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Research on Relay-Assisted Cellular System Coordination Mechanism Based on Energy-Efficient

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Abstract

Multi-user and multi-business lead to dense deployment relay stations in the relay-assisted cellular system. When active relay stations exceed actual needs, decreasing the network energy efficiency has direct correlation with web users, business, distribution and other parameters. In the case that satisfying requirements of service quality, such as delay and rate are satisfied, this paper mainly research on how to dynamically adjust the activation time and the number of relay stations according to the location of relay stations in the networks. In the meantime, we research on improving the efficiency of system energy and resource matching through the data forwarding of relay stations which have been activated.

Keywords: *energy efficiency, relay-assisted, relay station sleep, relay stations collaboration, mode conversion*

1. Introduction

In recent years, multi-protocol, multi-carrier, multi-user, and multi-business are characteristics of the rapid growth of cellular networks, and with the growing diversity of business needs, improving the energy efficiency of the cellular networks has become a critical issue. For cellular networks, Base Stations ($\mathrm{BS_s}$) altogether contribute between 60% to 70% energy consumption of the overall networks [1], it is an important issue to improve the energy efficiency of $\mathrm{BS_s}$. However, the spatial and temporal distribution of traffic exhibit a growing dynamic characteristics in the green cellular networks, therefore, improving the energy efficiency of the networks based on flexible coverage will become a hot issue in the research. For multi-user and multi-traffic, some studies have been made in improving the energy efficiency of cellular networks. The reference [2] expounded the meaning of energy saving and expounded the meaning of energy saving by combining low-carbon economy and development demand of power industry. Niu Zhisheng who is a professor at Tsinghua University [3] proposed the concept of cell zooming for energy-efficient green cellular networks, and presented some key technologies to realize cell zooming, such as physical adjustment (including the regulation of transmission power, height and angle of antenna), $\mathrm{BS_s}$ sleep, $\mathrm{BS_s}$ collaboration and Relay Stations ($\mathrm{RS_s}$) etc. The $\mathrm{BS_s}$ collaboration technology and $\mathrm{RS_s}$ technology lead to lower transmit power to meet business needs. In fact, for the point-to-point communications to meet business needs, using minimal power transmission is the most energy-efficient delivery. For example, the reference [4] explored an energy efficient routing protocol with a mobile sink based on the shortest path data transmission mode and calculated the coordinate value of each node in the wireless sensor network according to the position of the sink node and the common nodes' ID in the network. Therefore, in the premise of priority of energy efficiency as the principle, Niu Zhisheng, and Zhou Sheng who is a postdoctoral scholar in Electronic Engineering Department at Tsinghua University [5] proposed to improve the energy efficiency of networks through the cell cooperation mechanism. Prior to this, in order to reduce inter-cell interference in the multiple antenna cellular system, Lei Jun, Shi Mingjun [6] proposed the scheduling algorithm for multiple cooperative opportunity based on interference-limited two-cell model. For the interference problem in the downlink of the multi-cell distributed antenna system, Shi Dan, and Zhu Jinkang who is a professor at China University of Science and Technology [7] proposed combination of

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$\mathrm{BS_s}$ collaborative communication and distributed antenna technology to ensure the fairness of the user spectrum efficiency by optimizing the user spectral efficiency. Meanwhile C. Raman [8, Cao Dongxu [9], and Wang Xiaolei [10] proposed to improve energy efficiency of $\mathrm{BS_s}$ by using $\mathrm{RS_s}$ with low power. In fact, the traditional $\mathrm{RS_s}$ nodes selection is devoted to improve the performance of cell edge users, usually with the maximum power transmission, which overlooked the constraints and optimization of energy efficiency. However, in terms of energy consumption, Cui Shuguang and A. J. Goldsmith who are professors at Stanford University [11] pointed out that we should consider circuit power consumption of $\mathrm{RS_s}$.Because the network traffic has significant fluctuations in time domain and space domain, H. Kim and G. de Veciana [12] also pointed out that network energy resource can't be fully utilized. The system will consume a large amount of circuit power if $\mathrm{RS_s}$ always maintain the active state in the low business period. In order to minimize the overall energy consumption of the networks, we can adopt the $\mathrm{RS_s}$ dormancy mechanism [13]. However, the current $\mathrm{RS_s}$ dormancy mechanism only consider that $\mathrm{RS_s}$ can independently switch to sleep mode, without considering the dormancy coordination between $\mathrm{RS_s}$.

In this paper, we adopt the collaboration between the adjacent $\mathrm{RS_s}$ to improve the dormancy control of $\mathrm{RS_s}$ according to the characteristics of relay-assisted cellular system, such as multi-user, multi-traffic, etc., so that $\mathrm{RS_s}$ with lower transmit power can meet the requirements of service quality such as delay and rate, in the case, system energy efficiency is fully embodied in energy saving. Because the traffic load capacity and the number of carriers of each RS are limited, so whether the RS entered the sleep state is not only concerned with its own load and carriers, but also has a direct correlation with the load and the carriers of the adjacent $\mathrm{RS_s}$. While previous studies also mentioned that frequent mode conversion also affect the energy consumption of the networks, so the mode conversion must also be a important fact which should be considered.

2. Research Method

System model in this article is a downlink relay-assisted cellular system with multi-user, multi-traffic, multi-carrier and multi-protocol, as shown in Figure 1, N $\mathrm{RS_s}$ with the same technology (for example, frequency reuse) are deployed in the adjacent cell boundary, these $\mathrm{RS_s}$ form a set, represented by $\mathrm{R} = \{1, 2, \ldots, \mathrm{N}\}$.

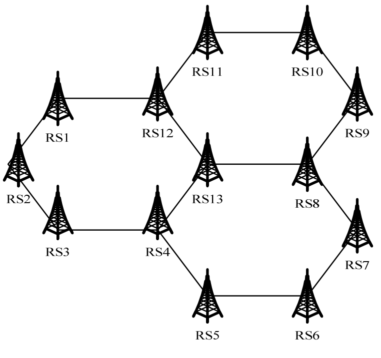

Figure 1. Deployment of the $\mathrm{RS_s}$ in the Relay-assisted Cellular System

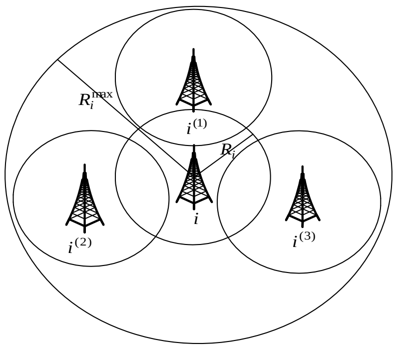

Figure 2. Coverage Schematic Diagram of the $\mathrm{RS_i}$

The maximum coverage of each $\mathrm{RS_i}$ is the region of its ability to meet the user delay, and data rate requirements, and compared with the other $\mathrm{RS_s}$, the region with the shortest user delay and highest data rate is called a zone i. As shown in Figure 2, the coverage radius of $\mathrm{RS_i}$ is $\mathrm{R_i}$, the maximum coverage radius of $\mathrm{RS_i}$ is $\mathrm{R_i^{max}}$, which means that the coverage of each $\mathrm{RS_i}$ can be extended to the adjacent regions. Assuming that the mutual interference between cells has been improved through some multiplexing and interference processing technique, when a number of $\mathrm{RS_s}$ has gone into sleep mode, the adjacent active $\mathrm{RS_s}$ can provide the corresponding delay and rate to users within the sleep region to meet the needs of users. Assuming the adjacent $\mathrm{RS_s}$ of $\mathrm{RS_i}$ are expressed as $\mathrm{RS_i^n} = \{\mathrm{i}^{(1)}, \mathrm{i}^{(2)}, \dots, \mathrm{i}^{(m)}\}$, m indicates the number of adjacent $\mathrm{RS_s}$, then $\mathrm{RS_s}$ in the set $\mathrm{RS_i^{n'}} = \{\mathrm{i}, \mathrm{i}^{(1)}, \mathrm{i}^{(2)}, \dots, \mathrm{i}^{(m)}\}$ can meet the requirements of users in the zone i , such as delay and rate etc.

At moment t, users with strength $\lambda_\mathrm{i}(\mathrm{t})$ for a Poisson process arrive zone i.Assuming users in the same area are uniformly distributed, users in different areas are non-uniformly distributed, according to the knowledge of probability theory to estimate the average arrival rate, i.e.

$$\bar{\lambda}(t) = \frac{1}{N}\sum_{i=1}^{N} \lambda_i(t) \tag{1}$$

Assuming that bandwidth resources of each active $\mathrm{RS_i}$ are limited, i.e., the total bandwidth is $\mathrm{B_i}$, rate requirements γ_j of the user j is a constant. When the user j is associated with$\mathrm{RS_i}$, and the spectral efficiency is $\mathrm{w_{ij}}$, then bandwidth is required by the user j:

$$b_{ij} = \frac{r_j}{w_{ij}} \tag{2}$$

Because traffic load in both time domain and space domain have significant fluctuations, for the new arrival users, each active $\mathrm{RS_i}$ will retain a part of the bandwidth to meet the requirements of service quality, the proportion of bandwidth reserved in $\mathrm{RS_i}$ as β_i, where $\beta_\mathrm{i} \epsilon [0,1]$. The user will be blocked if $\mathrm{RS_i}$ can't assign enough bandwidth for a newly arrived user k.

The user arrives rate $\lambda_\mathrm{i}(\mathrm{t})$ is a cycle for T periodic function, as shown in Figure 3, the cycle T is divided into ε time slots, each time slot is expressed as $\Delta\mathrm{t}^\alpha$,$\alpha = 1,2,..,\varepsilon$. The number of users Reached during a time slot $\Delta\mathrm{t}^\alpha$ is:

$$M_{\Delta t} = \int_{t^\alpha}^{t^\alpha + \Delta t^\alpha} \sum_{i=1}^{N} \lambda_i(t)\, dt \tag{3}$$

3. Results and Analysis

3.1. Problem Formulation

Assuming each $\mathrm{RS_i}$ works in two modes: the energy consumption $\mathrm{P_a}$ for active mode and energy consumption $\mathrm{P_s}$ for sleep mode.

In each time slot $\Delta\mathrm{t}^\alpha$,$\alpha = 1,2,\dots,\varepsilon$, the pattern of $\mathrm{RS_i}$ is fixed, the mode flag bit is represented by $\vartheta_\mathrm{i}^\alpha$,i.e.

$$\vartheta_i^\alpha = \begin{cases} 1, & RS_i \quad is \quad activated \\ 0, & otherwise \end{cases} \tag{4}$$

At each instant t^α,$\alpha = 0,1,2,\dots,\varepsilon$,$\mathrm{RS_i}$ decide whether to convert the model according to control flag bit, the control flag bit is represented by $\upsilon_\mathrm{i}^\alpha$,i.e.

$$\upsilon_i^\alpha = \begin{cases} 1, RS_i \quad switch \quad the \quad work \quad \mathrm{mod}\ e \\ 0, \quad otherwise \end{cases} \tag{5}$$

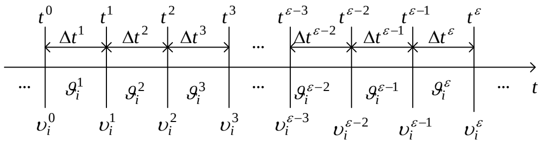

Figure 3. The Mode/Control Flag Bit of Change Over Time

If the current mode flag bit of $\mathrm{RS_i}$ is ϑ_i^α, and the current control flag bit of $\mathrm{RS_i}$ is υ_i^α, then the mode flag bit of the next time slot is:

$$\vartheta_i^{\alpha+1} = \sqrt{(\vartheta_i^\alpha - \upsilon_i^\alpha)^2} \tag{6}$$

As mentioned above, if the system is unable to provide enough bandwidth for the newly arriving user k, the user will be prevented and the system will be jammed, so the system blocking probability is:

$$p_b = \sum_{i=1}^{N} p_r\left(\bigcap_{\substack{i\in R,\vartheta_i=1\\ b_{ik}<\infty}} (b_{ik} > \beta_i B_i) \middle| k \in S_i \right) p_r\big(k \in S_i\big), \beta_i \in [0,1] \tag{7}$$

Where S_i represents the area of the zone i,

$$p_S = p_r\left(\bigcap_{\substack{i\in R,\vartheta_i=1\\ b_{ik}<\infty}} (b_{ik} > \beta_i B_i) \middle| k \in S_i \right), \beta_i \in [0,1] \tag{8}$$

The formula (8) represents the blocking probability of the newly arrived user k in the area S_i. For current cellular networks with multi-user, multi-traffic, multi-carrier and multi-protocol, it is clear that all of $\mathrm{RS_s}$ collaboration can get the best sleep scheme, however, considering the parameters of system are more and the degree of the complexity of the program is higher in the actual system, so we can adopt the adjacent $\mathrm{RS_s}$ collaboration sleep scheme.

P_S can be approximated as follows:

$$p_S \approx \tilde{p}_S = p_r\left(\bigcap_{\substack{h\in RS_i^{n}{}',\vartheta_h=1\\ b_{hk}<\infty}} (b_{hk} > \beta_h B_h) \middle| k \in S_i \right), \beta_h \in [0,1] \tag{9}$$

If the user k in the zone i is in position (x_1, x_2) for blocking probability $\nu(x_1, x_2)$, then the blocking probability in the zone i is:

$$\tilde{p}_S = \iint_{S_i} \nu(x_1, x_2)\, dx_1\, dx_2 \tag{10}$$

As pointed out that the arrival process of the users is assumed to be a Poisson distribution, therefore, the M/G/1 queue model can be used to calculate the stay time of a user in system. The user will be blocked if the stay time of a user in the system is longer than the basic delay requirements, so $\nu(x_1, x_2)$ is:

$$\nu(x_1, x_2) = \prod_{\substack{h\in R_i^{n}{}',\\ \vartheta_h=1}} p_h(x_1, x_2) \tag{11}$$

Where:

$$p_h(x_1, x_2) = p_r\left(\frac{1}{\mu_h(SNR\ (x_1, x_2))} + \frac{\rho_h^2 + \lambda_h^2\delta_h^2}{2(1-\rho_h)} \le \mathrm{T}_{th}\right) \tag{12}$$

In the formula (12), $\mu_h(\mathrm{SNR}(x_1, x_2))$ represents service rate of the zone h when the received signal-to-noise is SNR, λ_h represents arrival rate of a user in the zone h, δ_h represents a change of the normalized service rate, ρ_h represents the effective strength of the service, i.e.

$$\rho_h = \frac{\lambda_h}{\mu_h(SNR(x_1, x_2))} \tag{13}$$

Where:

$$SNR(x_1, x_2) = \frac{P_t G_{hk}(x_1, x_2)}{N_0 B_h} \tag{14}$$

P_t represents the transmit power,G_{hk} represents the channel gain when the user k relevant with RS_h, N_0 represents the power spectral density of the Gaussian white noise.

The blocking compensation in zone i is:

$$E_{bc}^{\alpha} = \sum_{h \in R_i^{n'}} E_{bh} \times \tilde{p}_S, \alpha = 1, 2, \ldots, \varepsilon \tag{15}$$

E_{bh} represents the blocking compensation when blocking is occurred.

The operation energy consumption of RS_s under the two work modes is:

$$E_{oc}^{\alpha} = \int_{t^{\alpha}}^{t^{\alpha}+\Delta t^{\alpha}} \sum_{h \in R_i^{n'}} [\vartheta_h^{\alpha} P_a + (1 - \vartheta_h^{\alpha}) P_s] dt, \alpha = 1, 2, \ldots, \varepsilon \tag{16}$$

The energy consumption of RS_s mode conversion is:

$$E_{sc}^{\alpha} = \sum_{h \in R_i^{n'}} E_{sh} \upsilon_h^{\alpha}, \alpha = 1, 2, \ldots, \varepsilon \tag{17}$$

E_{sh} represents the energy consumption of RS_h which switch between the active state and the hibernation.

In summary, the energy consumption of the system at each stage is:

$$E_c^{\alpha} = E_{oc}^{\alpha} + E_{sc}^{\alpha} + E_{bc}^{\alpha}, \alpha = 1, 2, \ldots, \varepsilon \tag{18}$$

Then the total energy consumption of the system at all stages is:

$$E_{con} = \sum_{\alpha=1}^{\varepsilon} E_c^{\alpha} = \sum_{\alpha=1}^{\varepsilon} (E_{oc}^{\alpha} + E_{sc}^{\alpha} + E_{bc}^{\alpha}) \tag{19}$$

In general, we are more concerned about minimizing energy consumption and minimizing the blocking probability. The energy savings will also be more if there are more RS_s worked in the sleep mode, however, this will result in a larger blocking probability.

Assuming the given initial state of the system is ϑ^0, so the minimum of total energy consumption is:

$$\begin{aligned} &\min_{(\upsilon^1, \ldots, \upsilon^{\varepsilon})} E_{con} \\ &s.t. \quad p_b \le p_{th} \\ &\qquad\ \ \tilde{p}_S \le p_{th} \end{aligned} \tag{20}$$

3.2. Simulation Analysis

We only consider the path loss between the RS and the user, i.e., $PL_{dB}(d) = \theta \log_{10} d$ (θ is attenuation coefficient, d is the distance between the RS and the user), and setting $R_i = 100m$, $R_i^{max} = 200m$, the power that RS works in the active state is $P_a = 10w$, the power of sleep state is negligible, the static energy consumption of each RS is a random variable from $200w$ to $250w$.

The available bandwidth is $\mathrm{B_j = 5MHZ}$, the power density of the Gaussian white noise is $\mathrm{N_0 = -174dBm/Hz}$. The average stay time of the user in system is $\mathrm{T_{th} = 1min}$, the user rate requirement is $\gamma_\mathrm{i} = \mathrm{122kbps}$, the threshold of blocking probability is $p_\mathrm{th} = 10^{-1}$. Setting the parameters of the RS , i.e., $\beta_\mathrm{j} = \beta$, then to calculate the average power consumption by adjusting the value of β.When β is increasing, the RS will reserve more bandwidth for the newly arrived users, this requires that more $\mathrm{RS_s}$ work in the active state, and system will get a smaller blocking probability.

Figure 4 shows the correspondence relationship between the user density and the average number of deployed $\mathrm{RS_s}$.From the figure 4,in case that it could satisfy the requirement of customer service quality, because the collaboration between the $\mathrm{RS_s}$ can extend the coverage of each RS,we can see that the number of deployed $\mathrm{RS_s}$ in collaborative approaches is less than non-collaboration approaches.

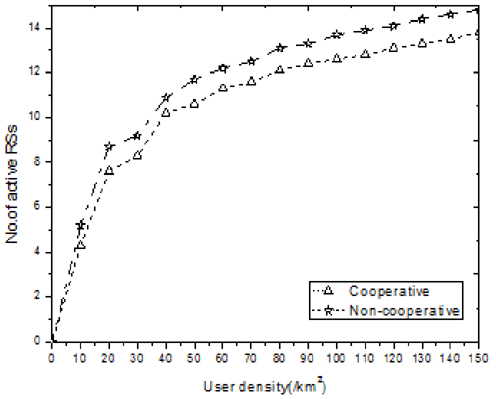

Figure 4. The Average Number of deployed $\mathrm{RS_s}$ Versus User Density

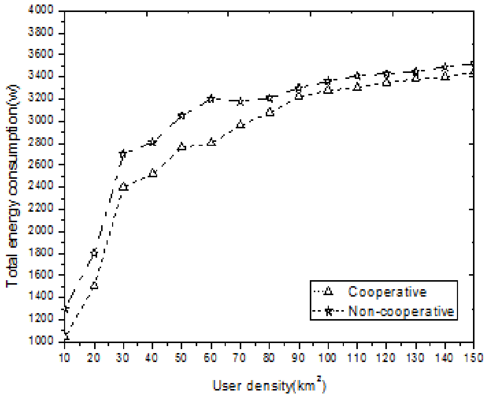

Figure 5. Energy Consumption Performance Versus User Density

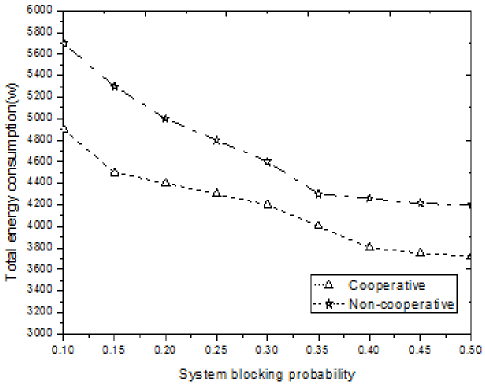

Figure 6. Energy Consumption Performance Versus System Blocking Probability

From Figure 4 and Figure 5, we can know that reducing the energy consumption of the network has direct relationship with parameters, such as users, traffic and distribution. As collaborative approach reduced the number of deployed $\mathrm{RS_s}$,so the energy efficiency of the system in the collaborative mode is higher than the non-collaborative manner, and with the increase of parameters such as user density and traffic, what's more, the number of active $\mathrm{RS_s}$ also shows ascendant trend. The static energy consumption and the dynamic energy consumption of the system are increasing state when the number of active $\mathrm{RS_s}$ is increasing.

In Figure 6, it is analyzed that the energy consumption of the system versus the blocking probability. From Figure 6, we can see that collaborative approach has more advantages than non-collaborative approach. The lower blocking probability will reduce the blocking compensation, while the static energy consumption of $\mathrm{RS_s}$ in the active state is the main event for the system. The system will consume more energy if it get a smaller blocking probability and activate more $\mathrm{RS_s}$, so with the increasing of the blocking probability, the whole curve shows a downward trend.

4. Conclusion

This paper points out that $\mathrm{RS_s}$ should go into sleep mode to save energy when we consider the circuit power consumption of active $\mathrm{RS_s}$ in the relay-assisted cellular system. Meanwhile, we only take into account $\mathrm{RS_s}$ independently switching to sleep mode before breaking it, we can realize the controlling of a sleep mode by $\mathrm{RS_s}$ collaboration with the adjacent ones at the same time. The frequent mode transformation will not only interrupt the user service, but will also affect the service life of equipments. Therefore, this article also considers the energy consumption of transform model. Through analyze the performance of the algorithm and simulation, the results show that the energy efficiency in the collaboration mode system is higher than in collaborative mode of energy efficiency.

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