^H \boldsymbol{G}^H \boldsymbol{G}\boldsymbol{\alpha}\boldsymbol{h}\right)^{-1} \boldsymbol{h}^H \boldsymbol{\alpha}^H \boldsymbol{G}^H \boldsymbol{P}^H \left(\boldsymbol{P}\boldsymbol{P}^H\right)^{-1} \quad (19)$$

$$\boldsymbol{G} = \boldsymbol{P}\boldsymbol{W}^H \boldsymbol{h}^H \boldsymbol{\alpha}^H \boldsymbol{R}_y^{-1} = \boldsymbol{P}^H \boldsymbol{W}^H \boldsymbol{h}^H \boldsymbol{\alpha}^H \left(\boldsymbol{\alpha}\boldsymbol{h}\boldsymbol{W}\boldsymbol{P}\boldsymbol{P}^H \boldsymbol{W}^H \boldsymbol{h}^H \boldsymbol{\alpha}^H + \boldsymbol{R}_n\right)^{-1} \quad (20)$$

where

$$\boldsymbol{R}_y = \mathrm{E}[\boldsymbol{y}\boldsymbol{y}^H] = \boldsymbol{\alpha}\boldsymbol{h}\boldsymbol{W}\boldsymbol{P}\boldsymbol{P}^H \boldsymbol{W}^H \boldsymbol{h}^H \boldsymbol{\alpha}^H + \boldsymbol{R}_n, \boldsymbol{R}_n = \mathrm{E}[\boldsymbol{n}\boldsymbol{n}^H].$$

Then, the received SNR of the MS turns out to be

$$\gamma = \mathrm{E}\left[\frac{\left\|\boldsymbol{\alpha h W P s}\right\|_2^2}{\left\|\boldsymbol{n}\right\|_2^2}\right] = \mathrm{E}\left[\frac{\left\|\boldsymbol{\alpha h}\left(\boldsymbol{h}^H\boldsymbol{\alpha}^H\boldsymbol{G}^H\boldsymbol{G\alpha h}\right)^{-1}\boldsymbol{h}^H\boldsymbol{\alpha}^H\boldsymbol{G}^H\boldsymbol{P}^H\left(\boldsymbol{PP}^H\right)^{-1}\boldsymbol{Ps}\right\|_2^2}{\left\|\boldsymbol{n}\right\|_2^2}\right] \tag{21}$$

Denoting $\bar{\boldsymbol{\alpha}}_h = \boldsymbol{\alpha h} \in \mathrm{C}^{N\times N_t}$ and $\overset{H}{\boldsymbol{\alpha}}_h = \left(\boldsymbol{\alpha h}\right)^H \in \mathrm{C}^{N\times N_t}$, it can be learned that the above equation is related to the numerator, *i.e.*,

$$\mathrm{E}\left[\left\|\boldsymbol{\alpha h}\left(\boldsymbol{h}^H\boldsymbol{\alpha}^H\boldsymbol{\alpha h}\right)^{-1}\boldsymbol{h}^H\boldsymbol{\alpha}^H\right\|_F^2\right] = \mathrm{E}\left[\left\|\bar{\boldsymbol{\alpha}}_h\left(\overset{H}{\boldsymbol{\alpha}}_h\boldsymbol{\alpha}_h\right)^{-1}\overset{H}{\boldsymbol{\alpha}}_h\right\|_F^2\right] \tag{22}$$

Substituting $\bar{\boldsymbol{\alpha}}_h = \begin{pmatrix}\alpha_1\boldsymbol{h}_1\\ \vdots \\ \alpha_N\boldsymbol{h}_N\end{pmatrix}$ and $\boldsymbol{\alpha}_h = \begin{pmatrix}\alpha_1\boldsymbol{h}_1\\ \vdots \\ \alpha_N\boldsymbol{h}_N\end{pmatrix}$ into (22) gives us

$$\mathrm{E}\left[\left\|\boldsymbol{c}\boldsymbol{\alpha}_h\left(\overset{H}{\boldsymbol{\alpha}}_h\boldsymbol{\alpha}_h\right)^{-1}\overset{H}{\boldsymbol{\alpha}}_h\right\|_F^2\right] = \mathrm{E}\left[\left\|\boldsymbol{c}\right\|_F^2\right] = \sum_{n=1}^{N}\left(1-\frac{N_t-1}{N_t}2^{-\frac{B_n}{N_t-1}}\right) \tag{23}$$

Thus, the solutions to B_n can be obtained by maximizing (23) without considering transmit power or distance, leading to equal allocation of bits among BSs. Therefore, the feedback resource allocation problem based on MMSE precoding can be independent of transmission energy or distance. And the rest part of the algorithm is similar to the EEFU algorithm for MRT precoding.

4. Simulation Results

This part verifies the performance of the proposed energy efficient feedback design scheme based on the unified EEFU for CoMP networks.

In the simulations, the CoMP cooperating set consists of three BSs, which are about 0.05 km, 0.3km and 0.5km away from the concerned MS, respectively. When homogeneous networks are considered, the three BSs are all macro BSs with a transmit power of 46dBm [17]. On the other hand, when a heterogeneous network is concerned, the closest BS becomes a pico BS with a transmit power of 30dBm [17]. Large-scale fading model is $PL(dB)$=128.1+37.6log$_{10}d(km)$[18]. Letσ^2=1andN_t=4.The values of P_{sp} and P_{fb} are related to the types of specific equipment. According to [4] and the energy consumption of mobile terminal, let $P_{sp,st}$=0.5W,$P_{sp,dy}$=0.01W, and P_b=10μJ/b[19]. The feedback cycles can be 5, 10 and 20 ms [9]. In the following evaluations, the normalized EEFU is employed for better illustration, which is the ratio of the EEFU value and the maximum value of the utility.

Given the utility coefficient μ=1, Fig. 2 illustrates the optimum total number of feedback bits B_{sum} for different feedback cycles. It can be seen that for any given feedback cycle, the normalized EEFU increases first as B_{sum} increased from a small value. Then a maximum EEFU is obtained at a certain B_{sum}. As B_{sum} increased further, EEFU decreased. This is because SE gain resulting from feedback CDI precision cannot compensate the increase in feedback energy after the certain B_{sum}.

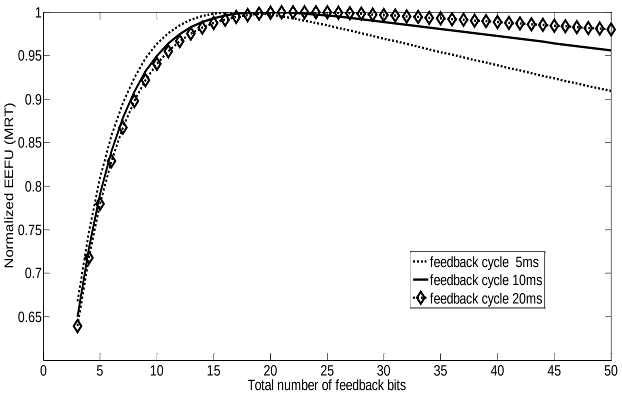

Figure 2. Normalized EEFU versus Total Number of Feedback Bits under Different Feedback Cycles

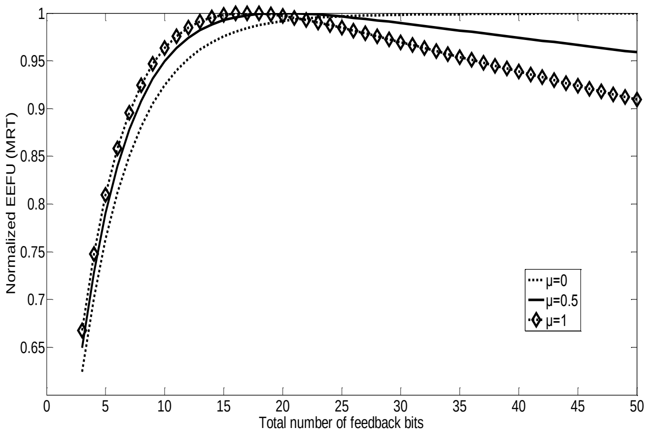

Figure 3. Impact of *μ* on the Normalized EEFU

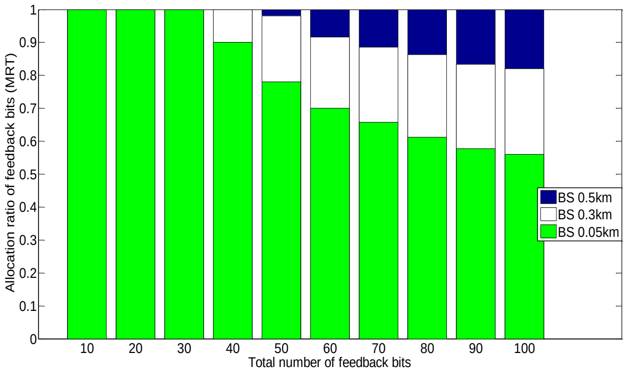

Figure 4. Allocation Ratio of Feedback Bits among Three Macro BSs

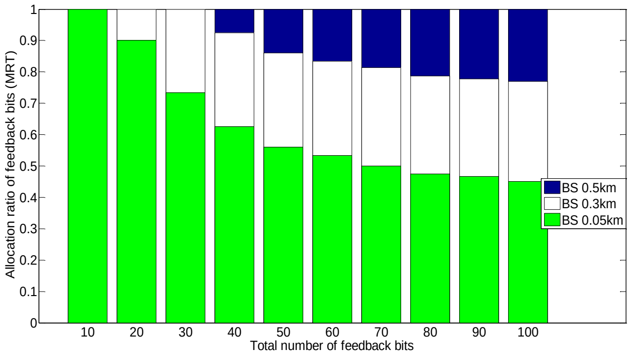

Figure 5. Allocation Ratio of Feedback Bits among Two Macro BSs and One Pico BS

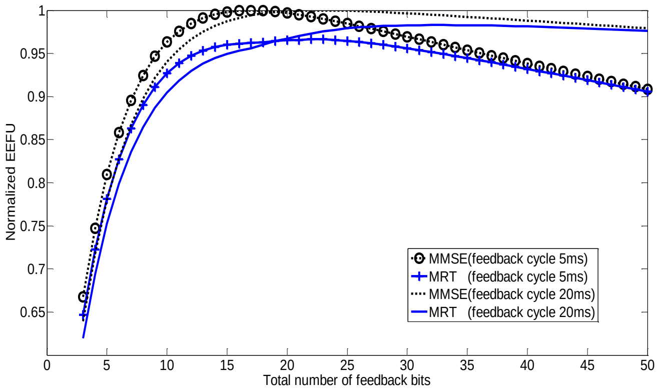

Figure 6. Comparison of MMSE and MRT under Two Feedback Cycles

When the feedback delay cycle is larger, the corresponding optimum B_{sum} is also larger. As the feedback cycle reduces, the feedback frequency increases, and the denominator of (4),P^{μ}_{tot}, will also increase with the feedback bits. In fact, it can be regarded that numerator of (4) multiplies$1/P^{\mu}_{tot}$. Since the SE will not change with the feedback cycle, while $1/P^{\mu}_{tot}$ reduces rapidly with the decrease of feedback cycle, the utility would change rapidly with small feedback cycle and it would reach the peak with fewer feedback bits.

Given a feedback cycle of 5ms, Figure 3 illustrates the effect of μon the normalized EEFU. When μ=0, the system only concerns SE and the normalized EEFU approaches the maximum value 1 as B_{sum} becomes infinite. When μ=1, the power consumption is important to the system and the maximum value of the utility is obtained when B_{sum}=16. Moreover, for μ=0.5, the power consumption is also concerned in the system with less importance. Hence, the best performance is obtained at B_{sum}=20, where more feedback bits are employed compared to that with μ=1.

Next, given a feedback cycle of 5msandμ=1, Figure 4 shows the bit allocation among the three cooperating BSs according to (12) that maximizes the unified EEFU. It can be seen that when B_{sum} is small, all bits will be allocated to the closest BS since it can provide a higher received SNR. As B_{sum} increases, the benefit of cooperation appears and some feedback bits should be allocated to further BSs.

Compared to Fig. 2, a pico BS is used to substitute closest macro BS in Figure 5. Since the pico BS has a lower transmitting power, it can be equivalent to a macro BS with higher power but placed further away. Different to Figure 4, the benefit of cooperation with two distant macro BSs will occur at a smaller number of feedback bits in Figure 5.

Using the same setting as in Figure 5, Figure 6 illustrates the system performance with MMSE and MRT precoding. The performance of MMSE is better than MRT with small number of feedback bits, while the performance of both precoders coincide with each other when a big number is considered. This is because CDI quantization errors of MMSE precoding are diminished cooperatively among three BSs by the joint design of precoding and decoding matrix at the expense of computation complexity. On the other hand, increase of feedback bits would make the CDI quantization of MRT more precise and help the two precoding methods achieve the same EEFU. Therefore, the MRT precoding method would be a better choice if there are sufficient feedback bits due to its simplicity. But when the number of feedback bits is small, MMSE could be chosen to provide better performance at the cost of higher complexity.

5. Conclusions

In this paper, we study the EEFU for CoMP networks and propose the utility function. The function can be applied for measuring the cost paid for feedback energy consumption and the benefits of SE gains. By adjusting utility coefficient, different application demands can be met with the EEFU function. It has been discovered that besides the number of feedback bits, the optimization of the function also relies on different environmental parameters aiming at different precoding methods. For instance, the optimization of EEFU relies on the transmission energy and distance of BSs for MRT precoding while feedback bits are equally allocated among BSs for MMSE precoding. The simulation results show that the optimization allows CoMP networks to take advantage of the feedback energy of MS much more efficiently. We mainly study the single-MS CoMP networks in this paper, and in the next step, studies will be conducted for more MSs scenarios.

Acknowledgements

The work is supported by National 863 Project (2013AA041101), National High Technology R&D Program of China (863 Program: 2014AA01A703), National Science and Technology Major Project (2014ZX03003004), National Natural Science Foundation of China (61331009), andthe211ProjectofAnhuiUniversity.

References

[1] L. J. Liu, J. Z. Zhang, Y. Yi, H. X. Li, and J. Y. Zhang, "Combating interference: MU-MIMO, CoMP, and HetNet," Journal of Commun., vol. 7, no. 9, **(2012)** , pp. 646-655.

[2] Q. Zhang, C. Y. Yang, and A. F. Molisch, "Downlink base station cooperative transmission under limited-capacity backhaul," IEEE Trans. Wirel. Commun., vol. 12, no. 8, **(2013)**, pp. 3746-3759.

[3] L. Qiang, Y. Yang, F. Shu, and W. Gang, "Coordinated beamforming in downlink CoMP transmission system," in Proc. 2010 5th International ICST Conf. Commun. and Networking in China (CHINACOM), **(2010)**,pp. 1-5

[4] Z. K. Xu, C. Y. Yang, G. Y. Li, Y. L. Liu, and S. G. Xu, "Energy-efficient CoMPprecoding in heterogeneous networks," IEEE Trans. Signal Processing, vol. 62, no. 4, **(2014)**, pp. 1005-1016.

[5] E. Bjornson, K. Ntontin, and B. Ottersten, "Channel quantization design in multiuser MIMO systems: Asymptotic versus practical conclusions," in Proc. IEEE Int. Conf. Acoustics, Speech and Signal Processing (ICASSP), **(2011)**, pp. 3072-3075.

[6] F. Yuan, C. Y. Yang, G. Wang, and M. Lei, "Adaptive channel feedback for coordinated beamforming in heterogeneous networks," IEEE Trans. Wirel. Commun., vol. 12, no. 8, **(2013)**, pp. 3980-3994.

[7] M. H. Hassan, Y. A. Fahmy, and M. M. Khairy, "Phase ambiguity mitigation for per-cell codebook-based limited feedback coordinated multi-point transmission systems," IET Commun., vol. 6, no. 15, **(2012)**, pp. 2378-2386.

[8] F. Yuan and C. Y. Yang, "Phase ambiguity quantization for per-cell codebook based limited feedback coordinated multi-point transmission systems," in Proc. 2011 IEEE Veh. Technol. Conf. –Spring, **(2011)**, pp. 1-5

[9] Z. J. Zhang, X. M. Luo, G. M. Lv, and G. M. Zhang, "A dynamically-updating adaptive codebook design for CoMP joint transmission," in Proc. Int. Conf. Systems and Informatics (ICSAI 2012), **(2012)**, pp. 1407-1411.

[10] Y.-N. R. Li, J. Li W. M. Li, Y. Xue, and H. Wu, "CoMP and interference coordination in heterogeneous network for LTE-Advanced," 2012 IEEE Golbecom Workshops, **(2012)**, pp. 1107-1111.

[11] C. Y. Yang, S. Q. Han, X. Y. Hou, and A. F. Molisch, "How do we design CoMP to achieve its promised potential?" IEEE Wirel.Commun., vol. 20, no. 1, **(2013)**, pp. 67-74.

[12] N. A. KaimKhani, Z. Chen, F. Yin, and H. Xing, "MU-MIMO Scheme: Single Layer Multi-User Transmission," Journal of Commun., vol. 8, no. 5, **(2014)**, pp. 441-418.

[13] X. Y. Hou and C. Y. Yang, "How much feedback overhead is required for base station cooperative transmission to outperform non-cooperative transmission?" in Proc. IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), **(2011)**, pp. 22-27.

[14] O. Onireti, F. Heliot, and M. A. Imran, "On the energy-spectral efficiency trade-off in the uplink of CoMP system," IEEE Trans. WirelssCommun., vol. 11, no. 2, **(2012)**, pp. 556-561.

[15] O. Arnold, F. Richter, G. Fettweis, and O. Blume, "Power consumption modeling of different base station types in heterogeneous cellular networks," in Proc. Future Network and Mobile Summit, **(2010)**, pp. 16-18.

[16] T. Yoo, N. Jindal, and A. Goldsmith, "Multi-antenna downlink channels with limited feedback and user selection," IEEE J. Sel. Areas Commun., vol. 25, no. 7, **(2007)**, pp. 1478-1491.

[17] Z. K. Xu, C. Y. Yang, G. Y. Li, Y. L. Liu, and S. G. Xu, "Energy-efficient CoMPprecoding in heterogeneous networks," IEEE Trans. Signal Processing, vol. 62, no. 4, **(2014)**, pp. 1005-1017.

[18] Further Advancements for E-UTRA Physical Layer Aspects, 3GPP TR 36.814 V9.0.0, **(2010).**

[19] C. Z. Han, T. Harrold, S. Armour, I. Krikidis, S. Videc, P. M. Grant, H. Haas, J. S. Thompson, I. Ku, C.-X. Wang, T. A. Le, M. R. Nakhai, J. Y. Zhang and L. Hanzo, "Green radio: radio techniques to enable energy-efficient wireless networks," IEEE Commun. Mag., vol. 49, no. 6, **(2011)**, pp. 46-54.

Authors

Yi Wang., He received the B.S. degree in electronic and information engineering from Xidian university, Xi'an, in 2005 and the M.S. degree in communication engineering from Anhui University, Hefei, in 2012. He is currently pursuing the Ph.D. degree in the School of Electronics and Information Engineering, Anhui University. His research interest includes wireless communication, cognitive radio and signal processing.

Yanjun Hu, She is a full professor at the School of Electronic Science & Technology, Anhui University, and the director of Key Laboratory of Intelligent Computing and Signal Processing, Ministry of Education, China. She received a B.S. in electronic engineering and an M.S. in circuits and systems from Anhui University in 1989 and 1992, respectively. Since 1992 she has been teaching at the Department of Electrical Engineering and Information Science of Anhui University. From September 1998 to 2001, she studied at the University of Science and Technology of China (USTC) as a Ph.D. student, and received a Ph.D. degree in communication and information systems in June 2001. From 2002 to 2003 she was a postdoctoral fellow at the School of Information Technology of USTC. From February 2005 to August 2006, she worked as a visiting research scientist at the PARADISE Research Laboratory, School of Information Technology and Engineering, University of Ottawa, Canada. Her research interests are wireless and mobile networking, wireless sensor networks, and wireless multimedia.

Yiqing Zhou (S’03–M’05–SM’10), she received the B.S. degree in communication and information engineering and the M.S. degree in signal and information processing from the Southeast University, China, in 1997 and 2000, respectively. In February 2004, she received the Ph.D. degree in electrical and electronic engineering from the University of Hong Kong, Hong Kong. Now she is a professor in Wireless Communication Research Center, Institute of Computing Technology, Chinese Academy of Sciences. Dr. Zhou has published over 80 papers and one book chapter in the areas of wireless mobile communications. Dr. Zhou is a senior member of IEEE and the associate/guest editor for IEEE Trans. Vehicular Technology, IEEE JSAC (Special issue on “Broadband Wireless Communication for High Speed Vehicles” and “Virtual MIMO”), WCMC, ETT and JCST. She is also the TPC co-chair of ChinaCom2012, symposia co-chair of IEEE ICC2015, symposium co-chair of ICC2014, tutorial co-chair of ICCC2014 and WCNC2013, and the workshop co-chair of SmartGridComm2012 and GlobeCom2011. Dr. Zhou has served many international conferences as a TPC member, including IEEE ICC, GlobeCom, WCNC and VTC.