Energy Efficient Link Adaptation Approach for Mobile Users in TDD Multi-User MIMO Systems

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Abstract: ***In mobile communication, the battery technology is an important development. In order to improve the energy efficiency of mobile users in a multiuser multiple input multiple output systems(MU-MIMO), a new approach pilot and link adaptation algorithm can be developed Assuming reciprocity between uplink and downlink channels, the transmission of downlink is depends on estimation of uplink channel. Higher pilot power gives higher downlink rate can be achieved; it consumes higher energy consumption of mobile users. This paper explains the tradeoff between pilot power and channel estimation. The energy efficiency of different users can be dissociated because downlink average throughput of each user is independent of pilot powers of the users. and energy-efficient design can be done on a per user basis. Based on the analysis, we propose an uplink pilot and downlink link adaptation algorithm to improve the EE of mobile users. Simulation results are finally provided to demonstrate the significant gain in energy efficiency for mobile users.***

Keywords: Energy efficient, multiuser mimo, Rayleigh fading, AWGN channel, TDD, l ink adaptation.

1. Introduction

The demand of cellular data traffic has grown significantly in recent years. To accommodate the need, cellular infrastructures are getting denser and denser and consuming more and more energy resulting in a large amount of carbon dioxide emission and high capital and operating expenditures. On the other hand, mobile terminals also desire high energy efficiency (EE) because the development of battery technology has not kept up with the demand of mobile communications. Thus, energy-efficient design is becoming more and more important for both mobile operators to fulfill their social responsibility in preserving environments and to minimize their costs and mobile terminals to extend their battery lives. In the past decades, significant efforts have been dedicated to improving the EE of wireless systems an adaptive modulation strategy that minimizes the total energy consumption for transmitting a given number of bits in a single input and single output (SISO) AWGN channel is investigated. It shows that using the lowest modulation order is not always energy efficient if circuit energy consumption is considered. Energy-efficient link adaptation for a single user multicarrier system is studied. Energy efficient link adaptation and subcarrier allocation scheme is proposed for uplink OFDMA systems assuming flat fading channels. It is proved that, for a given channel gain and constant circuit energy consumption, there exists a unique optimal transmission rate that maximizes EE. That work is extended to frequency-selective channels link adaptation for MIMO-OFDM wireless systems is formulated as a convex optimization problem and optimal transmission mode is chosen to maximize EE with quality of service (QoS) constraints. The problem of energy-efficient input covariance matrix is investigated when terminals have multiple antennas. An energy-efficient power allocation algorithm for a single antenna OFDM system is developed. That work is later extended to the power loading problem for a single-carrier MIMO-SVD system the EE capacity for an uplink MU-MIMO system is defined and a low-complexity power allocation algorithm that achieves this capacity is developed. An energy-efficient waterfilling algorithm for the downlink MU-MIMO system is developed. Assuming BS uses the zero-forcing precoder, the optimal power allocation that maximizes the EE in the downlink of a multiuser multicarrier system is studied. These studies assume the availability of perfect channel state information (CSI).

However, in practice, it is impossible to obtain perfect CSI because of channel estimation error and CSI cannot be obtained without additional cost. Hence, an energy-efficient system design should consider both energy consumption for channel estimation and the performance degradation as a result of imperfect channel estimation. An energy-efficient pilot design in a training based downlink system is studied for a single user case and the optimal overall transmit power and the power allocation between pilots and data symbols are investigated. This idea is later extended to a downlink multiuser OFDMA system. Both consider energy-efficient pilot power allocation for single-antenna systems. To the best of our knowledge, there has been no research in literature that investigates energy-efficient pilot power allocation for multiuser multiple-input and multiple-output (MU-MIMO) systems. In this paper, we study the EE of users in a time division duplexing (TDD) MU-MIMO system, where each user sends an uplink pilot sequence for channel estimation by the BS assuming perfect reciprocity between uplink and downlink channels. Based on the estimate, the BS performs zero-forcing (ZF) beamforming and transmits data to users. With higher pilot power, higher downlink rate can be achieved because the BS can perform ZF beamforming with higher accuracy and the interference between users can be suppressed. However, higher pilot power indicates higher user power consumption. This paper will find the optimal uplink pilot power for each user.

Our modeling considers channel estimation error and we show that the average throughput of each user is independent from the pilot power of others. The EE is defined as the average throughput per total energy consumed by the user and we find that the objective function is not quasi-concave in general.

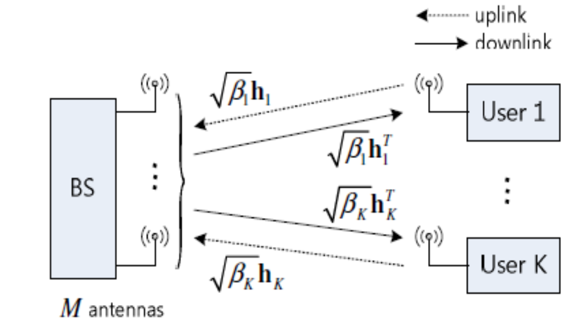

Fig. 1. TDD multiuser MIMO system model.

However, since the variables are uncoupled and the objective function is quasi-concave with respect to each variable in practice, we propose an iterative algorithm to find optimal uplink pilot power and downlink transmission rate that maximizes the EE of all the users in the network.

2. Existing System

As shown in figure1, Consider BS has M antennas and every user has one antenna. Assume zero-forcing precoding at the BS due to its low-complexity linear precoding scheme and at high SNR, it performs optimal among all the linear precoders. Under imperfect CSI at the transmitter, SINR analysis is tractable when ZF precoder is employed. When assuming flat fading channel, the discussion on the tradeoffs between the uplink pilot power and downlink rate of user in a multiuser MIMO system can be simplified. Compare to uplink transmission, downlink transmission is more efficient. Denote $\beta_k h_k^T$ to be the downlink channel from the BS to the kth user, where β_k models large-scale fading that incorporates path-loss and shadowing and h_k^T $CN(0, I_M)$ a 1 × M vector, models small-scale fading. The received signal at the kth user is

$$r_k = \sqrt{\beta_k} h_k^T X + n_k$$

Where x and $n_k \sim CN(0,\sigma^2)$ are the M × 1 transmitted signal vector and complex additive white Gaussian noise, respectively. Assume ideal channel reciprocity and the uplink channels are the same as the downlink channels. In addition, assume block fading and the channel is constant in each frame. The large-scale fading coefficient β_k is known and the small scale fading vector h_k needs to be estimated

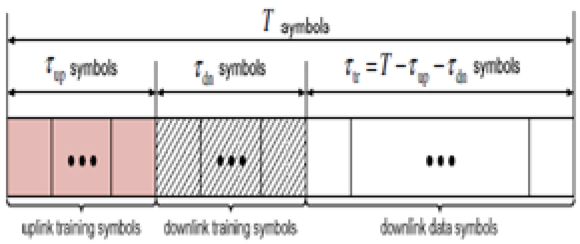

Figure 2: Frame structure of TDD system for downlink

The system consists of three parts:
- Uplink channel estimation
- Downlink effective channel estimation
- Downlink data transmission

As shown in Fig. 2, Each frame has T symbols. We allocate τ_{up} symbols for uplink channel estimation, τ_{dn} symbols for downlink effective channel estimation, and the remaining $\tau_{tr} \square T - \tau_{up} - \tau_{dn}$ for downlink data transmission. The $M \times \tau_{up}$ received signal matrix at the BS can be written as

$$Y = H(\Lambda^{\frac{1}{2}} \psi^T) + N$$

Where
$H = [h_1, \ldots.., h_k], \Lambda = diag(\beta_1 p_1, \beta_2 p_2, \ldots..\beta_K p_K)$,
$\Psi = [\Psi_1, .. \Psi_K]$ and N is a $M \times \tau_{up}$ noise matrix with its element in the ith row and the jth column $n_{ij} \sim CN(0,\sigma^2)$. Due to the orthogonality of the pilot sequences, $\Psi^T \Psi^* = \tau_{up} I_{\tau_{up}}$.

3. Multiuser MIMO Systems

Multiuser MIMO (MU-MIMO) systems consist of multiple antennas at the base station BS and a single or multiple antennas at each UE. MU-MIMO enables space-division multiple access (SDMA) in cellular systems. When the individual streams are assigned to various users is said to be Multi User MIMO (MU-MIMO). This mode is particularly useful in the uplink because the complexity on the UE side can be kept at a minimum by using only one transmit antenna.

The uplink and the downlink of a MU-MIMO system represent two different problems which are discussed in the following text. The architecture diagram of MIMO-TDD system is given below:

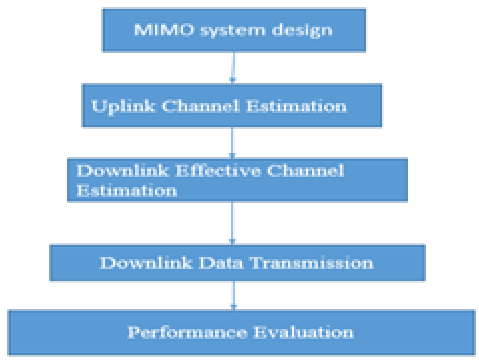

Figure 3: Architecture of MIMO-TDD system

3.1. Uplink MU-MIMO System

Consider the uplink of a multicell multiuser MIMO where the channel experiences large-scale fading. The data detection is done by using the linear zero-forcing technique, assuming the base station (BS) has perfect channel state information. We derive new, exact closed-form expressions for the uplink rate, symbol error rate, and outage probability per user, as well as a lower bound on the achievable rate. This bound is very tight and becomes exact in the large-number-of-antennas limit. We further study the asymptotic system performance in the high signal-to-noise ratio (SNR) and large number of users per cell. We show that at high SNRs, the system is interference-limited and hence, we cannot improve the system performance by increasing the transmit power of each user. Instead, by increasing the number of BS antennas, the effects of interference and noise can be reduced, thereby improving the system performance.

3.2. Downlink MU-MIMO System

Multiple antenna downlink channels have been the subject of a great deal of research for a number of years now, primarily motivated by the very significant capacity increase associated with multi-user MIMO techniques. In the downlink of a cellular-like system, a base station equipped with multiple antennas wishes to communicate with a number of terminals, each possibly equipped with multiple receive antenna. Under the assumption of perfect channel state information (CSI) at the transmitter and receivers, multi-user MIMO in the form of linear beam forming plus interference pre-cancellation (based on dirty-paper coding) is now known to achieve the capacity of the MIMO downlink channel.

3.3. Link Adaptation

Link adaptation or adaptive modulation, coding used to denote the matching of modulation coding and other signals on radio signals. For example, edge uses a rate adaptation algorithm that adapts the modulation and coding scheme (MCS) according to the quality of the radio channel, and thus the bit rate and robustness of data transmission. The process of link adaptation is a dynamic one and the signal and protocol parameters change as the radio link conditions change. link adaptation schemes uses different modulation schemes for different link qualities.

4. Proposed Algorithm

We are interested in the trade-off between the downlink rate that each user achieves and the uplink pilot power that the user consumes in the TDD MU-MIMO system. Therefore, we define the EE of each user as

$$\eta_{tr} \,\square\, \frac{\tau_{tr}\overline{R_k}}{\tau_{up} p_k + E_{cir}}$$

Where $E_{cir} \,\square\, Tp_{cir}$ is the circuit energy consumption during a frame and p_{cir} is the circuit power of a mobile user which includes power consumption in a mixer, a frequency synthesizer, low noise amplifiers (LNA), analog-to-digital (A/D) converters, and filters, etc.

Since the EE of a user η_k does not depend on the other users' pilot power $\{p_j\}_{j\neq k}$, each user can find optimal p_k to maximize its EE individually. Therefore, we formulate the following EE optimization problem.

(p1) $$\max_{r_k, p_k} imize\, \eta_k(r_k, p_k)$$

Subject to $p_k \leq p_{\max}$

$r_k \geq r_{\min}$

Where

$$\eta_k(r_k, p_k) = \frac{\tau_{tr} r_k e^{-\frac{K}{\rho_k p^{dn}}(2^{r_k}-1)} \left(\frac{\tau_{up}\rho_k p_k + 1}{\tau_{up}\rho_k p_k + 2^{r_k}}\right)^{K-1}}{\tau_{up} p_k + E_{cir}}$$

and $p_{\max}$ is the maximum pilot power and $r_{\min}$ is the minimum downlink transmission rate.

We can show that $p_k \leq p_{\max,}$ is strictly quasi-concave in r_k. Also, we can show that $\eta_k(r_k, p_k)$ is strictly quasi-concave in p_k if practical values are used for system parameters E_{cir} and ρ_k. Now, we prove the strictly quasi-concavity of η_k in each coordinate.

Since η_k is strictly quasi-concave in each coordinate, we use the cyclic coordinated search method [10], which alternatively updates r_k and p_k by solving the following two subproblems.

Subproblem A: Optimize p_k for a given r_k, i.e.,

$$\max_{r_k} imize\, \eta_k(p_k)$$

Subject to $p_k \leq p_{\max}$

Sub problem B: optimize r_k for a given p_k i.e.,

$$\max_{r_k} imize\, \eta_k(r_k)$$

Subject to $r_k \geq r_{\max,}$

Using the solutions of sub problem A and B, we obtain the following cyclic coordinated search algorithm.

Algorittham 1

Intialize: choose $r_k^{(1)} \geq r_{\min}$ and a tolerance $\varepsilon > 0$.

Iterations: $i \geq 1$.

1) Calculate $p_k^{(i+1)} = p_k^*(r_k^{(i)})$.
2) Calculate $r_k^{(i+1)} = r_k^*(p_k^{(i)})$.
3) Set $X^{(i+1)} = [r_k^{(i+1)}, p_k^{(i+1)}]$
4) If $\left\| X^{(i+1)} - X^{(i)} \right\| \leq \varepsilon$ then stop: else set i=i+1 and repeat next iteration.

The proposed algorithm converges to the same fixed point with in few iterations.

5. Experimental Results

As show the experimental results of proposed system. The figure4 explains about the convergence point of the proposed algorithm. Here x-axis considered downlink transmission rate in bits/sec/Hz. y-axis considered power of the kth user in mw. From the graph, the downlink transmission rate increases to 16 bits/sec/Hz with respect to proper pilot power allocation.

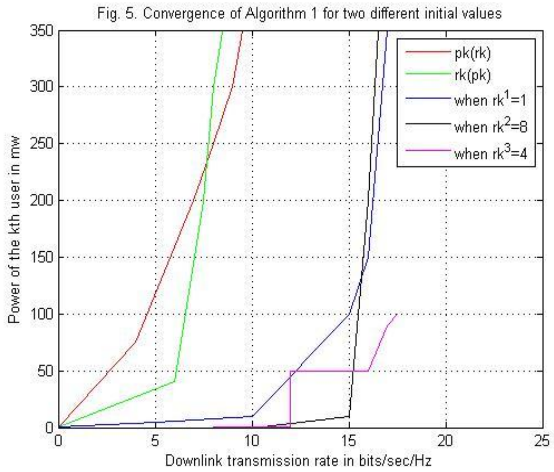

Figure 4: Convergence of algorithm 1 for two different initial values

The figure5 explains about the optimum uplink pilot power and downlink transmission rate. Here x-axis consider the optimum downlink transmission rate in bits/sec/Hz. Y-axis consider the optimum uplink pilot power in mw. Here zero forcing precoding algorithm can be used. Here, by comparing the exhaustive search and proposed algorithm, the proposed algorithm gives better results. Here by allocating proper allocation of power, the downlink transmission rate can be optimum value can reach to 20 bits/sec/Hz.

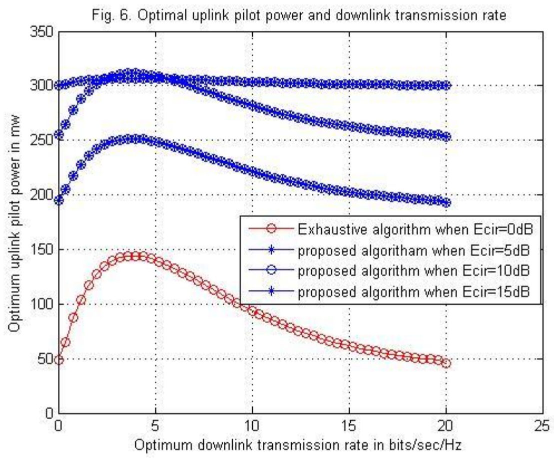

Figure 5: optimal up link plot power and down link transmission rate

The figure6 shows that the spectral efficiency of the kth user i.e. nothing but the existing approach. Here x-axis considered the downlink pilot power of the kth user in dBm. Y-axis considered the average throughput of the kth user in bits/sec/Hz. This graph explains the capacity maximization can be done upto 14 bits/sec/Hz in existing methods. Here the throughput can be calculated in theoretically.

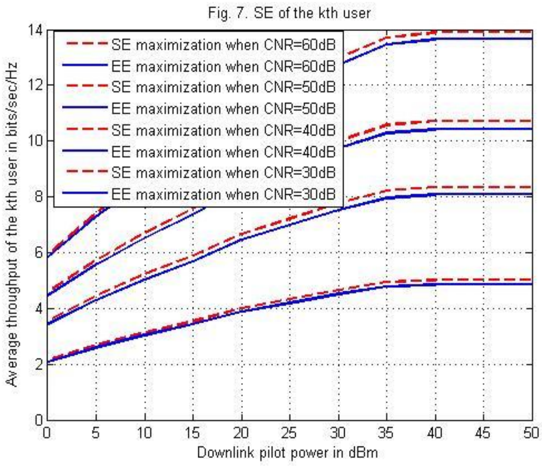

Figure 7: SE of the k-th user

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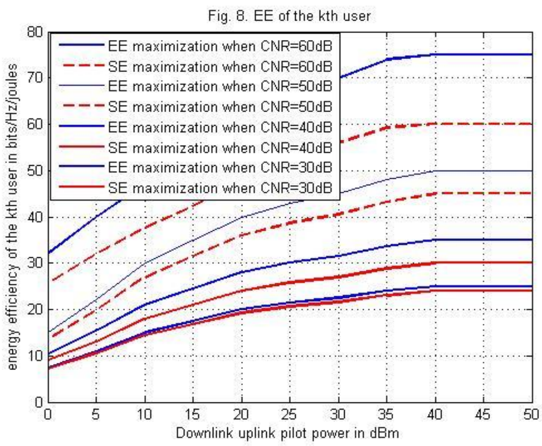


Figure 8: EE of the K-th user

The figure8 shows that energy efficiency of kth user. Here x-axis considered downlink uplink pilot power in dBm y-axis considered energy efficiency of the kth user in bits/Hz/joules By using MIMO-SVD algorithm, the energy efficiency can be increased by improving the capacity maximization. The number of users can be increased; the capacity and bandwidth can be shared. So finally reaches saturation point. Finally the energy efficiency can be improved to 80 bits/Hz/joules

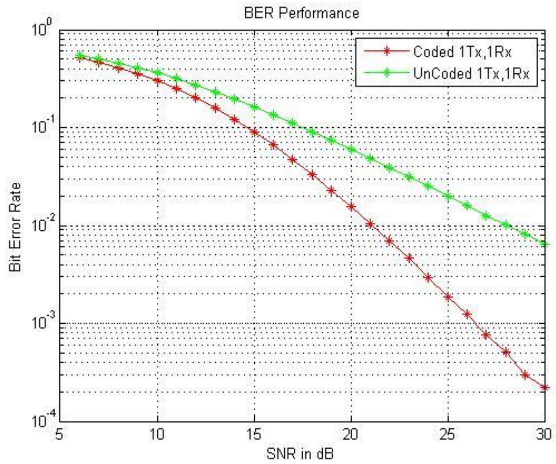
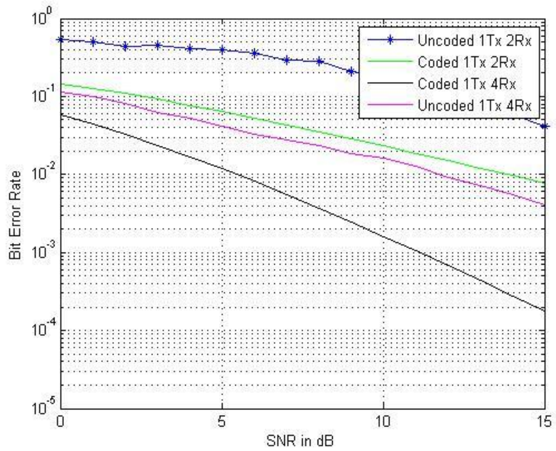
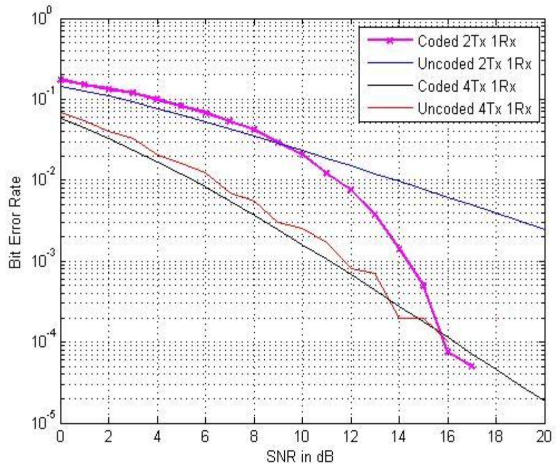


Figure 8: Performance of BER and SNR (DB)



(a)



(b)

Figure 9: (a) and (b) Average Performance Bit error rate and SNR (db).

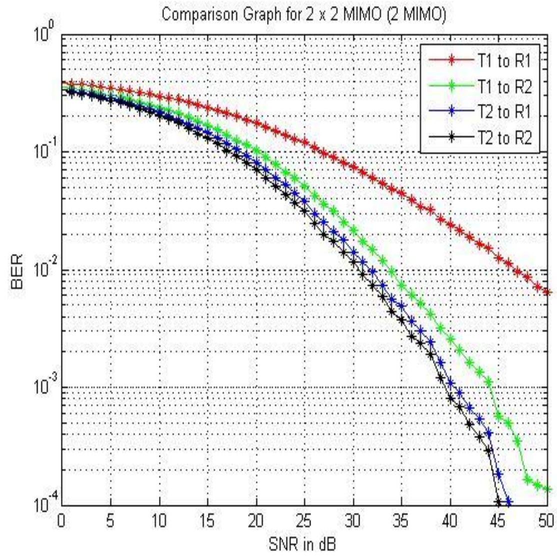


Figure 10: Comparison Graph for 2x2 MIMO

The above figures 8, 9(a)&(b) and 10 explains about the BER performance for different MIMO system cases. In x-axis, the signal to noise ratio in dB. Y-axis considers the bit error rate. Here, the BER performance can be calculated for coded and un-coded systems. The coded systems give better SNR than the un-coded systems. Finally the signal to noise ration can be increased up-to 45 dB

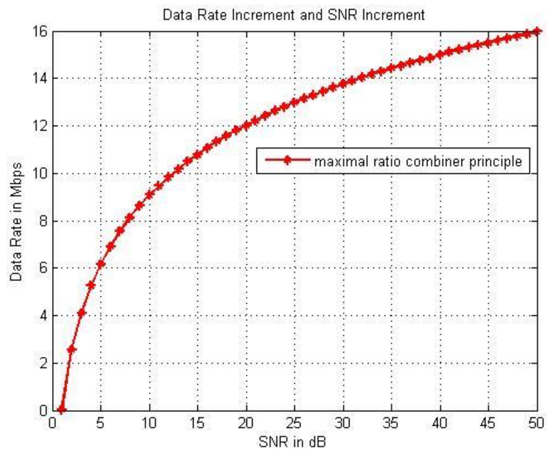


Figure 11: Data rate increment and SNR increment

The figure11 explains about the capacity can be increased in terms of data rate and signal to noise ratio. Here x-axis considers the signal to noise ratio in dB. Y-axis considers the data rate in terms of only mbps. In existing methods the capacity can be increased up to in bits/sec/Hz. The proposed methods can improve up to in mega bits/sec/Hz. By using the maximal ratio combiner principle, the capacity can be increased up to 16 mbps.

6. Conclusion

In this paper, we have derived the closed-form expression of the average throughput and shown that the average throughput of the Kth user is independent of the uplink pilot powers of the other users. Therefore, each user can maximize its EE independently. We have derived the closed-form expression of the average throughput and shown that the average throughput of the *k*th user is independent of the uplink pilot powers of the other users. Therefore, each user can maximize its EE independently. Unfortunately, the EE ηk (rk, pk) function is not quasi-concave in general. But, with practical system parameters, we have shown that the EE function is strictly quasi-concave with respect to each coordinate, rk and pk. Therefore, we have proposed an iterative uplink pilot power and downlink transmission rate adaptation algorithm to maximize the EE of users. We have proved that for any arbitrary starting point, the algorithm converges to a point that satisfies the first-order necessary condition. From simulation analysis, the existing system has energy efficiency capacity in terms of bps. In proposed method, it can improve by using maximal ratio combiner principle can increases the EE capacity in mbps, high SNR and low bit error ate Currently, our work considers the case of $M = K$ in a single-cell environment. In future work to the case of $M > K$ and to a multi-cell environment will be interesting future research topics.

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