Energy Efficient Power Allocation Algorithm for Downlink Massive MIMO with MRT Precoding

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***Abstract*—Massive multiple-input multiple-output (MIMO) has been seen as a promising technology to improve the spectrum efficiency (SE), reliability and energy efficiency (EE) for the next generation wireless communication systems. Excessive energy consumption of wireless communication networks induces both the increasing carbon emission and unaffordable operational expenditure in recent years. In this paper, energy efficient power allocation scheme is investigated for the massive MIMO system with the maximum ratio transmission (MRT) precoding, since MRT precoding can balance the system performance and complexity. As of the intractable expression of the received SINR at user terminal (UT), an approximate expression is deduced by proper simplification. Based on the simplified expression, a power allocation algorithm is proposed to achieve the optimal EE according to convex optimization theory. Compared with the power allocation scheme ignoring the inter user interference, the proposed power allocation algorithm can enhance EE and decrease transmission power, and does not impair the SE. Simulation results also show that both the EE and SE are improved by increasing the number of antennas at BS and the number of multiple UTs.**

***Index Terms*—Massive MIMO, MRT precoding, power allocation, energy efficiency, spectrum efficiency**

I. Introduction

With the rapid development of smart terminals, high-speed services induce huge traffic for wireless communication networks in recent years. Small cell has been proposed to enhance system capacity by shrinking cell radius [1]. But it is unaffordable for operators to pay for new base station (BS) sites in some countries. During past years, multiple-input multiple-output (MIMO) has been researched widely and applied to LTE or LTE-Advanced [2]; Recently, massive MIMO has been put forward to improve spectrum efficiency (SE), reliability and energy efficiency (EE) by installing massive antennas at the existing BS, which is promising for the next wireless communication systems [3]. There is an increasing research interesting on massive MIMO in academic field recently [4].

Massive MIMO system is the system that use antenna arrays with an order of magnitude more elements than in system being built today, say a hundred antennas or more [4]. The mainly research fields are as follows [3] [4]: design of massive antennas array, measure and modeling of massive MIMO channel, performance analysis of the massive MIMO system, precoding mechanisms for transmitter, channel estimation and detection at receiver, interference controlling and resource scheduling algorithm, etc. It has been proved from previous work that the system performance is limited by pilot contamination, the simplest precoder or detector, i.e. maximum ratio transmission (MRT) precoding and matched filter (MF), are optimal, and the transmission power can be made arbitrarily small when the number of antennas approaches infinite [4] [5].

Meanwhile, according to the statistics, energy consumption of mobile networks represents round 0.2% of total carbon emission, and electric bill accounts for about 18-40% of operator expenditure in different countries [6]. Green communications has been put forward to improve EE ensuring that there is no impairment to other evaluating metrics of communication systems, including SE and reliability, etc. Green communications mainly focuses on the following aspects [6-8]: energy efficient components, energy efficient radio technologies, energy efficient resource management and architectures. The previous research for the massive MIMO system assumes that the inter user interference (IUI) can be ignored when the number of antennas approaches infinite [4]. But there exists some affects on the power allocation for achieving the optimal EE, especially, the number of antennas is limited by the bulk of antenna array. In [9], it just considers the transmission power, however the circuit consumption can not be ignored in the realistic power consumption model.

In this paper, energy efficient power allocation scheme under the metric bit per joule is investigated for the massive MIMO system with the MRT precoding. Power consumption model consisting of both the transmission power and circuit power is adopted. As of the intractable expression of the received SINR at user terminal (UT), appropriate approximation is employed considering the characteristic of the massive MIMO system. Then the formulated EE optimization problem can be solved, and the energy efficient power allocation algorithm is developed according to convex optimization theory.

The remainder of this paper is organized as follows. Section II introduces the system model for the massive MIMO system. Optimization model of EE is established with the realistic power consumption model in Section III. Approximate power allocation algorithm achieving the optimal EE is developed in Section IV. Section V implements simulation and Section VI concludes this paper.

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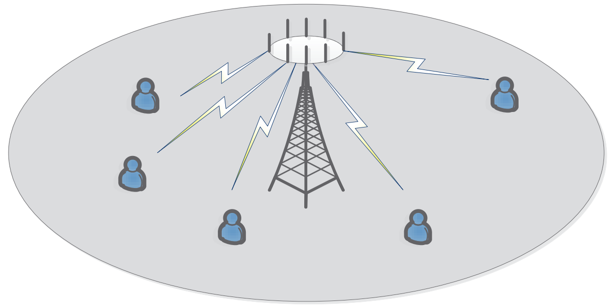

Fig. 1. System model for the downlink massive MIMO system.

II. System Model for Down-Link Massive MIMO

As shown in Fig. 1, a massive MIMO system consisting of one BS equipped with N antennas and $K\,(\ll N)$ UTs, each UT equipped with single antenna, is investigated in this paper. In this paper, we assume that the BS serving UTs over flat-fading channel on a single frequency or sub-carrier and can acquire the perfect channel state information through pilot in TDD system.

The channel matrix from the BS to K multiple UTs can be written as

$$\mathbf{G} = \mathbf{D}^{1/2}\mathbf{H} \tag{1}$$

where $\mathbf{D} = \operatorname{diag}\{\beta_1, \beta_2, \cdots, \beta_K\}$, the component $\beta_k = \varphi\zeta/d_k^{\alpha}$ consists of path loss and shadow fading, φ is a constant related to carrier frequency and antenna gain, d_k is the distance between the BS and UT k , $\alpha \in [2, 6]$ is the path loss exponent, ζ represents the shadow fading with the distribution $10\log_{10}\zeta \sim N\left(0, \sigma_{\mathrm{sh}}^2\right)$. Fast fading matrix is $\mathbf{H} = \left[\mathbf{h}_1^{\mathrm{T}}, \mathbf{h}_2^{\mathrm{T}}, \cdots, \mathbf{h}_K^{\mathrm{T}}\right]^{\mathrm{T}} \in C^{K\times N}$, the components $h_{ij} \sim CN(0,1)$ $(i = 1, 2, \cdots, K; j = 1, 2, \cdots, N)$ are i.i.d. Rayleigh flat-fading random variables.

According to [4][5], MRT precoding is the practical precoding which can balance the performance and system complexity for the massive MIMO system. MRT precoding adopted by the BS can be expressed as

$$\mathbf{x} = \sum_{l=1}^{K} \frac{\mathbf{h}_l^{\mathrm{H}}}{\|\mathbf{h}_l\|}\sqrt{p_l}\,s_l \tag{2}$$

where p_l is the power allocation value for UT l , s_l is the transmission symbol for UT l.

Through fading channel, the received signal at all UTs can be expressed as,

$$\mathbf{y} = \mathbf{G}\mathbf{x} + \mathbf{w} \tag{3}$$

where $\mathbf{w} \sim CN\left(0, \sigma^2\mathbf{I}_K\right)$ is the complex Gaussian vector. And the received signal for UT k can be written as

$$y_k = \underbrace{\sqrt{p_k\beta_k}\,\|\mathbf{h}_k\|\,s_k}_{desired\,signal} + \underbrace{\sum_{l=1,\neq k}^{K}\sqrt{p_l\beta_k}\frac{\mathbf{h}_k\mathbf{h}_l^{\mathrm{H}}}{\|\mathbf{h}_l\|}s_l}_{inter\,user\,interference} + \underbrace{w_k}_{noise} \tag{4}$$

Formula (4) shows that there exists IUI when BS adopts MRT precoding.

The received SINR for UT k can be expressed as

$$\gamma_k = \frac{p_k\beta_k\|\mathbf{h}_k\|^2}{\left\|\mathbf{h}_k\sum_{l=1\neq k}^{K}\sqrt{p_l\beta_k}\frac{\mathbf{h}_l^{\mathrm{H}}}{\|\mathbf{h}_l\|}\right\|^2 + \sigma^2} \tag{5}$$

And the SE for UT k can be written as

$$S_k = \log_2\left(1 + \frac{\gamma_k}{\mu}\right) \tag{6}$$

where $\mu = 2\ln(5P_{\mathrm{e}})/3$ is the SNR gap between Shannon channel capacity and a practical modulation and coding scheme achieving the BER P_{e} [10]. Then, the total SE achieved by all UTs can be expressed as

$$S_{\Sigma}(\mathbf{P}) = \sum_{k=1}^{K} S_k = \sum_{k=1}^{K}\log_2\left(1 + \frac{\gamma_k}{\mu}\right) \tag{7}$$

where $\mathbf{P} = [p_1, p_2, \cdots, p_K]^{\mathrm{T}}$ is the power allocation vector for all UTs at BS.

III. EE Formulation for Massive MIMO

In practical communication system, the realistic power consumption consists of both the transmission power and circuit power [10] [11]. According to [10], the realistic power consumption model can be written as

$$P_{\mathrm{BS}}(\mathbf{P}) = \frac{1}{\eta}P_{\mathrm{T}} + P_{\mathrm{TC}} = \frac{1}{\eta}\sum_{k=1}^{K}p_k + P_{\mathrm{TC}} \tag{8}$$

where P_{T} and P_{TC} are total transmission power consumption and total circuit power consumption at BS, respectively, $\eta \in [0, 1]$ is the efficiency of power amplifier (PA), p_k is the power allocation value for UT k at BS.

Assuming circuit power consumption at UT k is $P_{\mathrm{RC}k}$, Then the total circuit power consumption of all UTs is

$$P_{\mathrm{UT}} = \sum_{k=1}^{K}P_{\mathrm{RC}k} \tag{9}$$

Therefore, combining formula (8) and formula (9), the total power consumption of both BS and UTs is

$$\begin{aligned} P_{\Sigma}(\mathbf{P}) &= P_{\mathrm{BS}}(\mathbf{P}) + P_{\mathrm{UT}} \\ &= \sum_{k=1}^{K}\left(\frac{p_k}{\eta} + P_{\mathrm{RC}k}\right) + P_{\mathrm{TC}} \end{aligned} \tag{10}$$

According to the metric bits/J and within the time duration Δt, the EE of the massive MIMO system is defined as

$$\eta_{\mathrm{EE}}(\mathbf{P}) = \frac{\Delta t S_{\Sigma}(\mathbf{P})}{\Delta t P_{\Sigma}(\mathbf{P})} = \frac{\sum_{k=1}^{K}\log_2\left(1 + \frac{\gamma_k}{\mu}\right)}{\sum_{k=1}^{K}\left(\frac{p_k}{\eta} + P_{\mathrm{RC}k}\right) + P_{\mathrm{TC}}} \tag{11}$$

Therefore, the power allocation for the massive MIMO system can be formulated as the following optimization problem,

$$\eta_{\mathrm{EE}}^{\mathrm{o}}(\mathbf{P}) \triangleq \arg\max_{\mathbf{P}\in R_*^{1\times K}} \frac{\sum_{k=1}^{K}\log_2\left(1 + \frac{\gamma_k}{\mu}\right)}{\sum_{k=1}^{K}\left(\frac{p_k}{\eta} + P_{\mathrm{RC}k}\right) + P_{\mathrm{TC}}} \tag{12}$$

where R_* represents the non-negative set, i.e. $p_k \geq 0$.

IV. Energy Efficient Power Allocation Algorithm for Massive MIMO

In this section, detailed analysis is given firstly, then the approximately optimal power allocation is given and the power allocation algorithm is developed finally.

According to the description in Section II, random vectors $\mathbf{h}_l$ $(l = 1, 2, \cdots, k-1, k+1, \cdots, K)$ are independent of random vector $\mathbf{h}_k$. Denote $\alpha_l \triangleq \left|\mathbf{h}_k \mathbf{h}_l^{\mathrm{H}} / \|\mathbf{h}_l\|\right|^2$, then α_l $(l = 1, 2, \cdots, k-1, k+1, \cdots, K)$ are i.i.d. Gamma random variables with parameters $(1, 1)$ according to [12]. Denote $\alpha_0 \triangleq \|\mathbf{h}_k\|^2$, then α_0 is also a Gamma random variable with parameters $(N, 1)$. Since the expectation of α_l is $E[\alpha_l] = 1$, then

$$\begin{aligned} & E\left[\left|\mathbf{h}_k \sum_{l=1\neq k}^{K} \sqrt{p_l \beta_k} \frac{\mathbf{h}_l^{\mathrm{H}}}{\|\mathbf{h}_l\|}\right|^2\right] \\ & = \beta_k \sum_{l=1\neq k}^{K} p_l E[\alpha_l] = \beta_k \sum_{l=1\neq k}^{K} p_l \end{aligned} \tag{13}$$

and

$$E\left[p_k \beta_k \|\mathbf{h}_k\|^2\right] = N p_k \beta_k \tag{14}$$

As shown in (5), the SINR at UT k is complicated, and the optimal power allocation is impossible to be got by it. In order to develop the power allocation algorithm, we replace the denominator of γ_k with its expectation, i.e.,

$$\gamma_k = \frac{p_k \beta_k \|\mathbf{h}_k\|^2}{\left|\mathbf{h}_k \sum_{l=1\neq k}^{K} \sqrt{p_l \beta_k} \frac{\mathbf{h}_l^{\mathrm{H}}}{\|\mathbf{h}_l\|}\right|^2 + \sigma^2} \approx \frac{p_k \beta_k \|\mathbf{h}_k\|^2}{\beta_k \sum_{l=1\neq k}^{K} p_l + \sigma^2} \tag{15}$$

The magnitude of $\left|\mathbf{h}_k \sum_{l=1\neq k}^{K} \sqrt{p_l \beta_k} \mathbf{h}_l^{\mathrm{H}} / \|\mathbf{h}_l\|\right|^2$ may be the same with noise, so it is irrational to ignore the IUI in realistic communication system. Especially, the condition $N \gg K$ is tough to meet considering the bulk of massive antennas array.

Through the proper approximation by formula (15), the following theorem can be proved taking advantage of the convex optimization theory.

Theorem 1: When the massive MIMO system adopts the MRT precoding, the approximately power allocation vector achieving the optimal EE is

$$\mathbf{P}^{\mathrm{o}} = \left[\tilde{\mathbf{H}}^{-1} \mathbf{b}\right]^{+} \tag{16}$$

where $[\mathbf{x}]^{+} = \max\{0, x_i\}$, $\mathbf{b} = [b_1, b_2, \cdots, b_K]^{\mathrm{T}}$, and

$$b_k = \frac{\eta \|\mathbf{h}_k\|^2}{\eta_{EE}^{\mathrm{o}} \ln 2} - \frac{\sigma^2}{\beta_k} \tag{17}$$

$$\tilde{\mathbf{H}} = \begin{bmatrix} \|\mathbf{h}_1\|^2 / \mu & 1 & \cdots & 1 \\ 1 & \|\mathbf{h}_2\|^2 / \mu & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & \|\mathbf{h}_K\|^2 / \mu \end{bmatrix} \tag{18}$$

Proof: By the approximation in formula (15), the SE $S_\Sigma(\mathbf{P})$ is a concave function, because the first and second order partial derivative of SE can be expressed as

$$\frac{\partial S_\Sigma(\mathbf{P})}{\partial p_k} = \frac{1}{\ln 2} \frac{\beta_k \|\mathbf{h}_k\|^2 / \mu}{p_k \beta_k \|\mathbf{h}_k\|^2 / \mu + \beta_k \sum_{l=1\neq k}^{K} p_l + \sigma^2} \tag{19}$$

$$\frac{\partial^2 S_\Sigma(\mathbf{P})}{\partial p_k \partial p_l} = \frac{-\beta_k^2 \|\mathbf{h}_k\|^2 / (\mu \ln 2)}{\left(p_k \beta_k \|\mathbf{h}_k\|^2 / \mu + \beta_k \sum_{l=1\neq k}^{K} p_l + \sigma^2\right)^2} < 0 \tag{20}$$

and the Hessian matrix of $S_\Sigma(\mathbf{P})$ is negative semi-definite, i.e.,

$$\nabla^2 S_\Sigma(\mathbf{P}) = \left[\frac{\partial^2 S_\Sigma(\mathbf{P})}{\partial p_k \partial p_l}\right] \leq 0 \tag{21}$$

It is easy to see that $P_\Sigma(\mathbf{P})$ is an affine function, so the objective function is quasi-convex function, which can be transformed into the following form according to convex optimization theory [13].

$$\begin{aligned} & \max_{\eta_{\mathrm{EE}} \geq 0, \mathbf{P} \in R_*^{K \times 1}} \eta_{\mathrm{EE}} \\ & s.t. F(\eta_{\mathrm{EE}}, \mathbf{P}) \geq 0 \end{aligned} \tag{22}$$

where $F(\eta_{\mathrm{EE}}, \mathbf{P}) = S_\Sigma(\mathbf{P}) - \eta_{\mathrm{EE}} P_\Sigma(\mathbf{P})$ is a concave function and decreases as a function of η_{EE}.

Further, the optimization problem in formula (14) can be solved through the two-step optimization problem [13]. The following problem is considered when η_{EE} is given firstly.

$$\begin{aligned} F(\eta_{\mathrm{EE}}) &= \max_{\mathbf{P} \in R_*^{K \times 1}} F(\eta_{\mathrm{EE}}, \mathbf{P}) \\ &= \max_{\mathbf{P} \in R_*^{K \times 1}} \left(S_\Sigma(\mathbf{P}) - \eta_{\mathrm{EE}} P_\Sigma(\mathbf{P})\right) \end{aligned} \tag{23}$$

As the convexity of $F(\eta_{\mathrm{EE}}, \mathbf{P})$, there exists a unique globally optimal power allocation for a given η_{EE}. The following equation is valid when $\eta_{\mathrm{EE}} = \eta_{\mathrm{EE}}^{\mathrm{o}}$ according to the stationary condition $\frac{\partial F(\eta_{\mathrm{EE}}, \mathbf{P})}{\partial p_l} = 0$, i.e.

$$\frac{\partial F(\eta_{\mathrm{EE}}^{\mathrm{o}})}{\partial p_k^{\mathrm{o}}} = \frac{\beta_k \|\mathbf{h}_k\|^2 / (\mu \ln 2)}{\beta_k \left(p_k^{\mathrm{o}} \|\mathbf{h}_k\|^2 / \mu + \sum_{l=1\neq k}^{K} p_l^{\mathrm{o}}\right) + \sigma^2} - \frac{\eta_{\mathrm{EE}}^{\mathrm{o}}}{\eta} = 0 \tag{24}$$

Through some minor manipulations, the approximate optimal power allocation value should meet the following equation,

$$\frac{\|\mathbf{h}_k\|^2}{\mu} p_k^{\mathrm{o}} + \sum\nolimits_{l=1\neq k}^{K} p_l^{\mathrm{o}} = \frac{\eta \|\mathbf{h}_k\|^2}{\mu \eta_{\mathrm{EE}}^{\mathrm{o}} \ln 2} - \frac{\sigma^2}{\beta_k} \tag{25}$$

The above equation can be simply expressed as

$$\tilde{\mathbf{H}} \mathbf{P}^{\mathrm{o}} = \mathbf{b} \tag{26}$$

where $\tilde{\mathbf{H}} = \mathrm{diag}\{||\mathbf{h}_1||^2, ||\mathbf{h}_2||^2, \cdots, ||\mathbf{h}_K||^2\}/\mu + 1_{K \times K} - \mathbf{I}_{K \times K}$, $\mathbf{b} = [b_1, b_2, \cdots, b_K]$, $b_k = \frac{\eta \|\mathbf{h}_k\|^2}{\mu \eta_{\mathrm{EE}}^{\mathrm{o}} \ln 2} - \frac{\sigma^2}{\beta_k}$. As the independence of $\mathbf{h}_l\,(l = 1, 2, \cdots, K)$, the rank of matrix $\tilde{\mathbf{H}}$ is K. So $\tilde{\mathbf{H}}$ is invertible and the power allocation vector can be expressed as $\mathbf{P}^{\mathrm{o}} = [\tilde{\mathbf{H}}^{-1} \mathbf{b}]^{+}$. Thus, the approximate power allocation vector in theorem 1 is got. ■

As $\|\mathbf{h}_k\|^2 \overset{f}{\gg} 1, N \to \infty$, (16) can be simplified into

$$p_k^{\rm o} \approx \left[\frac{\eta}{\eta_{EE}^{\rm o} \ln 2} - \frac{\mu \sigma^2}{\beta_k \|\mathbf{h}_k\|^2} \right]^+ \tag{27}$$

Formula (27) is the power allocation scheme ingoring IUI, just considering noise. Meanwhile, it shows that the proposed power allocation scheme is the generalization of existing scheme ignoring the IUI. The proposed power allocation scheme is more proper to be applied to the practical system whether $N \gg K$ or not.

The optimal $\eta_{EE}^{\rm o}$ is unknown in formula (16), so it needs to develop an iterative scheme to achieve the optimal EE. According to [14] and the definition of $F(\eta_{EE})$ in formula (23), if $\eta_{EE}^{\rm o} = S_\Sigma(\mathbf{P}^{\rm o})/P_\Sigma(\mathbf{P}^{\rm o})$ is the optimal EE, the following equations can be got

$$F(\eta_{EE}) \begin{cases} < 0, \eta_{EE} > \eta_{EE}^{\rm o} \\ = 0, \eta_{EE} = \eta_{EE}^{\rm o} \\ > 0, \eta_{EE} < \eta_{EE}^{\rm o} \end{cases} \tag{28}$$

Then the following bisection power allocation (BPA) algorithm achieving the optimal EE can be developed according to theorem 1 and formula (28).

Algorithm 1 Energy efficient power allocation algorithm for the massive MIMO system with the MRT precoding

Step 1: Initialize $u = 0$, $v = \frac{\eta}{\mu\sigma^2 \ln 2} \min\limits_k \left\{ \beta_k \|\mathbf{h}_k\|^2 \right\}$, $\varepsilon > 0$, $p_k = 0 \ (k = 1, 2, \cdots, K)$.

Step 2: Let $\eta_{\rm EE} = \frac{u+v}{2}$, solve p_k according to formula(16), then a realistic EE $\eta_{\rm EE}^{\rm R}$ can be got by formula (11). if $\eta_{\rm EE} \geq \eta_{\rm EE}^{\rm R}$, then $u = \eta_{\rm EE}$, else $v = \eta_{\rm EE}$.

Step 3: If $v - u < \varepsilon$, then $\eta_{\rm EE}^{\rm o} \approx \frac{u+v}{2}$ and $\mathbf{P}^{\rm o} = \tilde{\mathbf{H}}^{-1}\mathbf{b}$, else go to Step 2.

Algorithm 1 requires at most $\left\lceil \log_2 \frac{v-u}{\varepsilon} \right\rceil$ iterations for getting the approximate optimal EE within the error limit ε. If we replace formula (16) with formula (27) at step 2, the existing scheme ignoring IUI can be got.

V. Simulation and Discussion

In this section, the proposed power allocation achieving the optimal EE for the massive MIMO system with MRT precoding is simulated and compared with the existing scheme ignoring IUI. Meanwhile, the corresponding SE and transmission power are also given. The main parameters used in simulation are listed in Table 1. Each snapshot, UTs are uniformly located within the cell with the radius $R = 500$. Without loss of generality, we assume $P_{{\rm RC}k} = P_{\rm RC} \ (k = 1, 2, \cdots, K)$.

As shown in Fig. 2 and Fig. 3, both EE values achieved by the proposed algorithm and the existing scheme are enhanced by increasing the number of antennas at BS. When the number of antennas at BS is relatively smaller, EE performance is deteriorated by increasing the number of UTs served by the same time-frequency resource. But EE performance can be improved by increasing the number of UTs when the number of antennas at BS is large enough. In another words, EE performance can be improved only when the average freedom degree is superfluous for each UT (about 15 antennas per UT seen from Fig. 2). The proposed algorithm can better system EE by considering the IUI compared with the existing scheme ignoring IUI. But the gap, between EE achieved by the proposed algorithm and EE got by the existing scheme, shrinks when the number of antennas increases and is enlarged by increasing the number of multiple UTs, which is consistent with the above analysis in Section IV.

TABLE I
Parameters for the Massive MIMO System

Parameters	value
Cell radius R	500 [m]
Circuit power at BS $P_{\rm TC}$	1 [mW/Hz]
Circuit power at UT $P_{\rm RC}$	0.01 [mW/Hz]
Efficiency of PA η	0.5
Factor φ	1
Path loss exponent α	3.7
Variance of log-normal shadow fading $\sigma_{\rm sh}^2$	10 [dB]
Noise power spectrum density σ^2	-120 [dBm/Hz]
Target BER	0.001

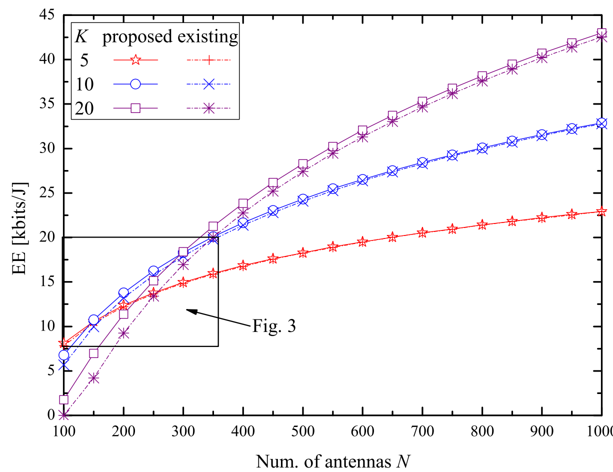

Fig. 2. EE v.s. the number of antennas at the BS with different number of UTs under the proposed algorithm and the existing scheme.

Fig. 4 shows that the proposed algorithm achieves the same SE compared with the existing scheme. It also demonstrates that SE of the massive MIMO system with MRT precoding can be enhanced by increasing both the number of antennas at BS and the number of multiple UTs when the average freedom degree is large enough per UT. Compared with EE in Fig. 2, bettering SE needs less average freedom degree because there exists the circuit power consumption for EE. Another advantage of the proposed power allocation algorithm is shown in Fig. 5, the transmission power is lower compared with the existing scheme. It means that the proposed power allocation algorithm can match the SINR at UT more accurately. But the gap, between transmission power needed by the proposed

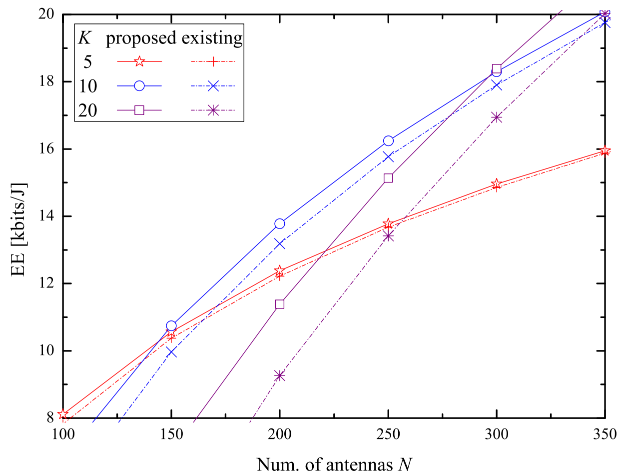

Fig. 3. Enlargement EE of the square in Fig. 2.

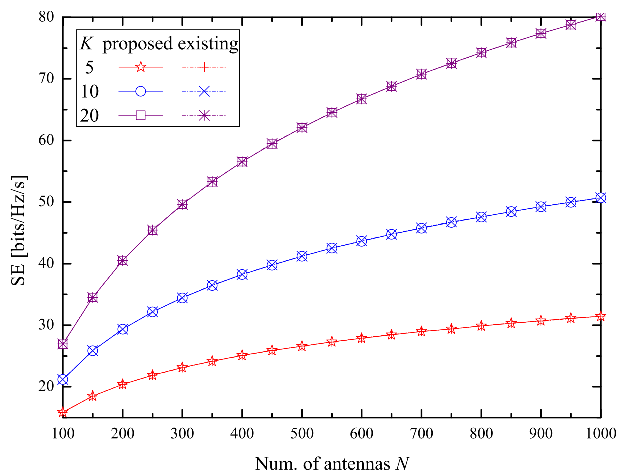

Fig. 4. SE v.s. the number of antennas at BS with different number of UTs corresponding to EE in Fig. 2.

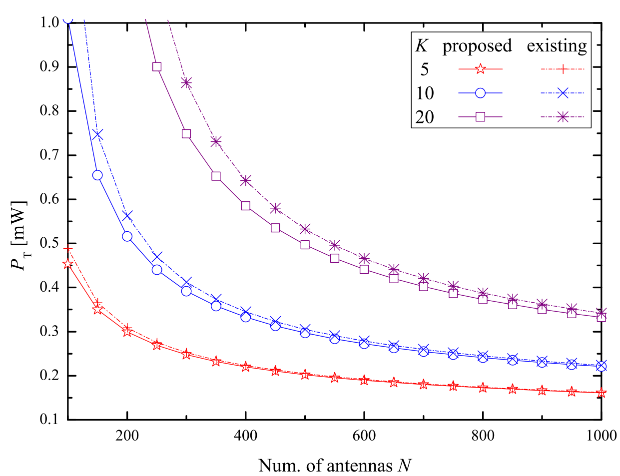

Fig. 5. Total transmission power v.s. the number of antennas at BS with different number of UTs corresponding to EE in Fig. 2.

algorithm and it needed by the existing scheme, enlarged by increasing the number of multiple UTs and is weaken by increasing the number of antennas at BS, which coincides with the rule of EE in Fig. 2.

VI. Conclusion

This paper investigates energy efficient power allocation for the massive MIMO system with MRT precoding. MRT is a practical precoding to balance the performance and system complexity, but it can not remove IUI at each UT. Considering the intractable received SINR at UT for power allocation, properly approximate SINR is adopted compared with the existing scheme ignoring the IUI. Then, a power allocation algorithm to achieve the optimal EE was proposed according to the convex optimization theory. Simulation show that the proposed power allocation algorithm performs better than the existing scheme ignoring the IUI, which demonstrates the effectiveness of the proposed power allocation algorithm. Meanwhile, simulation results also shows massive MIMO can improve the SE and reduce power consumption.

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