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CoMP-transmission-based energy-efficient scheme selection algorithm for LTE-A systems

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Abstract: In order to achieve higher system energy efficiency (EE), a new coordinated multipoint (CoMP)-transmission-based scheme selection energy saving (CTSES) algorithm is proposed for downlink homogeneous cellular networks. The problem is formulated as an optimization of maximizing system EE, under the constraints of the data rate requirement and the maximum transmit power. The problem is decomposed into power allocation and alternative scheme selection problems. Optimal power allocation is calculated for CoMP-JT (joint transmission) and CoMP-CS (coordinated scheduling) transmissions, and the scheme with higher EE is chosen. Since the optimal problem is a nonlinear fractional optimization problem for both CoMP transmission schemes, the problem is transformed into an equivalent problem using the parametric method. The optimal transmit power and optimal EE are obtained by an iteration algorithm in CoMP-JT and CoMP-CS schemes. Simulation results show that the proposed algorithm offers obvious energy-saving potential and outperforms the fixed CoMP transmission scheme. Under the condition of the same maximum transmit power limit, the empirical regularity of user distribution for scheme choice is presented, and using this regularity, the computational complexity can be reduced.

Key words: energy efficiency; green radio; coordinated multipoint; scheme selection; nonlinear fractional programming

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Green radio enjoyed popular support in past years. From an operator's perspective, decreasing energy consumption will reduce operating expenditure (OPEX) costs. From the point of environmental protection, an ever increasing expenditure of energy directly leads to the rise of carbon dioxide emissions. Naturally, there is an imperative need to find more effective ways of reducing energy consumption in future wireless communication systems.

Generally speaking, energy efficient technologies are mainly divided into the following three aspects: energy saving technology in base stations, network deployment strategy and enabling technologies[1]. The coordinated multipoint (CoMP) transmission technique is one of the enabling technologies, which has the potential to promote system EE[2-4]. Based on different data sharing and channel state information (CSI) feedback mechanisms, CoMP transmission is mainly classified into joint transmission (JT) and coordinated scheduling (CS) transmission schemes[5]. Extensive work has been done in the area of CoMP and there is no doubt that the cell-edge user's capacity can be effectively improved under CoMP transmission[5-6]. However, higher capacity is not necessarily related to higher EE because of the additional power consumption for the signal processing and backhauling[7]. EE comparison between CoMP and the conventional non-CoMP system is presented over realistic power consumption models (PCM) in Ref. [8]. The overall energy consumption of a network is composed of transmit power, processing power and backhaul power in realistic PCM. The authors defined EE gain and provided the comparison. The results show that in comparison with conventional non-cooperative systems, EE gain arises from an increase in spectral efficiency.

One of the recently proposed energy saving schemes in CoMP scenario is the cell switch-off scheme. In traditional cell switch-off schemes, the traffic in the switched-off cell is served by surround cells whose transmit powers may increase. Combining cell switch-off with CoMP technology leads to a more energy efficient solution, while the transmit powers of the remaining active cells may not increase[9].

Another type of energy saving schemes in CoMP scenario is the resource allocation strategy[10-12]. In Ref. [11], the authors put forward an iterative energy-efficient power allocation algorithm in an CoMP-JT system. The original non-convex optimization problem is transformed into a subtractive equivalent optimization problem. Dual decomposition is used to achieve the power allocation. As we mentioned, either a CoMP-JT or CoMP-CS transmission scheme can be employed. However, the authors did not consider the CoMP-CS scheme. Another previous re-

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port showed that system EE can be maximized by optimizing the allocation of both transmit time and transmit power under CoMP-JT and CoMP-CS schemes[12]. The authors formulated the problem as minimizing the total transmit power. Yet, the power consumption model only consists of the basic transmit power, while both the circuit power and backhaul power are not taken into account.

It is well accepted that CoMP schemes can promote system EE, while it is not clear which scheme is better in a specific scenario. Compelling evidence in this regard is currently lacking. Therefore, we investigate the energy-efficient CoMP transmission scheme selection algorithm employing a realistic power consumption model. Results show that the proposed algorithm is more energy-efficient than CoMP-JT only and CoMP-CS only modes. We summarize the regularity based on enormous simulation data for a fixed maximum transmit power scenario.

1 System Model

A downlink CoMP system consisting of N cooperative BSs and N users is considered, as shown in Fig. 1. ($\boldsymbol{P}$, $\boldsymbol{\Omega}$) denote the transmit power of users and the selected CoMP scheme by the central server, respectively. All transceivers are equipped with a single antenna. Both the CoMP-JT scheme and the CoMP-CS scheme are considered. Assume that global channel state information is perfectly known by the central server and all calculations and power allocation management are performed in it. In the considered scenario, interference is assumed to be eliminated by the precoding algorithm.

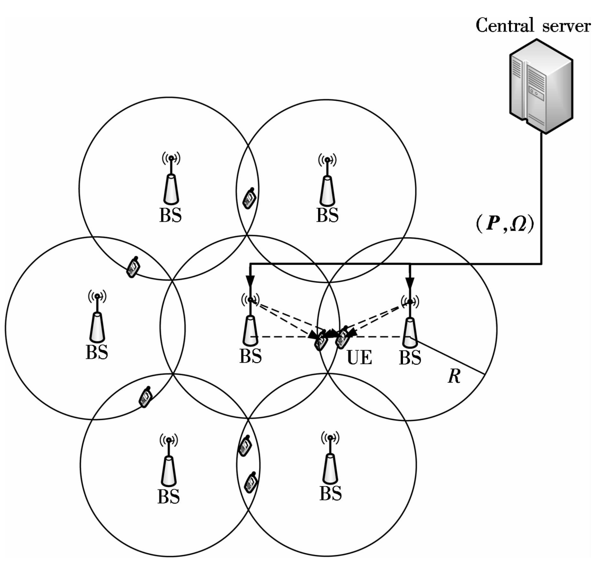


Fig. 1 An example of CoMP system

1.1 CoMP-JT

Let x_u, $u = \{1, 2, \ldots, N\}$, denote the data symbol jointly transmitted by the N cooperative BSs under CoMP-JT transmission. Assuming that x_u is normalized as $E\{|x_u|^2\} = 1$, let $p_{b,u|\mathrm{JT}}$ denote the transmit power for user u from the b-th BS, $b = \{1, 2, \ldots, N\}$. Then, the signal-to-noise ratio (SNR) of user u can be expressed as

$$\gamma_u^{\mathrm{JT}} = \frac{\left\| \sum_{b=1}^{N} \sqrt{p_{b,u|\mathrm{JT}}\psi_{b,u}}\, h_{b,u} \right\|^2}{N_0} = \frac{\sum_{b=1}^{N} p_{b,u|\mathrm{JT}}\psi_{b,u} \| h_{b,u} \|^2}{N_0} \qquad u = 1, 2, \ldots, N \quad (1)$$

where $\psi_{b,u}$ represents the combined path loss and shadow fading[13] between BS b and user u; $h_{b,u}$ represents the small scale fading channel between BS b and user u, which is an independent and identically distributed complex Gaussian random variable with zero mean and unit variance; N_0 is the variance of complex independent zero mean additive white Gaussian noise. The achievable spectral efficiency (SE) of user u in bit/(s · Hz) is determined by

$$S_u^{\mathrm{JT}} = \log_2(1 + \gamma_u^{\mathrm{JT}}) \quad (2)$$

1.2 CoMP-CS

The data symbol of a user is only transmitted by its serving BS under CoMP-CS. Let $p_{b,u|\mathrm{CS}}$ denote the transmit power for user u from the b-th BS. The possible BS-user sets are denoted by $\Psi(i) = \{\varphi_{i,1}, \varphi_{i,2}, \cdots, \varphi_{i,N}\}$, $i = \{1, 2, \cdots, N^N\}$, where i and $\varphi_{i,u}$ represent the set index and the serving BS of user u, respectively. The exhaustive search method is employed to find the appropriate BS-user set $\hat{\Psi} = \{\varphi_{\hat{i},1}, \varphi_{\hat{i},2}, \cdots, \varphi_{\hat{i},N}\}$, which has the best channel state. $\hat{i}$ is given by

$$\hat{i} = \arg\max_i \Big(\sum_{u=1}^{N} l_{\varphi_{i,u},u} \| h_{\varphi_{i,u},u} \|^2 \Big) \quad (3)$$

The SNR of user u can be expressed as

$$\gamma_u^{\mathrm{CS}} = \frac{p_{\varphi_{\hat{i},u},u|\mathrm{CS}}\psi_{\varphi_{\hat{i},u},u} \| h_{\varphi_{\hat{i},u},u} \|^2}{N_0} \qquad u = 1, 2, \cdots, N \quad (4)$$

and the achievable SE is

$$S_u^{\mathrm{CS}} = \log_2(1 + \gamma_u^{\mathrm{CS}}) \quad (5)$$

1.3 Energy consumption model

The total power consumption of a coordinated mobile radio network includes the backhaul power, the transmit power and circuit power. Let $P_{\mathrm{CoMP}}^{\mathrm{JT}}$ and $P_{\mathrm{CoMP}}^{\mathrm{CS}}$ denote the overall power consumption of CoMP-JT and CoMP-CS scheme. They are obtained by[14-15]

$$P_{\mathrm{CoMP}}^{\mathrm{JT}} = \sum_{b=1}^{N} \sum_{u=1}^{N} \frac{1}{\varepsilon} p_{b,u|\mathrm{JT}} + NP_{\mathrm{c}} + N_{\mathrm{BH}}^{\mathrm{JT}} P_{\mathrm{BH}} \quad (6\mathrm{a})$$

$$P_{\mathrm{CoMP}}^{\mathrm{CS}} = \sum_{u=1}^{N} \frac{1}{\varepsilon} p_{\varphi_{\hat{i},u},u|\mathrm{CS}} + NP_{\mathrm{c}} + N_{\mathrm{BH}}^{\mathrm{CS}} P_{\mathrm{BH}} \quad (6\mathrm{b})$$

The first terms in Eqs. (6a) and (6b) represent the power consumption of the power amplifiers, and $0 < \varepsilon \leqslant 1$

is a constant which stands for the efficiency of the power amplifier. The second terms represent the overall signal processing consumption of N BSs, and P_c is the constant signal processing power. The last terms represent the backhaul consumption; N_{BH}^{CS} and N_{BH}^{JT} are the numbers of backhaul links, and each link is assumed to have a fixed power consumption of P_{BH}.

1.4 Definition of energy efficiency

In the literature, several different definitions of energy efficiency have been used[16]. We adopt the most popular one, which is defined as the ratio of the system SE to the power consumption, measured in bit/(J · Hz):

$$Y_{\mathrm{eff}}^{\mathrm{JT}} = \frac{\sum_{u=1}^{N} S_u^{\mathrm{JT}}}{P_{\mathrm{CoMP}}^{\mathrm{JT}}} \tag{7a}$$

$$Y_{\mathrm{eff}}^{\mathrm{CS}} = \frac{\sum_{u=1}^{N} S_u^{\mathrm{CS}}}{P_{\mathrm{CoMP}}^{\mathrm{CS}}} \tag{7b}$$

2 Problem Formulation

Let Ω^* denote the selected CoMP scheme and $P^*(\Omega) = [p_{b,u}^* \mid \Omega^*]$, $b = \{1,2,\cdots,N\}$, $u = \{1,2,\cdots,N\}$, denote the optimal power allocation policy under the scheme policy $\Omega \in \{'\mathrm{JT}', '\mathrm{CS}'\}$. The optimization problem can be formulated as

$$\max_{P(\Omega),\Omega} \{Y_{\mathrm{eff}}^{\mathrm{JT}}, Y_{\mathrm{eff}}^{\mathrm{CS}}\} \tag{8}$$

$$\text{s.t.} \quad p_{b,u} \mid \Omega \in [0, P_{\mathrm{T}}^{\max}] \qquad \forall b, \forall u \tag{9}$$

$$\sum_{u=1}^{N} p_{b,u} \mid \Omega \leqslant P_{\mathrm{T}}^{\max} \qquad \forall b \tag{10}$$

$$\log_2(1+\gamma_u) \geqslant R^{\min} \qquad \forall u \tag{11}$$

where $P_{\mathrm{T}}^{\max}$ denotes the maximum transmit power of BS b. Eq. (10) specifies the power constraint of individual BS. Eq. (11) ensures obtaining the users' quality of service (QoS) requirement.

3 Solution of the Problem

In this section, a CoMP-transmission-based scheme selection energy saving (CTSES) algorithm is proposed to maximize the system energy efficiency, with the flow chart in Fig. 2. For a specific location in the coverage area, we need to determine the optimal power allocation policy and transmission scheme policy. First, the central server evaluates the optimal power allocation and system energy efficiency under CoMP-JT and CoMP-CS schemes. Then, the CoMP scheme with higher energy efficiency is selected by the central server. The system obtains the maximum energy efficiency by applying the chosen CoMP scheme and power allocation.

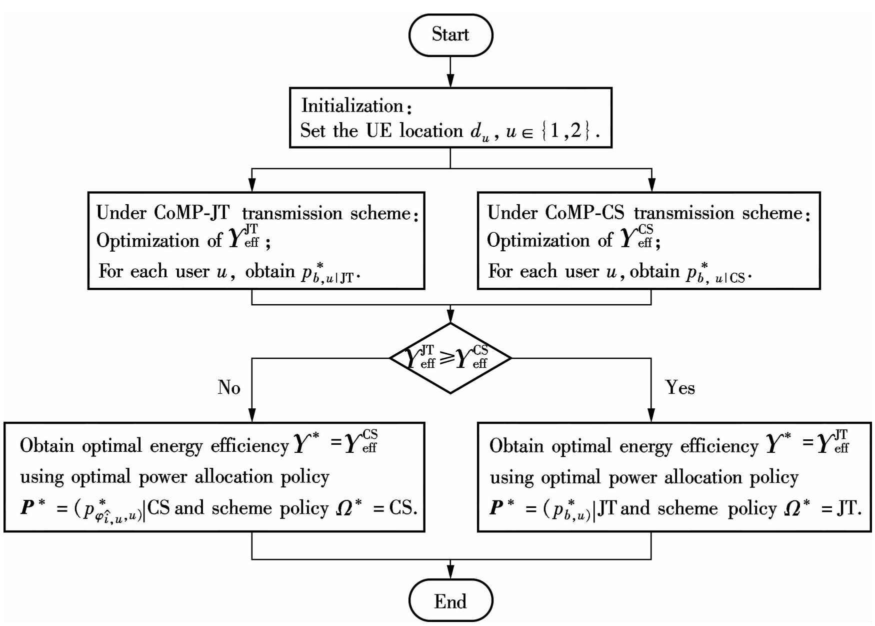


Fig. 2 Flowchart of the CTSES algorithm

3.1 Iterative algorithm for power allocation

The objective function (8) is the ratio of two functions. The optimization problem is commonly known as nonlinear fractional programming. Dinkelbach's parametric approach is employed to solve the problem. First, problem (8) is converted into the following non-fractional optimization problem[17]:

$$\max_{P^*(\Omega)} \sum_{u=1}^{N} \mathrm{SE}_u^{\Omega} - Y P_{\mathrm{CoMP}}^{\Omega} \qquad \Omega \in \{'\mathrm{JT}', '\mathrm{CS}'\}$$

$$\text{s.t.} \quad \text{Eqs. (9) to (11)} \tag{12}$$

where Y is a constant. According to Ref. [17], finding Y^* that renders

$$\max_{P^*(\Omega)} \sum_{u=1}^{N} \mathrm{SE}_u^{\Omega} - Y P_{\mathrm{CoMP}}^{\Omega} = 0 \tag{13}$$

is equivalent to solving problem (8). An iterative algorithm for power allocation is put forward to solve the equivalent problem (12), which is summarized below. $\Upsilon^{(t)}$ means the value of Υ at the t-th iteration. $T_{\max}$ and ϕ represent the maximum number of iterations and the maximum tolerance, respectively. The algorithm guarantees the convergence to the optimal energy efficiency as long as we can solve problem (12) in each iteration[17]. Next, the above-mentioned iterative method is adopted to solve problem (12) under CoMP-JT and CoMP-CS transmission schemes.

Algorithm 1 Iterative algorithm for power allocation

Initialization: Set $\Upsilon^{(1)}=0$, $T_{\max}=10$, $\phi=10^{-4}$.

For $t=1: T_{\max}$

Calculate the power allocation policy $\boldsymbol{P}^{(t)}(\Omega)$ for a given $\Upsilon^{(t)}$ according to Eqs. (13) and (18);

If $\sum_{u=1}^{N}\mathrm{SE}_u^{\Omega}-\Upsilon^{(t)}P_{\mathrm{CoMP}}^{\Omega}<\phi$

$\boldsymbol{P}^{*}=\boldsymbol{P}^{(t)}(\Omega)$ and convergence $=1$; break;

else

$\Upsilon^{(t+1)}=\sum_{u=1}^{N}\mathrm{SE}_u^{\Omega}/P_{\mathrm{CoMP}}^{\Omega}$ and convergence $=0$, $t=t+1$;

End if;

End for;

If convergence $=0$;

$\boldsymbol{P}^{*}(\Omega)=\boldsymbol{P}^{(T_{\max})}(\Omega)$ and $\Upsilon^{*}(\Omega)=\Upsilon^{(T_{\max})}$;

End if;

Stop the algorithm and the solution is $\boldsymbol{P}^{*}(\Omega)$, $\Omega=$ ('JT','CS');

3.2 Power allocation for CoMP-JT transmission scheme

Under CoMP-JT transmission scheme, the Lagrangian function of problem (12) can be written as

$$L(\boldsymbol{P},\boldsymbol{\lambda},\boldsymbol{\mu})=\sum_{u=1}^{N}(1+\lambda_u)\log_2\left(1+\frac{\sum_{b=1}^{N}p_{b,u|\mathrm{JT}}\psi_{b,u}\|h_{b,u}\|^2}{N_0}\right)-\Upsilon\left(\sum_{b=1}^{N}\sum_{u=1}^{N}\frac{1}{\varepsilon}p_{b,u|\mathrm{JT}}+NP_{\mathrm{c}}+N_{\mathrm{BH}}^{\mathrm{JT}}P_{\mathrm{BH}}\right)-\sum_{u=1}^{N}\lambda_u R^{\min}-\sum_{b=1}^{N}\mu_b\left(\sum_{u=1}^{N}p_{b,u|\mathrm{JT}}-P_{\mathrm{T}}^{\max}\right)\tag{14}$$

where $\boldsymbol{\lambda}=\{\lambda_1,\lambda_2,\cdots,\lambda_N\}\geqslant 0$ and $\boldsymbol{\mu}=\{\mu_1,\mu_2,\cdots,\mu_N\}\geqslant 0$ are the introduced Lagrange multipliers. Then, differentiating Eq. (14) with respect to $p_{b,u|\mathrm{JT}}$ leads to

$$\frac{\partial L(\boldsymbol{P},\boldsymbol{\lambda},\boldsymbol{\mu})}{\partial p_{b,u|\mathrm{JT}}}=(1+\lambda_u)\frac{\psi_{b,u}\|h_{b,u}\|^2}{\ln 2(p_{b,u|\mathrm{JT}}\psi_{b,u}\|h_{b,u}\|^2)+N_0}-\frac{\Upsilon}{\varepsilon}-\mu_b\tag{15}$$

Power allocation for user u from BS b can be obtained by applying the Karush-Kuhn-Tucker (KKT)[18] conditions.

$$p_{b,u|\mathrm{JT}}=\left[\frac{1+\lambda_u}{\ln 2\left(\frac{\Upsilon}{\varepsilon}+\mu_b\right)}-\frac{N_0}{\psi_{b,u}\|h_{b,u}\|^2}\right]^{+}\tag{16}$$

where $[x]^{+}=\max\{0,x\}$; λ_u and μ_b are the multipliers, which can be updated using the sub-gradient method[19].

$$\lambda_u^{m+1}=\left[\lambda_u^{m}-\varphi_1^{m}\left(\log_2\left(1+\frac{\sum_{b=1}^{N}p_{b,u|\mathrm{JT}}\psi_{b,u}\|h_{b,u}\|^2}{N_0}\right)-R^{\min}\right)\right]^{+}\tag{17}$$

$$\mu_b^{m+1}=\left[\mu_b^{m}-\varphi_2^{m}\left(P_{\mathrm{T}}^{\max}-\sum_{u=1}^{N}p_{b,u|\mathrm{JT}}\right)\right]^{+}\tag{18}$$

where $m\geqslant 0$ is the iteration index; $\varphi_1^{m}\geqslant 0$ and $\varphi_2^{m}\geqslant 0$ are the step sizes.

3.3 Power allocation for CoMP-CS transmission scheme

As for the CoMP-CS transmission scheme, the Lagrangian function of problem (12) is

$$L(\boldsymbol{P},\boldsymbol{\eta},\boldsymbol{\theta})=\sum_{u=1}^{N}(1+\eta_u)\log_2\left(1+\frac{p_{\varphi_{i,u},u|\mathrm{CS}}\psi_{\varphi_{i,u},u}\|h_{\varphi_{i,u},u}\|^2}{N_0}\right)-\Upsilon\left(\sum_{u=1}^{N}\frac{1}{\varepsilon}p_{\varphi_{i,u},u|\mathrm{CS}}+NP_{\mathrm{c}}+N_{\mathrm{BH}}^{\mathrm{CS}}P_{\mathrm{BH}}\right)-\sum_{u=1}^{N}\eta_u R^{\min}-\sum_{u=1}^{N}\theta_u(p_{\varphi_{i,u},u|\mathrm{CS}}-P_{\mathrm{T}}^{\max})\tag{19}$$

where $\boldsymbol{\eta}=\{\eta_1,\eta_2,\cdots,\eta_N\}\geqslant 0$ and $\boldsymbol{\theta}=\{\theta_1,\theta_2,\cdots,\theta_N\}\geqslant 0$ are the introduced Lagrange multipliers. After differentiating (19) with respect to $p_{\varphi_{i,u},u|\mathrm{CS}}$, we obtain

$$\frac{\partial L(\boldsymbol{P},\boldsymbol{\eta},\boldsymbol{\theta})}{\partial p_{\varphi_{i,u},u|\mathrm{CS}}}=(1+\eta_u)\cdot\frac{\psi_{\varphi_{i,u},u}\|h_{\varphi_{i,u},u}\|^2}{\ln 2(p_{\varphi_{i,u},u|\mathrm{CS}}\psi_{\varphi_{i,u},u}\|h_{\varphi_{i,u},u}\|^2+N_0)}-\frac{\Upsilon}{\varepsilon}-\theta_u\tag{20}$$

Similarly, applying the KKT conditions, power allocation for mobile users under the CoMP-CS transmission scheme can be obtained by

$$p_{\varphi_{i,u},u|\mathrm{CS}}=\left[\frac{1+\eta_u}{\ln 2\left(\frac{\Upsilon}{\varepsilon}+\theta_u\right)}-\frac{N_0}{\psi_{\varphi_{i,u},u}\|h_{\varphi_{i,u},u}\|^2}\right]^{+}\tag{21}$$

The multipliers are given by

$$\eta_u^{m+1}=\left[\eta_u^{m}-\varphi_3^{m}\left(\log_2\left(1+\frac{p_{\varphi_{i,u},u|\mathrm{CS}}\psi_{\varphi_{i,u},u}\|h_{\varphi_{i,u},u}\|^2}{N_0}\right)-R^{\min}\right)\right]^{+}\tag{22}$$

$$\theta_u^{m+1}=\left[\theta_u^{m}-\varphi_4^{m}(P_{\mathrm{T}}^{\max}-p_{\varphi_{i,u},u|\mathrm{CS}})\right]^{+}\tag{23}$$

where $\varphi_3^{m}\geqslant 0$ and $\varphi_4^{m}\geqslant 0$ are the step sizes.

3.4 CoMP scheme selection algorithm

With optimal power allocation policy $\boldsymbol{P}^{*}$(JT) and $\boldsymbol{P}^{*}$(CS) obtained from the above procedures, EE is given by

$$\Upsilon_{\mathrm{eff}}^{\mathrm{JT}*}=\frac{\sum_{u=1}^{N}\log_2\left(1+\sum_{b=1}^{N}\psi_{b,u}\|h_{b,u}\|^2p_{b,u|\mathrm{JT}}^{*}/N_0\right)}{P_{\mathrm{CoMP}}^{\mathrm{JT}}}\tag{24a}$$

$$\Upsilon_{\mathrm{eff}}^{\mathrm{CS}*}=\frac{\sum_{u=1}^{N}\log_2\left(1+\psi_{\varphi_{i,u},u}\|h_{\varphi_{i,u},u}\|^2p_{\varphi_{i,u},u|\mathrm{CS}}^{*}/N_0\right)}{P_{\mathrm{CoMP}}^{\mathrm{CS}}}\tag{24b}$$

The CoMP scheme with higher EE is selected as follows:

$$\Omega^{*}=\begin{cases}\text{JT} & \text{if } Y_{\text{eff}}^{\text{JT}*}\geqslant Y_{\text{eff}}^{\text{CS}*}\\ \text{CS} & \text{others}\end{cases} \tag{25}$$

4 Simulation and Analysis

The performance of the proposed CTSES algorithm is validated through simulations. In order to facilitate illustration and reduce complexity, only two-user two-BS situation is considered. We assume that users are distributed on the straight line between two BSs. Main system parameters are listed in Tab. 1. The 3GPP urban path loss model is adopted[20]. Let $d_{b,u}$ represent the distance between user u and BS b, in km. The minimum rate requirement of each user is 0.5 bit/(s · Hz).

Tab. 1 Simulation parameters

Parameter	Value
Cell radius R/m	500 to 1 000
Maximal transmit power P_T^{max}/dBm	5 to 50
Noise power N_0/(dBm · Hz^{-1})	−134
Path loss from BS b to user u	$131.1+42.8\lg d_{b,u}$
Standard deviation of shadow fading/dB	8
Efficiency of the power amplifier ε	1/6
Signal processing power P_c/dBm	40
Power consumption of each back link P_{BH}/W	15

4.1 EE performance comparison of CTSES, CoMP-JT and CoMP-CS

Fig. 3 shows that the proposed CTSES algorithm outperforms the conventional CoMP-JT transmission and CoMP-CS transmission. Here, we assume that users are located around BSs with the same distance, namely $d_{1,1}=d_{2,2}$. Maximum transmit power $P_T^{max}=40$ dBm, and cell radius $R=500$ m. When $d_{1,1}=500$ m, CTSES outperforms CoMP-CS and CoMP-JT by 7.5% and 2.2%, respectively. From Fig. 3, we can see that system EE decreases gradually as the distance between BS and users increases. In addition, CoMP-CS transmission is more efficient than CoMP-JT transmission when the users are closer to the BS. CoMP-JT achieves higher EE than CoMP-CS when users are located around the edge of the cell.

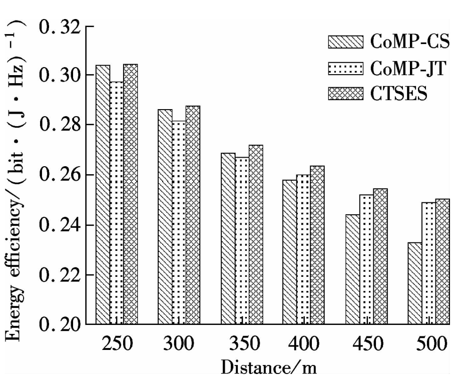


Fig. 3 Normalized EE performance comparison between CTSES algorithm, traditional CoMP-JT and CoMP-CS ($P_T^{max}=40$ dBm, $R=500$ m)

4.2 EE of CTSES vs. maximum transmit power

Figs. 4(a) and (b) show the normalized EE vs. the maximum transmit power P_T^{max}. We can see that the EE increases with P_T^{max} at lower transmit power and saturates at high transmit power. Furthermore, when $P_T^{max}=30$ dBm, cell radius $R=500$ m, EE performance achieves 9.6% improvement as users move from $0.8R$ to $0.6R$. When $P_T^{max}=30$ dBm and users are located at $0.8R$, EE performance achieves 27% improvement as the cell radius changes from 900 m to 500 m. We can infer that EE increases when the cell range reduces or users move to the center. The latter has a larger impact on EE. In Fig. 4(b), when $P_T^{max}=30$ dBm, CoMP-CS achieves 34.5% performance improvement as users' location varies from R to $0.5R$, while CoMP-JT achieves 11.2% improvement. Fig. 4(b) indicates that CoMP-CS transmission scheme is more susceptible to users' location compared with CoMP-JT.

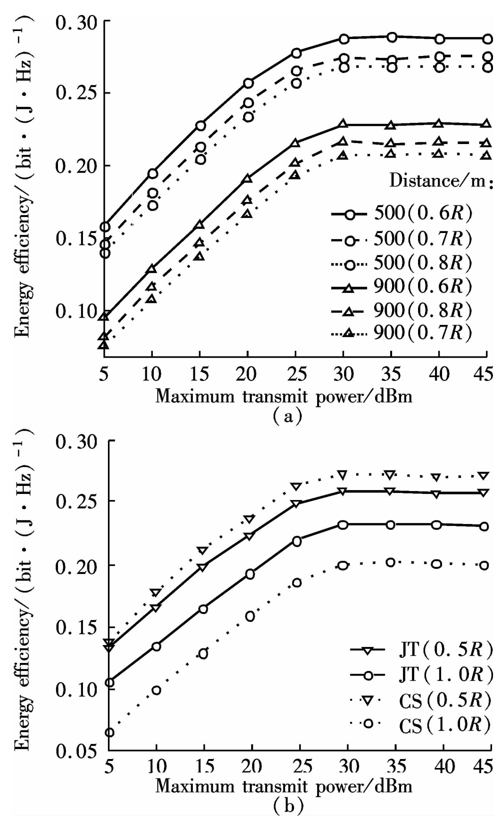


Fig. 4 Normalized EE performance vs. maximum transmit power. (a) $P_T^{max}=30$ dBm; (b) $P_T^{max}=30$ dBm, $R=700$ m

4.3 EE of CTSES vs. users' location

Fig. 5 shows the normalized EE vs. the distance between the BS and users for the proposed algorithm with the fixed maximum transmit power. Assume that maximum transmit power $P_T^{max}=46$ dBm, the cell radius R varies from 500 to 1 000 m, and users are distributed from $0.5R$ to R. We find that when R increases from 500 m to 1 000 m, system EE decreases approximately 36% due to the increasing transmit power and decreasing total capacity.

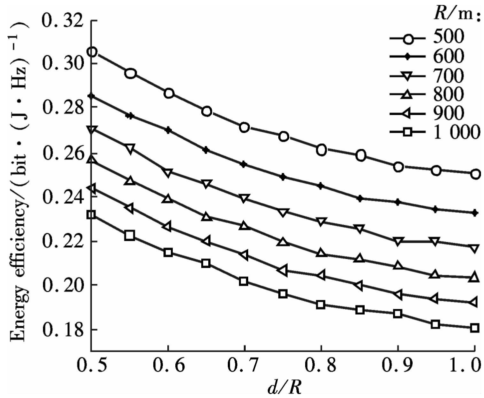


Fig. 5 Normalized EE performance vs. the distance between the BS and users ($P_T^{max}=46$ dBm)

4.4 Scheme selection region

Herein we put forward CoMP transmission scheme suggestions based on user's location. For conveniently describing the advice, we define $0<d_u\leqslant 1$ as the ratio of the distance between user and nearer BS to the cell radius. Extensive simulation experiments have been done and we summarize some regularities. An example is shown in Figs. 6 to 7, showing the selection region of the CoMP system. The horizontal and vertical axes represent the ratios of two users' distance to cell radii, respectively. Maximum transmit power $P_T^{max}=46$ dBm. The CoMP-CS scheme is recommended for the black region where users are relatively far away from the edge. When users are located in the gray area, the CoMP-JT scheme is selected according to the proposed CTSES algorithm.

From Fig. 6, we can give similar suggestions for scheme selection under different cell radii for a fixed maximum transmit power. We can infer that scheme selection mainly depends on the relative locations of the users. The different cell radii affect the absolute value of EE.

Figs. 7(a) and (b) indicate the suggestions when $R=500$ m and $R=1\ 000$ m, respectively. We divide the area into three parts based on the user distribution. The CoMP-CS scheme is selected in area ①, where two users' location satisfies $d_1^2+d_2^2-2d_1-2d_2\leqslant -0.41$. The CoMP-JT scheme is recommended in area ③, $d_1^2+d_2^2-2d_1-2d_2\geqslant -0.384\ 4$. When the users are distributed in area ②, $-0.41<d_1^2+d_2^2-2d_1-2d_2<-0.384\ 4$, we can choose any of the CoMP transmission schemes at random since simulations demonstrate that CoMP-JT and CoMP-CS achieve nearly the same EE in area ②.

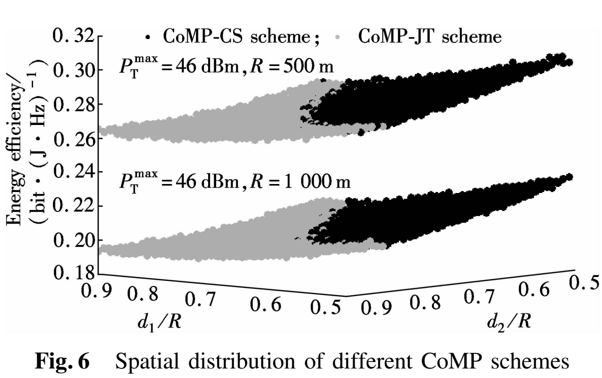
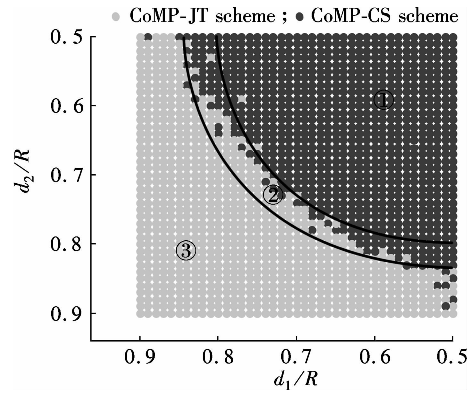
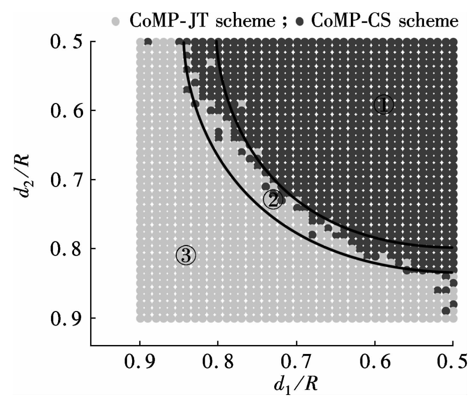


Fig. 6 Spatial distribution of different CoMP schemes



(a)



(b)

Fig. 7 Spatial distribution of different CoMP schemes. (a) $P_T^{max}=46$ dBm, $R=500$ m; (b) $P_T^{max}=46$ dBm, $R=1\ 000$ m

5 Conclusion

In this paper, the CoMP transmission scheme selection energy saving algorithm is proposed. The problem of maximizing EE is formulated as a non-convex problem considering the transmit power consumption, circuit power consumption and backhaul power consumption. It is transformed into an equivalent problem using the parametric method and power allocation is obtained by an iteration algorithm in both CoMP-JT and CoMP-CS schemes. Then, the scheme with maximum EE is selected. Simulation results show that the proposed algorithm achieves higher EE compared with CoMP-JT or CoMP-CS only. We summarize the regularity for a fixed maximum transmit power based on a large number of simulations. It is worthy of further detailed study on the impact of more complicated user distribution.

References

[1] Hasan Z, Boostanimehr H, Bhargava V K. Green cellular networks: a survey, some research issues and challenges [J]. *IEEE Communications Surveys & Tutorials*, 2011, **13**(4):524 − 540.

[2] Ismail M, Zhuang W. Network cooperation for energy saving in green radio communications[J]. *IEEE Wireless Communications*, 2011, **18**(5):76 − 81.

[3] Han F, Safar Z, Liu R. Energy-efficient base-station cooperative operation with guaranteed QoS [J]. *IEEE Transactions on Communications*, 2013, **61**(8): 3505 − 3517.

[4] Niu Z S, Zhou S, Hua Y, et al. Energy-aware network planning for wireless cellular system with inter-cell cooperation[J]. *IEEE Transactions on Wireless Communications*, 2012, **11**(4):1412 − 1423.

[5] Sawahashi M, Kishiyama Y, Morimoto A, et al. Coordinated multipoint transmission/reception techniques for LTE-advanced coordinated and distributed MIMO [J]. *IEEE Wireless Communications*, 2010,**17**(3):26 − 34.

[6] Irmer R, Droste H, Marsch P, et al. Coordinated multipoint: concepts, performance, and field trial results[J]. *IEEE Communications Magazine*, 2011, **49**(2): 102 − 111.

[7] Fehske A J, Marsch P, Fettweis G P. Bit per Joule efficiency of cooperating base stations in cellular networks [C]//*IEEE Globecom Workshops*. Miami, USA, 2010: 1406 − 1411.

[8] Onireti O, Heliot F, Imran M A. On the energy efficiency-spectral efficiency trade-off in the uplink of CoMP system [J]. *IEEE Transactions on Wireless Communications*, 2012, **11**(2):556 − 561.

[9] Gencer C, Yanikomeroglu H, Yu F R. Cell switch off technique combined with coordinated multi-point transmission for energy efficiency in beyond-LTE cellular networks [C]//*IEEE ICC Workshop*. Ottawa, Canada, 2012:5931 − 5935.

[10] Zhao W T, Wang S W. Joint subchannel and power allocation in multiuser OFDM systems with minimal rate constraints[J]. *International Journal of Communication Systems*, 2014, **27**(1):1 − 12.

[11] Ng D W K, Lo E S, Schober R. Energy-efficient resource allocation in multi-cell OFDMA systems with limited backhaul capacity[J]. *IEEE Transactions on Wireless Communications*, 2012, **11**(10): 3618 − 3631.

[12] Xu Z K, Yang C Y, Li G Y, et al. Energy-efficient cooperative transmission in heterogeneous networks[C]// *IEEE Wireless Communications and Networking Conference*. Shanghai, China, 2013:4226 − 4231.

[13] Goldsmith A. *Wireless communications* [M]. Cambridge, UK: Cambridge University Press, 2005: 105 − 107.

[14] Arnold O, Richter F, Fettweis G, et al. Power consumption modeling of different base station types in heterogeneous cellular networks [C]//*Future Network Mobile Proceedings*. Florence, Italy, 2010: 1 − 8.

[15] Monti P, Tombaz S, Wosinska L, et al. Mobile backhaul in heterogeneous network deployments: technology options and power consumption[C]//*Transparent Optical Networks*. Hong Kong, China, 2012:1 − 7.

[16] Chen M T, Kim H, Yang Y. Energy efficiency metrics for green wireless communications [C]//*International Conference on Wireless Communications and Signal Processing*. Nanjing, China, 2010:1 − 6.

[17] Dinkelbach W. On nonlinear fractional programming[J]. *Management Science*, 1967, **13**: 492 − 498.

[18] Boyd S, Vandenberghe L. *Convex optimization* [M]. Cambridge, UK: Cambridge University Press, 2004: 213 − 215.

[19] Palomar D P, Chiang M. A tutorial on decomposition methods for network utility maximization[J]. *IEEE Journal on Selected Areas in Communications*, 2006, **24**(8): 1439 − 1451.

[20] 3GPP. TR 36. 814 V9. 0. 0. 3rd generation partnership project; Technical specification group radio access network; Evolved universal terrestrial radio access (EUTRA); Further advancements for E-UTRA physical layer aspects (Release 9) [S]. Valbonne, France: 3GPP, 2010.

LTE-A 系统中基于 CoMP 传输模式选择的节能算法

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摘要:为了有效提升系统能量效率,提出下行同构网络中基于多点协作传输模式选择的节能算法. 在考虑用户速率需求和系统发射功率限制条件前提下构建以最大化系统能效为目标函数的最优化问题. 将目标问题分解成功率优化和模式选择 2 个子问题:首先计算 CoMP-JT 和 CoMP-CS 传输模式下的功率分配矩阵,然后选择能量效率较高的模式作为当前的传输模式. 功率优化子问题是非线性分数优化问题,运用参数化方法将其转化为等效凸问题,在 CoMP-JT 和 CoMP-CS 下分别通过迭代算法求解最优功率和能效. 仿真结果证实了所提方案具有明显的节能潜力,其系统能效优于固定 CoMP 模式. 此外,还总结了相同最大发射功率限制条件下的模式选择规律,运用该规律可大大减少此类场景下的计算复杂度.

关键词:能量效率;绿色无线电;多点协作;模式选择;非线性分数规划

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