An energy-saving mechanism for mobile terminals based on LTE-A uplink CoMP

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***Abstract*—The current power consumption of intelligent terminals are over burden for their battery capacities, which directly restrict the hours used. In order to realize the energy saving of terminals in the LTE-A system, this paper puts forward the concept of virtual cells and a related uplink energy saving mechanism. Virtual Cell's resources and the outage probability of terminals are proposed by this mechanism as constraint conditions. The first step is sectioning off energy saving area in virtual cell. Secondly, we use the uplink CoMP (Coordinated Multiple Points Transmission/Reception) technology to provide diversity gain for the terminals of energy saving area. The third step depends on uplink power control which could adjust the mobile terminals' transmission power for energy saving. The simulation results show that the energy consumption of total terminals will decrease nearly 50% in the virtual cell while its capacity is lower than the 50% of maximum.**

Index Terms: Diversity gain; CoMP; Energy Saving; LTE-A; Virtual Cell

I. INTRODUCTION

According to the data released by the international telecommunication union (ITU), the global purchase handset number has reached 6 billion units. Comparing with base stations, the transmission power of handheld terminals are much lower, but the research of energy saving for each of the user sides is still a hotspot. In the current mobile communication system, the time-frequency resources cannot be used efficiently for most of the time. How to utilize the limited resources reasonably to meet the needs of terminals, meanwhile, reduce energy consumption of terminals to extend the time of mobile devices' stand-by time has become an increasingly prominent problem.

Former researches mainly focused on the increasing marginal user throughput, and neglected mobile terminals energy saving effect with the Uplink CoMP technology. The current measures of terminal energy saving mainly focus on reducing energy consumption, while ignoring to consider the quality of terminal services. That is the purpose of our research: making the terminal energy saving as a starting point, meanwhile, considering resource block and quality of service of handheld terminal. In the process of energy saving, considering the system resources and interrupt probability as constraint conditions, it will preferentially reduce the transmission power of high-energy terminal in the energy saving area.

This paper is organized as follow: The second chapter mainly introduces the system model, including the channel model, the detail issues such as the allocation of resources. The third chapter describes terminal energy saving mechanism of virtual cell. The fourth chapter shows the system simulation and the analysis of the results. Finally, the summary and outlook are drawn in chapter fifth.

II. SYSTEM MODEL

This part mainly introduces the concepts about virtual cell terminal energy saving mechanism, including uplink CoMP, virtual cell, channel model of virtual cell and related interference.

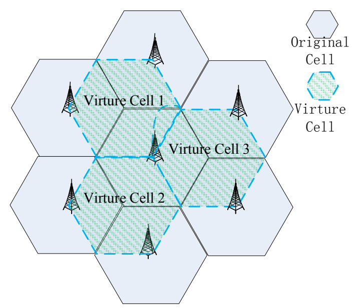

Fig. 1. Virtual cell schematic

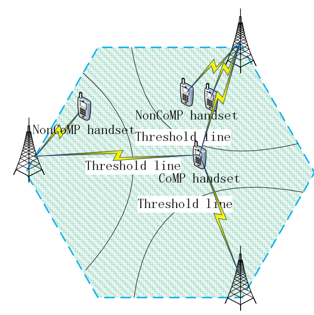

Fig. 2. Virtual cell structure

A. Uplink CoMP

Uplink CoMP refers to the geographical separation of Multiple transfer Points, which cooperate with each other receiving data from terminals. It can make the ideal throughput and the signal gain for the edge terminals of BS (Base Station), therefore, this technology is introduced into LTE - A standard.

B. Virtual Cell

As shown in Fig. 1, a virtual cell is made up of three BSs and three sectors in these BSs. In service mechanism of the virtual cell, the base stations are divided into two types based on the distance between the terminal and base stations(BSs) : the main service BS and subservice stations. Generally, the main service BS has the shortest distance from terminal, while other two are subservice BSs. In energy saving area, the main service BS and the subservice BSs receive jointly. Finally the main service station will take diversity gain combination of all signals; in outside of energy saving area, the signals of terminal are only dealt by the main service BS. The uplink interference in one virtual cell mainly comes from white noise.

C. The outage probability model

Channel fading $h_{i,j}$ satisfies random variables of lognormal distribution, so stochastic variable $\eta_{i,j}=10\lg(h_{i,j})$ satisfies normal distribution. So the outage probability of $h_{i,j}$ satisfies the following formula:

$$f(\mathrm{h}_{i,j})=\frac{\xi}{\sqrt{2\pi}\,\mathrm{h}_{i,j}\times\sigma'_{i,j}}\exp[-\frac{(10\log_{10}\mathrm{h}_{i,j}-\kappa'_{i,j})^2}{2(\sigma'_{i,j})^2}]\ \ (make\,\xi=\frac{10}{\ln(10)}) \quad (1)$$

$k'_{i,j}$ and $\delta'_{i,j}$ stand for expectation and standard deviation of $\eta_{i,j}$. we make $k'_{i,j}$ is path loss about $d_{i,j}$ which stands for the distance between i-th BS and j-th terminal and $\delta'_{i,j}$ =C,

$$\begin{cases} \Re_{i,j} = E(\mathrm{h}_{i,j}) = \exp[\frac{\kappa'_{i,j}}{\xi} + \frac{(\sigma'_{i,j})^2}{2\xi^2}] \\ \vartheta^2 = Var(\mathrm{h}_{i,j}) = (\exp[\frac{2\kappa'_{i,j}}{\xi} + \frac{(\sigma'_{i,j})^2}{\xi^2}]) \times (\exp[\frac{(\sigma'_{i,j})^2}{\xi^2}] - 1) \end{cases} \quad (2)$$

$\Re_{i,j}$ and ϑ is the expectation and var of $\mathrm{h}_{i,j}$ .Because $\sigma'_{i,j}$, ξ is constant, $\kappa'_{i,j}$ is a function about $d_{i,j}$. In all, the expectation of $\mathrm{h}_{i,j}$ is $\Re_{i,j}$ about $d_{i,j}$, too.

Because of channel attenuation, i-th BS detects the SNR for j-th terminals in the virtual cell, which satisfies the type:

$$\Upsilon_{i,j} = \frac{P_j \times \mathrm{h}_{i,j}}{N_0} \quad (3)$$

Because P_j is transmission power of terminal j and N_0 is white noise power, where P_j and N_0 are fixed values, $\gamma_{i,j}$ also meets the lognormal distribution where $\zeta_{i,j}$ and $\Omega^2_{i,j}$ denotes expectation and var. $\zeta_{i,j} = \frac{p_j}{N_0}\Re_{i,j}$ and $\Omega^2_{i,j} = (\frac{p_j}{N_0}\vartheta)^2$

After diversity reception combination, SNR satisfies the formula in [9]:

$$\Upsilon^c_j = \sum_{i=1}^{N} \Upsilon_{i,j} \quad (4)$$

γ^c_j stands for diversity gain of j-th terminal, where N is the number of antenna of virtual cell. As we analyzed, γ^c_j meets the logarithmic normal distribution, so, to the Non-CoMP j-th terminal, the outage probability in the i-th BS is as follows:

$$f(\Upsilon_{i,j}) = \frac{\xi}{\Upsilon_{i,j}\Omega'_{i,j}\sqrt{2\pi}} e^{-\frac{1}{2}((10\log_{10}\Upsilon_{i,j} - \zeta'_{i,j})/\Omega'_{i,j})^2} \quad (5)$$

In (6), $\zeta'_{i,j}$, $\Omega'_{i,j}$ stands for the means and var of $10\lg\gamma_{i,j}$, which are expressed in dB. $\zeta'_{i,j} = 10\log_{10}(\frac{P_j}{N_0}) + \kappa'_{i,j}$ and $\Omega'^2_{i,j} = (\sigma'_{i,j})^2$

Make $\psi_{i,j}=(10\lg\gamma_{i,j}-\zeta'_{i,j})/\Omega'_{i,j}$, i=1,2…N, according to (5), the j-th CoMP teminal's probability density is as follow

$$f_{(\Upsilon_{1,j},\Upsilon_{2,j}\ldots\ldots\Upsilon_{N,j})} = \frac{\xi^n \exp[-\Psi \times (\mathrm{C}_{1\ldots N})^{-1} \times \Psi^T/2]}{\sqrt{(2\pi)^N \det\{\mathrm{C}_{1\ldots N}\}}} \quad (6)$$

In (6), $\psi=[\psi_{1,j}, \psi_{2,j}\ldots\ldots\psi_{N,j}]^T$, C1….N is the correlation matrix for $\psi_{1,j}$, $\psi_{2,j}$ ….. $\psi_{N,j}$ consisting of correlation coefficient $\rho_{i,j}$ at row i, column j and ones at the diagonal.

$$P_{out\_j} = P(\Upsilon_c < \Upsilon_{threshold}) = \iiint\limits_{\Upsilon_{1,j}+\Upsilon_{2,j}\ldots+\Upsilon_{N,j}<\Upsilon_{threshold}} f_{(\Upsilon_{1,j},\Upsilon_{2,j}\ldots\ldots\Upsilon_{N,j})} d\Upsilon_{N,j}..d\Upsilon_{i,j}..d\Upsilon_{1,j} \quad (7)$$

P_{out_j} stands for j-th CoMP terminal outage probability, meanwhile, $\gamma_{threshold}$ represents the threshold of SNR.

III. THE ENERGY SAVING MECHANISM FOR TERMINALS OF VIRTUAL CELL (ESMTVC)

This chapter mainly introduces the energy saving mechanism of virtual cell from the following several aspects: 1) the mathematical model of energy saving about terminal, 2) terminal power control, 3) energy saving mechanism.

A. The mathematical model of energy saving

The terminal energy saving mechanism based on virtual cell uses the diversity gain of CoMP to make up the influence that introduced by bringing down terminals' transmission power. Furthermore, the QoS and RB (resource block) are taken into consideration.

The energy saving problem can be converted into minimum value problem inside the virtual cell. The mathematical model are described as follows.

$$\begin{aligned} &\arg\min_P(\sum_{l=1}^{\phi 1} P_l^{NonCoMP} + \sum_{k=1}^{\phi 2} P_k^{CoMP}) \\ &s.t \begin{cases} \sum_{l=1}^{\phi 1} RB_l^{NonCoMP} + \sum_{k=1}^{\phi 2} RB_k^{CoMP} < RB_{ALL} & \phi 1 + \phi 2 = \phi_{all} \\ P_{\mathrm{out\_}j}^{After} \le P_{\mathrm{out\_}j}^{Before} & w \in \phi_2 \end{cases} \end{aligned} \quad (8)$$

$P_l^{NonCoMP}$, P_k^{CoMP} stands for transmission power of i-th NonCoMP terminal and k-th CoMP terminal. □*1*, □*2* represent for the number of NonCoMP terminal and CoMP terminal. $RB_l^{NonCoMP}$, RB_k^{CoMP}, RB_{ALL} mean the RB number of *l*-th NonCoMP terminal, *k*-th CoMP terminal and the whole virtual cell. $P_{\mathrm{out\_}j}^{Before}$ is the outage probability before processing. In contrast, $P_{\mathrm{out\_}j}^{After}$ shows the outage probability when the terminal has been dealt in ESMTVC .

AS we known, the terminals in the edge of cell can obtain the more diversity gain than the terminal near BS. So we can make full use of this character of virtual cell to choose reasonable □*1*, □*2* . Because the distance between the base station antennas is more than half wavelength, therefore $\gamma_{i,j}$ are mutually independent. So we define a threshold μ_j .

$$\mu_j = 10\log(\frac{\mathrm{E}(\Upsilon^c_j)}{\mathrm{E}(\Upsilon_{m,j})}) = 10\log(\frac{\sum_{i=1}^{N}\Re_{i,j}(\mathrm{d}_{i,j})}{\Re_{m,j}(\mathrm{d}_{m,j})}) \quad (9)$$

Because $\sigma'_{i,j}$ is constant, $\Re_{i,j}(\mathrm{d}_{i,j})$ is a monotone continuous function about $d_{i,j}$. if we choose the terminal diversity gain which is greater than $\mu_{threshold}$. Hence, we can get the energy saving area. The set of □*1*, □*2* can be distinguished, if we do above.

The distance between the base station antenna is more than half wavelength, so the correlation coefficient $\rho_{i,j}$ (i!=j) is 0. That means $C_{1\ldots N}$ is Unit matrix. Then, we can calculate the optimal $\mu_{threshold}$. In all, (8) can be described by following:

$$\begin{cases} j \in \phi 1 & when \;\; \mu_j < \mu_{threshold} \\ j \in \phi 2 & when \;\; \mu_j > \mu_{threshold} \end{cases} \quad (10)$$

Based on (8), all terminal probability can meet following formulas:

$$P_{out} = \begin{cases} P_{out\_j}^{NonCoMP} = \int_0^{\Upsilon_{threshold}} \frac{\xi}{\Upsilon_{i,j}\Omega'_{m,j}\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{(10\log_{10}\Upsilon - \zeta''_{m,j})}{\Omega'_{m,j}})^2} d\Upsilon & j \in \phi_1 \\ P_{out\_j}^{CoMP} = \int_0^{\Upsilon'_1}\int_0^{\Upsilon'_2}\int_0^{\Upsilon'_3} \prod_{i=1}^{3}(\frac{\xi}{\Upsilon_{i,j}\Omega'_{i,j}\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{(10\log_{10}\Upsilon_{i,j} - \zeta''_{i,j})}{\Omega'_{i,j}})^2}) d\Upsilon_{1,j} d\Upsilon_{2,j} d\Upsilon_{3,j} & j \in \phi_2 \end{cases} \quad (11)$$

where $(\Upsilon'_1, \Upsilon'_2, \Upsilon'_3) = (\Upsilon_{threthold}, \Upsilon_{threthold} - \Upsilon_{2,j}, \Upsilon_{threthold} - \Upsilon_{2,j} - \Upsilon_{3,j})$

B. Power control of terminal

It is mainly separated into two parts. One shows original transmitting power, another is how to lower transmitting power in the energy saving area. The transmitting power of terminal is mainly affected by resource, channel attenuation, receiver threshold [8]. So the terminal transmitting power before adopting energy-saving processing satisfy the type:

$$\mathrm{P}'_j = 10\log_{10} M + \theta + P_{fix} + \varepsilon \times \kappa'_{\mathrm{m},j} \tag{12}$$

In (12), P'_j is original transmitting power; M is the number of RBs (Resource Block) assigned to terminal j; ε is the path loss compensation coefficient for cell, depending on the part of the range of the power control. That is complete compensation when $\varepsilon = 1$; θ means the threshold of receiver; P_{fix} is correction factor for the power which can make sure the all terminal outage probability can be reasonable and keep the same pace.

CoMP terminals obtain SNR enhancement brought by diversity gain, therefore guaranteeing (11) conditions, reducing part of these terminal transmission power to meet energy saving demands.

$$SNR_j^{Before} = SNR_j^{After} + \Delta\tau_j \qquad j \in \phi 2 \tag{13}$$

SNR_j^{After} stands for terminal j's SNR after CoMP; SNR_j^{Before} means terminal j's SNR before CoMP, $\Delta\tau$ is the difference value(D-value) between 'before CoMP' and 'after CoMP'. SNR_j^{After}, SNR_j^{Before} and $\Delta\tau$ are expressed in dB.

In energy saving area, combining (12) and (13)，the CoMP terminal transmission power meet the type:

$$P'_{real} = \mathrm{P}'_j - P'_{\max}(\Delta\tau_j) \tag{14}$$

$\mathrm{P}'_{\mathrm{real}}$ is The final transmission power of CoMP terminal ,which should guarantees the outage probability of (11). $\mathrm{P}'_{\max}(\Delta\tau)$ is the biggest saving power, which can be calculated by Multiple iterations.

TABLE I. POWER CONTROL

Algorithm:
Begin;
$\mathrm{P}'_{\max}(\Delta\tau) = \Delta\tau + \mathrm{N}'_0$; % initial value
While（$\mathrm{P}_{\mathrm{out\_j}}^{\mathrm{After}} < \mathrm{P}_{\mathrm{out\_j}}^{\mathrm{Before}}$）
$\mathrm{P}'_{\max}(\Delta\tau) = \mathrm{P}'_{\max}(\Delta\tau) + 0.1\mathrm{dB}$;
end
$\mathrm{P}'_{\mathrm{real}} = \mathrm{P}'_{\mathrm{j}} - \mathrm{P}'_{\max}(\triangle\tau)$;

IV. THE SIMULATION AND ANALYSIS

In order to analyze the energy saving effect of ESMTVC, supposing that terminals satisfy uniform distribution in the virtual cell. In order to simplify the process of simulation system in LTE-A, the number of uplink RB was designated as the number of 60,80,100,120. At the same time, because the RB distribution is not the key point of this article, therefore, each common terminal will only be assigned 1 RB, and CoMP terminal will takes 3RB in the virtual cell.

A. Simulation Setting

The relevant parameters in the Table II：

TABLE II. RELATIVE PARAMETERS

Parameters (Unit)	**Value**	**Parameters (Unit)**	**Value**
The threshold of reciever $\boldsymbol{\theta}$	-110dBm	The power of white noise $\boldsymbol{N'_0}$	-114dBm
The threshold of SNR $\gamma_{\mathbf{threshold}}$	$10^{-0.4}$	Carrier frequency $\boldsymbol{fc}$	2600M Hz
Hight of BS $\boldsymbol{h_{te}}$	35m	Hight of terminal $\boldsymbol{h_{re}}$	1.6m
Ratio of BS $\boldsymbol{r}$	0.5km	compensation factor for terminal $\boldsymbol{\beta(h_{re})}$	0
The city compensation factor ***CM***	3dB	$\sigma'_{i,j}$	1dB
Step Length $\boldsymbol{\Delta\mu}$	0.1dB	$\boldsymbol{P_{fix}}$	$3\sigma'_{i,j}$

The path loss is assessed by Hata231 model of big cities.

At the same time in order to evaluate virtual cell energy-saving mechanism for terminals' energy saving effect, terminal efficiency η, is defined inside the virtual cell:

$$\eta = \frac{P_{Before} - P_{After}}{P_{Before}} \tag{15}$$

where P_{before} , $\mathrm{P}_{\mathrm{After}}$ stands for energy used by all terminals before and after taking ESMTVC .

B. Simulation Results

All the simulation will be show in this part, which have been divided into 3 parts, as follow:

1) Value of $\mu_{threshold}$

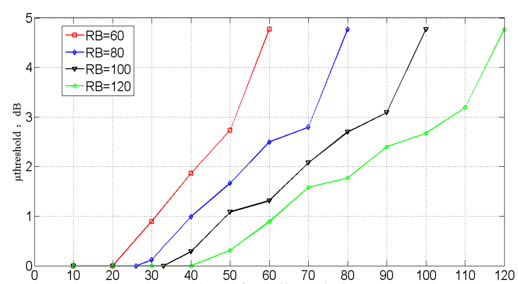

Fig3. The influence of terminal number and RB number on $\mu_{\mathrm{threshold}}$.

As shown in Fig. 3, when all terminals are CoMP terminal and the consumption of RBs is still less than all RBS, $\mu_{\mathrm{threshold}}$ is 0. In that situation, the energy saving effect is only related to the location of terminals. When the $\mu_{\mathrm{threshold}}$ is greater than 0, the number of CoMP terminals become less and less, so the influence of resource constraints are becoming ever more obvious. As this figure shows, the max num of CoMP terminals is that the max num of RBs divides 3. On the contrary, when the number of terminals reaches the maximum capacity of the whole cell, $\mu_{\mathrm{threshold}}$ approach 10lg3 dB at this time, and all terminals are not to participate in the CoMP.

2) Effects of Terminal Energy Saving

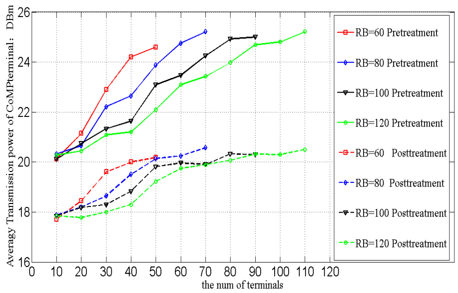

Fig. 4. The average transmission power of terminal in energy saving area.

Fig. 4 shows the average transmission of CoMP terminal on different RBs. The difference of energy saving becomes bigger with the increase of UE num, but in fact, the CoMP UEs decrease due to limit of resouce. The performance of CoMP is well in the center of Virtual cell so that difference become larger.

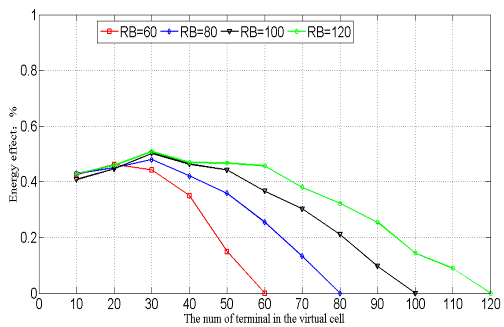

Fig. 5. Energy-saving efficiency of virtual cell.

In Fig. 5, for a fixed RB number with different terminal density, energy-saving efficiency of the virtual cell increases firstly and then decreases. Before the CoMP terminals reach maxnum at fixed RB, the efficiency of the energy-saving rises. This is because that when all terminals participate in the CoMP and RB number is still enough in the virtual cell, $u_{threshold}$ still stays 0 so that the new terminals also can participate in the CoMP and η can goes up. However, when the number of the terminals exceeds the maxnum of the CoMP users, $u_{threshold}$ increases while CoMP terminals decrease, and RB is becoming the bottleneck of energy-saving, therefore the energy-saving efficiency reduces gradually until η=0.

3) Outage probability

Because NonCoMP terminal is processed by the main service BS in the virtual cell, we just analysis the terminals' outage probability of the CoMP terminals. And in actual simulation, we use the Monte - Carlo Integration Techniques [10] to discuss outage probability system.

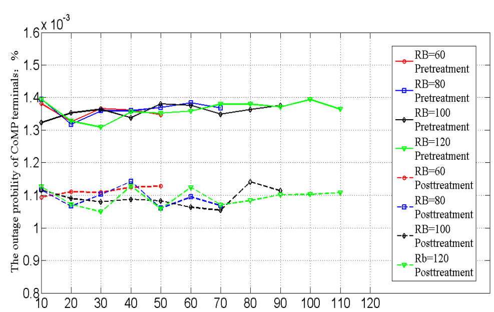

Fig. 6. The outage probability of terminals in energy saving area

In Fig. 6 , because the CoMP terminal transmission power is adjusted to meet (14), you can see the interrupt probability of CoMP terminal appear slightly lower after the energy saving. When CoMP terminal reaches the maximum capacity of virtual cell, there will not be terminal to participate in the CoMP, namely the terminal number is equal to the max number of resources. That is why the average outage of terminals probability and average transmission power are not shown in Fig. 6. Such as RB = 100, terminal = 100.

V. CONCLUSION

From the perspective of energy efficiency, based on the theoretical derivation and the simulation model, when terminal density is low, the effect of energy-saving mechanism of virtual cell is ideal in the lower terminal density, and the maximum of energy saving may reach 50%; however, when terminal density is high, the effect of energy-saving declines fast due to the limitation of resources. Referring to the outage probability, CoMP terminals reduces about 17% through the energy-saving mechanism of virtual cell, resulting in a better QoS as well. In the further studies, blocking rate can be introduced to the simulation model, thus we can get a more accurate verification of the effect in our energy-saving mechanism of the virtual cell.

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