Energy Efficient Resource Allocation for Wireless Power Transfer Enabled Massive MIMO System

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Abstract—This paper proposes an energy-efficient resource allocation scheme for a wireless power transfer (WPT) enabled multi-user massive MIMO system with imperfect channel estimation. In the considered system, the users who have data to be transmitted only can be empowered by the WPT in the downlink from a base station (BS) with a large scale of multiple antennas. The problem of optimizing the energy efficiency objective is formulated with consideration of imperfect channel state information (CSI) at the BS. In particular, the proposed antenna selection scheme is to find the optimal number of antennas and then employ the energy beamforming. The nonlinear fractional programming based scheme is utilized to address optimization of energy efficiency and to find the optimal power and time allocation. Performance evaluation is presented to demonstrate the effectiveness of the proposed schemes.

Index Terms—imperfect channel estimation; wireless power transfer; beamforming; antenna selection; energy efficiency; resource allocation; massive MIMO

I. INTRODUCTION

A. Background and Motivation

Many types of wireless networks, such as wireless sensor networks, are energy constrained, in the sense that the network elements need to be empowered by inconstant energy sources (such as batteries, etc.). While the lifetime of these devices can be extended by replacing or recharging the battery, sometimes it may be inconvenient and expensive. Another way to prolong the lifetime of devices is to realize the energy harvesting (EH) capabilities and to design the energy efficient schemes to improve the energy-efficiency (EE). The EH techniques enable the elements in wireless networks to harvest energy from the surrounding environment. Meanwhile, it is worth mentioning that most of the EH sources are location-depend, such as solar and wind, etc. However, for the wireless elements that have difficulty to access these sources, how to provide energy supply is problematic. Recently, apart from the techniques that harvest energy from solar, wind, or other physical phenomena, scavenging from radio frequency (RF) signals offers another way for addressing the problem of energy supply. So called simultaneously wireless information and power transfer (SWIPT) attracts increasingly interests from the research and industrial communities [1].

Meanwhile, it is widely acknowledged that the current cellular structure has immense difficulties confronting the data traffic increase as well as the spectrum crunch. To further improve the spectrum utilization, massive multiple input multiple output (MIMO) system makes a clean break with current practice through the use of a large excess of antennas. A large number of extra antennas helps bring significant improvements in throughput comparing with the current MIMO system by focusing transmit energy into smaller regions of space. However, one of the main disadvantages of employing a large scale of multiple antennas is the associated complexity of employing a separate RF chain for every employed antenna, which also brings a significant increase in the energy consumption cost. Most of the energy-efficient communication techniques typically focus on minimizing the transmit power only, which is reasonable when the transmit power is large enough and the number of used RF chains is small. However, when the transmit power is relatively small, especially in large scale multiple antenna system where the circuit power consumption can be comparable to or even dominates the transmit power, it would be worthwhile to investigate whether large scale multiple antenna systems can outperform the systems with less antennas in term of EE [2].

B. Contribution

In this paper, the aim is to investigate the energy-efficient resource allocation algorithm for a wireless power transfer (WPT) enabled multi-user massive MIMO system. We consider that the users who have data to transmit to the BS can only be empowered by the WPT in the downlink. In particular, a joint optimization of antenna selection, power allocation and time allocation is studied with the objective to maximize system EE. Moreover, we also consider only the imperfect channel state information (CSI) is available, which is rather a practical case in the wireless networks. Taking into consideration of imperfect CSI can also enhance the robustness of the proposed resource allocation algorithm. Our contributions over the existing literatures can be summed as follows,

- In this paper, we study the EE optimization for a multi-user massive MIMO system empowered by the WPT with imperfect CSI. A novel antenna selection scheme is presented to find the optimal number of transmit antennas at the BS, which are able to obtain the optimal EE performance. The introduced antenna selection scheme is
based on the binary searching algorithm to find the optimal solution. Moreover, a energy beamforming scheme is proposed for the selected antennas.

- In the considered system, the whole time slot $T$ is divided to energy transfer time and data transmission time. If more time is allocated to energy transfer, higher transmit power is available at the user. However, less time is remained for data transmission, which leads to lower system throughput. Therefore, we also propose a time allocation scheme to determine the optimal time allocation. Power allocation algorithm is also presented to find the optimal transmit power at the BS.
- To address the formulated problem, a nonlinear fractional programming scheme is presented. The proposed schemes are illustrated and verified through extensive simulations. The performance evaluation demonstrates the effectiveness and superior performance compared with recent proposed scheme.

The rest of paper is organized as follows. In Section II, we briefly overview the recent development in the related research area. Section III introduces the system model and problem formulation. Section IV presents the antenna selection algorithm and resource allocation optimization. Simulation results are discussed in Section V. Finally, we conclude this study in Section VI.

II. RELATED WORK

Recently, the resource allocation problems of wireless powered communications system have been widely investigated [3]-[6]. In [3] and [4], the problems of maximizing the throughput of MIMO WPT systems are studied when considering single-user and multi-user cases, respectively. In [5], with the objective to optimize the EE of a point-to-point MIMO system with a large scale of multiple antennas and SWIPT, the authors present a joint optimization of power and time allocation. The authors of [6] also propose an energy efficient resource allocation scheme for a multi-user MISO system. Meanwhile, in order to improve the energy transfer efficiency of multiple antenna system with SWIPT, various beamforming methods are adopted [7]-[10]. In [7], a beamforming strategy for a secure wireless information and power transmission system is proposed. In [8], the authors study a multiuser MISO beamforming scheme for wireless information and power transmission with the objective to maximize the weighted sum-power under a series of constraints. [9] and [10] also propose different robust beamforming schemes to maximize the WPT in a multiuser MISO SWIPT system.

It can be well observed that most of the aforementioned work assume that the CSI can be perfectly obtained. However, in the practical wireless communication systems, the CSI cannot be perfectly obtained due to the imperfection of channel estimation and feedback. Such imperfection of the CSI can typically induce system performance degradation. In [11], the authors focus on the resource allocation for OFDMA-based networks with imperfect CSI and multiple classes of services that have diverse QoS requirements. In [12], energy efficient resource allocation for OFDMA relay systems with imperfect CSI is presented, and a proportional fairness design for EE maximization problem is considered. In [13], the authors formulate a non-convex optimization problem for determining the training interval of channel estimation, user scheduling, and power allocation strategies to maximize the energy efficiency, and transform the problem into a tractable convex one. The authors of [14] investigate the performance of OFDMA relay system with imperfect CSI and propose a resource allocation algorithm to obtain throughput maximization.

III. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Model

As shown in Fig. 1, we consider a multi-user massive MIMO system with WPT. In the system, there is one BS and $K$ mobile users and the set of users is denoted as $K$. The BS is equipped with $N \gg 1$ antennas and each user is equipped with one antenna. In this model, the role of the BS is to charge the users via downlink WPT, while the users have the functionality of storing the energy transmitted by the BS and use the received energy to deliver data to the BS in the uplink.

![Fig. 1. A multi-user wireless powered communications system with transmit antenna selection.](image)

![Fig. 2. Time protocol for wireless information and power transfer.](image)
We assume that the whole transmission process including WPT in the downlink and data transmission in the uplink is within a time block $T$. As shown in Fig. 2, in the first time slot $\tau_k$, the BS charges user $k$ via WPT and the user stores the harvested energy in a rechargeable battery. Then, in the time duration $T - \tau_k$, user $k$ sends its own data to the BS.

We consider a quasi-static block fading channel model where the channel between the BS and user is constant for a given transmission block $T$, and it can vary independently from one block to another. In each transmission block, user $k$ uses a minimum mean square error (MMSE) channel estimator to estimate the channel. The estimated channel is denoted as $\hat{h}_k$ and the estimation error is $\hat{e}_k$. Thus, we have the expression of imperfect CSI as follow

$$\hat{h}_k = h_k + \hat{e}_k,$$

where $h_k$ is the channel coefficient. The BS is equipped with $N$ antennas, where $N$ is very large. Meanwhile, each antenna of BS requires a RF chain, which increases the energy cost of massive MIMO system. In order to reduce the energy consumption and improve the system EE, we propose an antenna selection algorithm at the BS, that is, $L$ antennas are selected from the $N$ antennas with the objective to maximize the EE of the considered system. Meanwhile, we also propose to design the energy beamforming vector for the selected antennas to improve the efficiency of WPT. With the imperfect CSI model, the received energy signal of user $k$ is:

$$y_k^{EH} = \alpha_k b_k^H \hat{h}_k s + n_d,k,$$

where $\alpha_k$ is the path loss from the BS to user $k$, $b_k^H$ is a energy beamforming vector for user $k$ at the BS and $s$ is the transmitted signal. $n_d,k$ is an additive white Gaussian noise (AWGN) in the downlink (DL), and $n_d,k \sim \mathcal{CN}(0, \sigma^2)$ is the channel noise. In the system, when $L$ antennas are selected, we have $\hat{h}_k \in \mathbb{C}^{1 \times L}$. Moreover, the transmit power of the BS is $E[|s|^2] = P_t$.

According to the law of conservation of energy, user $k$ can obtain the received energy from the BS as follows [4],

$$E_k = \eta \tau_k (\alpha_k^2 |b_k^H \hat{h}_k|^2 P_t),$$

where $\eta (0 < \eta \leq 1)$ is the conversion efficiency which transfer the harvested energy into electric energy stored by the user. In order to maximize the harvested energy, we design the energy beamforming policy as $b_k = \frac{\hat{h}_k}{||\hat{h}_k||}$, which is named as maximum ratio transmission (MRT). According to the estimated CSI and beamforming strategy, the energy transfer direction can be adjusted properly to maximize the received energy at the user. Then, the obtained energy of user $k$ can be reformulated as follows:

$$E_k = \eta \tau_k (\alpha_k^2 |\hat{h}_k|^2 P_t).$$

B. Throughput Analysis

During the second time slot $T - \tau_k$, user $k$ sends its data to the BS using the harvested energy, and the received signal at the BS is can be expressed as,

$$y_k^{ID} = \sqrt{\frac{E_k}{T - \tau_k}} \alpha_k \hat{h}_k^H x_k + n_u,k,$$

where $y_k^{ID}$ is the received signal at the BS, $x_k$ is the transmitted signal at user $k$, and $n_u,k \sim \mathcal{CN}(0, \sigma^2)$ is the channel noise. It is also worth noticing that $\frac{E_k}{T - \tau_k}$ is the transmit power of user $k$.

In a massive MIMO system, with the increase of the number of antennas, the channel hardening effect emerges [15]. In other words, the trend of the mutual information function curve tends to its expected value. Therefore, in order to obtain the expected data rate of the considered system with imperfect CSI, we first study the mutual information distributions with/without antenna selection. When considering all $N$ antennas are used, i.e., $\hat{h}_k \in \mathbb{C}^{1 \times N}$, the uplink throughput between user $k$ and the BS is expressed as [6][15],

$$C_k = (T - \tau_k) \log_2(1 + N \rho_k),$$

where the signal to interference plus noise ratio (SINR) $\rho_k$ of user $k$ in the uplink can be expressed as:

$$\rho_k = \frac{E_k \alpha_k^2}{\sigma^2 + \frac{E_k \alpha_k^2}{T - \tau_k} \sigma_k^2 + \sum_{j \neq k} \frac{E_j \alpha_j^2}{T - \tau_j}},$$

where $\sum_{j \neq k} \frac{E_j \alpha_j^2}{T - \tau_j}$ is the interference caused by the other users.

It can be concluded from [2] that the addition of antenna selection does not affect the channel hardening effect. Correspondingly, when $L$ antennas are selected, i.e. $\hat{h}_k \in \mathbb{C}^{1 \times L}$, the throughput is

$$C(P_t, \tau_k, L) = \sum_{k=1}^{K} (T - \tau_k) \log_2(1 + (1 + \ln \frac{N}{L}) * \rho_k * L).$$

C. Energy Consumption Model

Meanwhile, the total energy consumption of the system can be expressed as:

$$U(P_t, \tau_k) = P_c \cdot T + P_t \max_{k \in K} \tau_k,$$

where $P_c$ is the constant circuit power consumption, and it can be expressed as [17]

$$P_c \approx L(P_{DAC} + P_{mix} + P_{filt})$$

$$+ K(2P_{syn} + P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC}),$$

where $P_{DAC}, P_{mix}, P_{filt}, P_{syn}, P_{LNA}, P_{IFA}, P_{filr}, P_{ADC}$ denotes the power consumption of the DAC, the mixer,
the transmit filter, the frequency synthesizer, the low noise amplifier, the frequency amplifier, the receiver filter and ADC. We denote $P_{\text{user}}$ as the power consumption of each user, i.e., $P_{\text{user}} = 2P_{\text{syn}} + P_{LNA} + P_{\text{mix}} + P_{\text{FA}} + P_{\text{filr}} + P_{\text{ADC}}$. $P_{\text{bs}}$ is expressed as a power consumption for each antenna on the BS, i.e., $P_{\text{bs}} = P_{DAC} + P_{\text{mix}} + P_{\text{filr}}$. Then we have $P_{c} = KP_{\text{user}} + LP_{\text{bs}}$. Since the BS and users have to be active for the whole time and the transmit power only exists in the first time slot, in (9), the denominator of EE is rewritten as:

$$U(P_t, \tau) = (KP_{\text{user}} + LP_{\text{bs}})T + P_{\text{user, max}} \tau_k.$$  

(11)

D. Problem Formulation

With the above analysis, the objective of EE in [bits/J/Hz] can be defined as follows,

$$\Pi(P_t, \tau_k, L) = \frac{C(P_t, \tau_k, L)}{(KP_{\text{user}} + LP_{\text{bs}})T + P_{t, \text{max}} \max_{k \in K} \tau_k}.$$  

(12)

From the (4), (8) and (12), $\Pi(P_t, \tau_k, L)$ can be given as follows:

$$\Pi(P_t, \tau_k, L) = \sum_{k=1}^{K} \frac{(T - \tau_k) \log_2(1 + (1 + \ln \frac{T}{\tau_k})P_k L)}{(KP_{\text{user}} + LP_{\text{bs}})T + P_{t, \text{max}} \max_{k \in K} \tau_k}. \quad (13)$$

With the defined objective, the optimization problem $P_1$ can be formulated as follows,

$$\max_{P_t, \tau_k, L} \Pi(P_t, \tau_k, L),$$  

s.t.

$$C_1 : 0 \leq P_t \leq P_{\text{bs, max}},$$

$$C_2 : \frac{E_k}{T - \tau_k} \leq P_{\text{user, max}},$$

$$C_3 : 0 \leq \tau_k \leq T,$$

$$C_4 : \frac{C_k}{T - \tau_k} \geq R_{\text{min}},$$

$$C_5 : L \leq N.$$  

(15)

In $P_1$, the objective is to maximize the overall system EE. In (15), $C_1$ is the BS transmit power constraint, which shows that the transmit power of the BS cannot be larger than the maximum transmit power $P_{\text{bs, max}}$. $C_2$ is the transmit power constraint for user $k$. $C_3$ means that $\tau_k$ cannot be larger than $T$ and $C_4$ can ensure that Quality of Service (QoS) $R_{\text{min}}$ can be meet. Because the channel hardening phenomenon after antenna selection still exists, we can bring (4) into $C_2$, and we can arrive

$$P_t \leq \frac{P_{\text{user, max}}(T - \tau_k)}{\eta \tau_k \| \hat{h}_k \|^2 \alpha_k^2}.$$  

(16)

Combining $C_1$ and (16), we can obtain

$$\tau_k \leq \frac{P_{\text{user, max}}T}{(\eta \alpha_k^2 P_{\text{bs, max}} \| \hat{h}_k \|^2 + P_{\text{user, max}})} = \tau_{\text{max}}.$$  

(17)

IV. ANTENNA SELECTION AND RESOURCE ALLOCATION

In this section, antenna selection and resource allocation schemes are introduced to addressed the formulation problem $P_1$. At first, we propose an antenna selection scheme to find the optimal number of antennas that the BS can use to obtain the EE maximization. Then, power and time allocation schemes are presented to find the optimal transmit power and time duration of WPT.

A. Proposed Antenna Selection Algorithm

The proposed scheme is based on an improved bisection method to find the solution for antenna selection. The antenna selection scheme is presented in Algorithm 1. First, we initialize three variables: the lower bound of the number of antennas, the upper value and the intermediate value, denoted as $\omega_l$, $\omega_h$ and $\omega_m$, respectively. Among them, the initial values of $\omega_l$ and $\omega_h$ are 1 and $N$, respectively, and the intermediate values is calculated as $\omega_m = \frac{\omega_l + \omega_h}{2}$. In each cycle, we need to compare the two values of $\Pi(\omega_m)$ and $\Pi(\omega_m + 1)$, and determine which subset of the maximum value is located. If $\Pi(\omega_m)$ is less than $\Pi(\omega_m + 1)$, $\omega_m + 1$ is assigned to $\omega_l$; if $\Pi(\omega_m)$ is bigger than $\Pi(\omega_m + 1)$, $\omega_m$ is assigned to $\omega_h$. Thus, the maximum value of EE is found by selecting the optimal number of antennas. At the end of each cycle, the $\omega_m$ value is updated to the new $\omega_l$ or $\omega_h$. When $\omega_h - \omega_l = 1$, the searching is ended. Finally, the corresponding $L$ can be obtained.

Algorithm 1 Antenna Selection Algorithm

1: Initialize $N$, $\Pi(N)$, $\omega_l = 1$, $\omega_h = N$, $\omega_m = \frac{\omega_l + \omega_h}{2}$.
2: while $(\omega_h - \omega_l) > 1$ do
3: if $\Pi(\omega_m) < \Pi(\omega_m + 1)$ then
4: set $\omega_l = \omega_m + 1$;
5: else if $\Pi(\omega_m) > \Pi(\omega_m + 1)$ then
6: set $\omega_h = \omega_m$;
7: else
8: break;
9: end if
10: end while
11: if $\omega_h - \omega_l = 1$ then
12: $\Pi(L) = \max\{\Pi(\omega_l), \Pi(\omega_h)\}$;
13: else
14: $\Pi(L) = \Pi(\omega_m)$;
15: end if

B. Power and Time Allocation Schemes

It can be found that the formulated problem with objective in (14) is a non-convex fractional programming problem. Based on the method in [18], we are able to transform it into a subtractive form. First, given $L$ is obtained, we consider $q^*$ as the global optimal solution of EE, i.e.,
where $P^*_t$ is the optimal transmit power and $\tau^*_k$ is optimal WPT time. Then, we can obtain the following Theorem 1.

**Theorem 1.** $q$ can reach its optimal value if and only if

$$\max_{P_t, \tau_k} C(P_t, \tau_k) - qU(P_t, \tau_k) = 0. \tag{19}$$

The proof can be found in [18]. Therefore, the problem $P_1$ can be transformed into a problem $P_2$:

$$\max_{P_t, \tau_k} \Gamma(P_t, \tau_k), \tag{20}$$

s.t.

$$C1, C3, C4, \quad \tau_k < \tau_{max}, \tag{21}$$

where $\Gamma(P_t, \tau_k) = C(P_t, \tau_k) - q^*U(P_t, \tau_k)$. We can see that $\Gamma(P_t, \tau_k)$ is a concave function with respect to $P_t$ and $\tau_k$ as its Hessian matrix is semi-negative. Therefore, $P_2$ is now a convex optimization problem and we are able to address it in dual domain to obtain the closed-form solution. The Lagrange dual function corresponding to $P_2$ is

$$\mathcal{L}(P_t, \tau_k, \alpha, \beta, \mu, \varphi) = C(P_t, \tau_k) - q^*U(P_t, \tau_k) - \lambda(P_t - P_{bs,max}) - \beta(\tau_k - \tau_{max}) - \mu(\tau_k - T) - \varphi(R_{min} - \frac{C_k}{T - \tau_k}), \tag{22}$$

where \{\lambda, \beta, \mu, \varphi\} are the positive Lagrange multipliers associated with the constraint in (21), respectively. Correspondingly, the dual problem of (22) can be expressed as

$$P_3 : \min_{\alpha, \beta, \mu, \varphi} \max_{P_t, \tau_k} \mathcal{L}(P_t, \tau_k, \alpha, \beta, \mu, \varphi). \tag{23}$$

The optimal transmit power $P^*_t$ and the optimal time for WPT $\tau^*_k$ can be obtained by solving the Karush-Kuhn-Tucker (KKT) condition:

$$\frac{\partial \mathcal{L}(P_t, \tau_k, \lambda, \beta, \mu, \varphi)}{\partial P_t} = 0, \tag{24}$$

and

$$\frac{\partial \mathcal{L}(P_t, \tau_k, \lambda, \beta, \mu, \varphi)}{\partial \tau_k} = 0. \tag{25}$$

From (24), we can obtain

$$P^*_t = \frac{-(\Omega_4 + \Omega_3)\Omega_2 + \sqrt{(\Omega_3 - \Omega_4)^2\Omega_2^2 + 4 \prod_{i=1}^{4} \Omega_i}}{2\Omega_3\Omega_4}, \tag{26}$$

where $\Omega_1 \sim \Omega_5$ are given as

$$\Omega_1 = \eta \tau_k (\alpha_k^2 \|\hat{h}_k\|^2)(L + L \ln(N/L)), \quad \Omega_2 = (T - \tau_k)\sigma^2, \quad \Omega_3 = \eta \tau_k (\alpha_k^2 \|\hat{h}_k\|^2)(\sigma^2_k + K - 1),$$

$$\Omega_5 = \frac{(T - \tau_k + \varphi)K}{(\lambda + q^* \max_{k \in \mathbb{K}} \tau_k)(\ln 2)}. \tag{27}$$

Next, $\tau^*_k$ can be obtained by addressing (25) numerically. To obtain the lagrangian multipliers $\lambda, \beta, \mu, \varphi$, the subgradient method with guaranteed convergence [19] can be applied,

$$\lambda(n + 1) = \lfloor \lambda(n) - \Delta \lambda(P_{bs, max} - P_t) \rfloor^+, \quad \beta(n + 1) = \lfloor \beta(n) - \Delta \beta(\tau_{max} - \tau_k) \rfloor^+, \quad \mu(n + 1) = \lfloor \mu(n) - \Delta \mu(T - \tau_k) \rfloor^+, \quad \varphi(n + 1) = \lfloor \varphi(n) - \Delta \varphi(C_k / T - \tau_k - R_{min}) \rfloor^+, \tag{28}$$

where $n$ is iteration index, $[x]^+ = \max\{0, x\}$, $\Delta \lambda, \Delta \beta, \Delta \mu, \Delta \varphi$ are the step sizes. Based on the optimal value $q^*$ and the iterative update of the time allocation and power allocation parameter, the convergence can be obtained by satisfying the following relations: $|C(P_t, \tau_k, L) - q^*U(P_t, \tau_k)| < \varepsilon$, where $\varepsilon$ is a sufficiently small positive number. If this condition cannot be meet, $q^* = C(P_t, \tau_k)$ will be updated until the convergence condition is satisfied. The proposed power and time allocation scheme is summarized in Algorithm 2.

**Algorithm 2 Energy Efficient Resource Allocation**

1: Initialization:
2: $N, L, K, \eta, \alpha_k, P_{bs}, P_{user}, P_{bs, max}, P_{user, max}, R_{min},$ $\Delta \lambda, \Delta \beta, \Delta \mu,$ and $\Delta \varphi$.
3: Define $\varepsilon$ as a sufficiently small positive real number.
4: while (!Convergence) do
5: Update $\lambda, \beta, \mu, \varphi$ according to (28).
6: Obtaining the $P'_t$ and $\tau'_k$ by solving the equations (26) and (25).
7: if $|C(P'_t, \tau'_k) - q'U(P'_t, \tau'_k)| \leq \varepsilon$ then
8: Convergence = true,
9: return $P^*_t = P'_t, \tau^*_k = \tau'_k,$ and obtain optimal $q^*$
10: else
11: Convergence = false,
12: return $q = C(P'_t, \tau'_k)/U(P'_t, \tau'_k),$
13: end if
14: end while
15: return Obtain $P^*_t$ and $\tau^*_k$.

**V. Simulation Results**

In this section, the performance of the proposed scheme is presented and illustrated. Some simulation parameters are given in Table I [17].

In Fig. 3, we present the performance of our proposed schemes and prove the effectiveness of the proposed antenna
TABLE I
SIMULATION PARAMETERS

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<th>Parameter</th>
<th>Value</th>
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<td>$K$</td>
<td>10</td>
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<tr>
<td>$P_{\text{bs,max}}$</td>
<td>$46dBm$</td>
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<tr>
<td>$P_{\text{user,max}}$</td>
<td>$23dBm$</td>
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<tr>
<td>$R_{\text{min}}$</td>
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<tr>
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<td>$\eta$</td>
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<tr>
<td>$\varepsilon$</td>
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<td>$P_{\text{IFA}}$</td>
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Fig. 3. EE w/wo antenna selection and time allocation

Fig. 4. Effect of imperfect CSI

Fig. 5 describes the EE performance when considering different transmit power with the change of the number of antennas. It can be seen that with the increase of the number of antennas, the EE performance generally first increases and then decreases after reaching the maximum. For the considered system, different transmit power allocation leads to different optimal number of antennas. For example, when the transmit power is $30dBm$, the optimal $L = 30$ and when the transmit power is $35dBm$, $L = 50$. In addition, from the comparison of the EE performance of different transmit power allocation, we can clearly find that increasing transmit power can not guarantee the increment of EE. In Fig. 5, the EE of $P_t = 30dBm$ is higher than the other two curves of the EE also illustrates the effectiveness of the optimized transmit power allocation.
VI. CONCLUSION

In the future wireless network, massive antennas will be explored to improve the system capacity. Meanwhile, as an emerging technique, wireless power transfer offers a potential solution to prolong the lifetime of mobile devices. This paper studies the energy efficiency of a wireless power transfer enabled multi-user massive MIMO system under imperfect channel estimation. A joint optimization of beamforming design, antenna selection, power and time allocation is studied. In particular, the antenna selection algorithm is based on an improved bisection scheme to find the optimal number of transmit antennas at the BS. Moreover, the nonlinear fractional programming scheme are utilized to address resource allocation problem and find the optimal power and time allocation. Simulation results can demonstrate the effectiveness of the proposed schemes.

REFERENCES