Lowering Area Power Consumption via Coded Cooperation Assisted by Layered Relays

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***Abstract*—Energy efficiency in cellular networks has recently received a significant attention and incorporating cooperative relays in cellular networks is believed to be a promising technology to greatly lower the energy consumption of cellular networks while sustaining high data rates. In this paper, we focus on improving energy efficiency of a single cellular system assisted by relays. We propose a novel relay deployment strategy and a corresponding relay selection procedure. Using coded cooperation as the transmission scheme, we derive the area power consumption under a target area spectral efficiency. Besides, the impact of different parameters such as cell radius, target area spectral efficiency, number and position of relays on the area power consumption is also studied. Compared with direct transmission and decode-and-forward (DF) relaying, our work significantly improves the energy efficiency of cellular systems and sheds key insights into the tradeoff between the energy consumption and the spectral efficiency via dynamically adjusting the resource allocation between BS and relay in coded cooperation.**

I. INTRODUCTION

For lessening the environmental impact of the information and communication industry, efforts to increase the energy efficiency of communication networks have recently gained momentum [1]. Besides environmental factors, lowering the energy consumption of cellular mobile radio networks in particular, also appears beneficial from an economical (lower energy costs) and practical (increased battery life in mobile devices) perspective. In this regard, employing heterogeneous deployment, for instance using micro-, pico- and femto- BS or relays alongside conventional macro sites has been believed to greatly lower the energy consumption of cellular mobile radio networks [2][3].

Heterogeneous deployment is a promising approach to make cellular networks more energy efficient and sustain high speed data-traffic at the same time [4–6]. However, literatures are scarce when it comes to the deployment issues on relays in cellular networks. In [7], relays are deployed in a circle around BS. Although the deployment is simple, the distribution of relays is non-uniform and energy inefficient when the cell radius is large. In this paper, we assume relays are scattered throughout the cell and serve much smaller area with low power. This deployment strategy is flexible, practical and more energy efficient for cellular systems.

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In order to incorporate cooperative relaying technology in cellular networks, an important issue is how to forward, i.e., the cooperative transmission scheme. In [7], the authors investigate area power consumption of a cellular system assisted by relays using decoded-and-forward (DF) as the transmission scheme. However, in the large area spectral efficiency case, the performance gain of DF decreases a lot due to the equal resource allocation between BS and relay. Our work employs coded cooperation [8] as the transmission scheme which can make up the deficiency of DF via dynamically adjusting the resource allocation between BS and relay, and thus achieves a better energy efficiency.

The main contributions of this paper are as follows:

- We propose a deployment strategy for relays in a single cellular system where relays are scattered throughout the cell and divided into layers with different radii circularly around BS based on the distance between BS and relays. For simplicity of analysis, we take two layered relays for instance.
- We propose a relay selection procedure for the cellular system with layered relays. Due to the limited area covered by relays, users with different locations can only access to the nearest one of the relays in its corresponding layer.
- Based on our system model and relay selection procedure, we derive the area power consumption of coded cooperation under a target area spectral efficiency. Besides, simulations show that using coded cooperation in relay-assisted cellular systems achieves a better energy efficiency compared with DF and direct transmission.
- The impact of different parameters such as cell radius, target area spectral efficiency, number and position of relays on the power consumption is also studied in detail.

II. SYSTEM MODEL AND METRICS

Consider a down-link noise limited cellular system with a macro base station (BS), K relays and several users. All nodes in the cell are assumed to be equipped with a single antenna. To make the deployment of relays more uniform and realistic, we propose a novel relay deployment strategy where relays are scattered throughout the cell and divided into layers with different radii circularly around BS based on the distance between BS and relays. Specifically, we take two layered relays for instance, shown in Figure 1. Users

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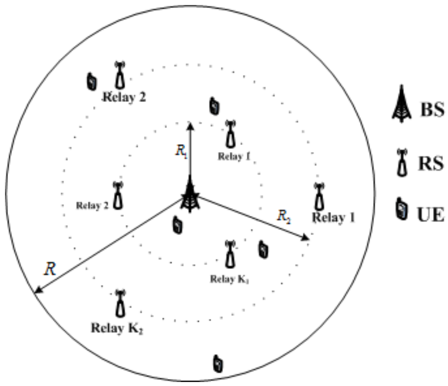


Fig. 1. Single Cell with Base Station and Layered Relays.

are located randomly in the cell area following a uniform distribution.

Using the polar coordinates, the location of BS is represented by $(0,0)$ and the cell radius is R. Relays in the first layer are located at $(R_1, \frac{2\pi(i+1/2)}{K_1}), i = 1,2,...,K_1$, while relays in the second layer are located at $(R_2, \frac{2\pi i}{K_2}), i = 1,2,...,K_2$, and $K_1 + K_2 = K$. The position of any active user, is expressed as (r,θ), where r is the distance between BS and the user, and θ is the corresponding angle. We assume that each user only seeks help from the best relay because of relay selection procedure (details in III-B).

A. Propagation Model

Suppose h_1, h_2 and h_3 are the channel between BS and the user, BS and the relay, the best relay and the user, respectively. For simplicity, we only consider the pass-loss, while omitting shadowing and multipath fading. Consequently, the channel model $|h_i|^2$ can be written as follows

$$|h_i|^2 = L_i = a_i d_i^{-\alpha}, i = 1,2,3 \tag{1}$$

where a_i denotes the parameter to further adapt the model, and α denotes the path loss exponent. L_i represents the distance dependent path loss term in general, and its expression has been borrowed from the proposed Long Term Evolution (LTE) heterogeneous network deployment structure [9] as follows

$$\begin{aligned} BS\ to\ UE &: 128 + 37.6\log_{10}(d_1)\ dB \\ BS\ to\ Relay &: 124.5 + 37.6\log_{10}(d_2)\ dB \\ Relay\ to\ UE &: 140.7 + 36.7\log_{10}(d_3)\ dB \end{aligned} \tag{2}$$

where $d_i, i = 1,2,3$ denotes the distance in kilometers.

B. Power Models and Energy Consumption

We use the area power consumption [5], under a given area spectral efficiency [10], as the performance metric. In our system model, the total cell area is $S = \pi R^2$ and the area power consumption can be obtained as follows

$$\eta = \frac{\overline{P}}{S} \tag{3}$$

where $\overline{P}$ is the average power consumed by BS and relays. It can be denoted as

$$\overline{P} = \int_0^{2\pi}\int_0^R P(r,\theta)\frac{r}{\pi R^2}drd\theta \tag{4}$$

For calculating the instantaneous power consumption $P(r,\theta)$ for a particular user, a simple power consumption model including operation mode and idle mode [7] is introduced as follows

$$\begin{aligned} &P_{O,i} = b_i\widehat{P}_i + c_i, \\ &P_{I,i} = q_i, \quad for\ i = B, R \end{aligned} \tag{5}$$

where $P_{O,i}$ and $P_{I,i}$ denote the operation mode and idle mode powers, while B, R represent BS and relay, the term $\widehat{P}_i$ represents the instantaneous transmit power required for a particular user under the target spectral efficiency. The coefficient b_i accounts for power consumption that scales with the average radiated power due to amplifier and feeder losses. The term c_i models an offset of site power which is consumed independently of the average transmit power due to signal processing, battery backup, as well as site cooling [5].

Depending on the specific transmission scheme used, we can calculate $P(r,\theta)$ with the help of the power consumption for BS and relays.

III. Transmission Scheme

In this section, we will calculate the area power assumption for a given target area spectral efficiency $\mathcal{C}_T$ when using coded cooperation in the relay-assisted system. As a baseline, we also consider direct transmission. Assuming the noise power at relay and user are both N, and the target spectral efficiency for each user in the cell is $C_T = \mathcal{C}_T\pi R^2$.

A. Direct Transmission

For direct transmission, relays are not used in the cell, then BS has to transmit during the whole transmission period and the instantaneous power consumption will be $P_{O,B}$. According to the Shannon capacity theorem, we have

$$C_T = \log_2(1 + \frac{\widehat{P}_B}{N}|h_1|^2) \tag{6}$$

the corresponding instantaneous transmit power for BS is

$$\widehat{P}_B = \frac{N}{|h_1|^2}(2^{C_T} - 1) \tag{7}$$

Hence using (5) the instantaneous power consumption for a single user can be obtained as follows

$$P(r,\theta) = P_{O,B} = b_B\widehat{P}_B + c_B \tag{8}$$

by substituting (8) in (4), we can get the average power consumption for the cell below

$$\overline{P} = \int_0^{2\pi}\int_0^R (b_B\widehat{P}_B + c_B)\frac{r}{\pi R^2}drd\theta \tag{9}$$

then the area power consumption η_{Direct} can be obtained by substituting (9) in (3).

B. Coded Cooperation Transmission

Coded cooperation works by sending different portions of the source's codewords via two independent fading paths. Equivalently, the two transmissions can be viewed as time sharing between two independent channels, where the first channel ($BS \rightarrow UE$) is used a fraction β of the time and the second channel ($RS \rightarrow UE$) is used a fraction $1-\beta$ of the time. Since β can be adjusted by varying the coding rate, it is possible to dynamically modulate the resource allocation between BS and relay which makes utilization of power more rational and efficient. According to [8], the instantaneous spectral efficiency C_T provided to a user is

$$C_T = \beta \log_2(1+\frac{\widehat{P}_B}{N}|h_1|^2)+(1-\beta)\log_2(1+\frac{\widehat{P}_R}{N}|h_3|^2) \quad (10)$$

Based on the proposed relay deployment strategy, a corresponding relay selection procedure is put forward that depends on the position of the user. The specific description of the relay selection procedure is incorporated in the subsequent analysis which is divided into three cases and presented below.

***Case 1**: $R_2 < r \leq R$*

Considering the energy efficiency, we assume that the coverage of each relay is limited and that the user in this case is out of the coverage of relays in the first layer. Therefore, the best relay for the user should be the nearest one of the relays in the second layer with radius R_2. According to [8], the transmit power of BS and the best relay can be obtained through some simple calculations as follows

$$\widehat{P}_B^{(1)} = \frac{N}{|h_2^{(1)}|^2}(2^{C_T/\beta}-1) \quad (11)$$

$$\widehat{P}_R^{(1)} = \frac{N}{|h_3^{(1)}|^2}\left(\frac{2^{C_T/(1-\beta)}}{(1+\frac{\widehat{P}_B^{(1)}}{N}|h_1^{(1)}|^2)^{\beta/(1-\beta)}}-1\right) \quad (12)$$

Here, the superscript is used to represent the case that the current calculation belongs to. Then the instantaneous power consumption for the user can be obtained

$$\begin{aligned} P^{(1)} &= \beta P_{O,B}^{(1)} + (1-\beta)P_{I,B}^{(1)} + \beta K P_{I,R}^{(1)} \\ &\quad +(1-\beta)(P_{O,R}^{(1)} + (K-1)P_{I,R}^{(1)}) \end{aligned} \quad (13)$$

Using (5) in (13) we get

$$\begin{aligned} P^{(1)} &= \beta(b_B\widehat{P}_B^{(1)} + c_B) + (1-\beta)(b_R\widehat{P}_R^{(1)} \\ &\quad +c_R + q_B) + (K+\beta-1)q_R) \end{aligned} \quad (14)$$

***Case 2**: $R_1 < r \leq R_2$*

Since only path-loss is considered in the propagation model and the quality of channel is merely related to the distance, the best relay for the user in this case is the nearest one selected from the first layer with radius R_1. The calculation of the instantaneous power consumption $P^{(2)}$ is similar to Case 1, just revise the superscript to (2). Thus, omit the remaining analysis here.

***Case 3**: $0 < r \leq R_1$*

In this case, no relay is selected for the user and the transmission mode will regress to direct transmission. Referring to the analysis in III-A, we can get the instantaneous power consumption $P^{(3)}$ as follows

$$P^{(3)} = b_B\widehat{P}_B^{(3)} + c_B + KP_{I,R}^{(3)} \quad (15)$$

where

$$\widehat{P}_B^{(3)} = \frac{N}{|h_1^{(3)}|^2}(2^{C_T}-1) \quad (16)$$

At last, the average power consumption can be obtained as follows

$$\begin{aligned} \overline{P} &= \int_0^{2\pi}\int_0^R P(r,\theta)\frac{r}{\pi R^2}drd\theta \\ &= \int_0^{2\pi}\int_0^{R_1} P^{(3)}\frac{r}{\pi R^2}drd\theta + \int_0^{2\pi}\int_{R_1}^{R_2} P^{(2)}\frac{r}{\pi R^2}drd\theta \\ &\quad + \int_0^{2\pi}\int_{R_2}^{R} P^{(1)}\frac{r}{\pi R^2}drd\theta \end{aligned} \quad (17)$$

thus the area power consumption of the coded cooperation relay-assisted system referred as η_{CC} can be obtained by substituting (17) in (3).

IV. Numerical Results

In this section, we study how the area power consumption is affected by two main factors, namely the deployment of relays and the cooperative schemes employed in a cellular system. We employ Monte Carlo simulations for the scenario described in II to estimate the area power consumption with different deployment strategies and transmission schemes. In our simulations, each iteration has only a single user served in the cell. We use the propagation model presented in II-A, and for comparison, the power model parameters are set as $b_B = 21.45, c_B = 354.44W, q_B = 35.444W, b_R = 7.15, c_R = 17.722W$ and $q_R = 1.772W$ according to [7]. The noise power is set as $-90dBm$.

A. Transmission Schemes

In this subsection, we concentrate on the impact of different transmission schemes on the area power consumption so that the scenario can be simplified to a single layered relaying system used in [7]. Specifically, we consider the direct transmission as a baseline and compare the area power consumption of our coded cooperation with decode and forward (DF) relaying using the same relay selection procedure in [7]. Besides, we also study the impact on the area power consumption of different factors such as position of relays, number of relays and target area spectral efficiency.

1) Area Power Consumption vs. Relay Position: Figure 2 shows how the position of relays affects the area power consumption when $R = 0.8km, K = 8, \beta = 0.5$ and $\mathcal{C}_T = 1bps/(Hz \cdot km^2)$. We denote the relationship between cell radius and relay position as $\kappa = R_R/R, (0 \leq \kappa \leq 1)$. From the figure, we can see that the area power consumption of direct transmission is not affected by κ, as relays are not used. For DF, there is a certain range about [0.32 0.82] with

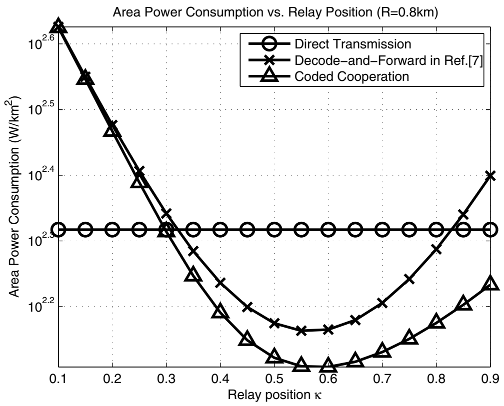


Fig. 2. Area power consumption versus position of relays.

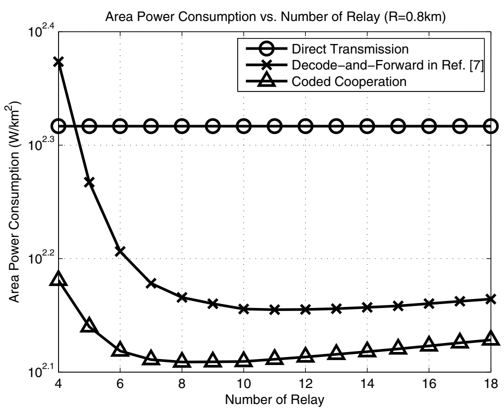
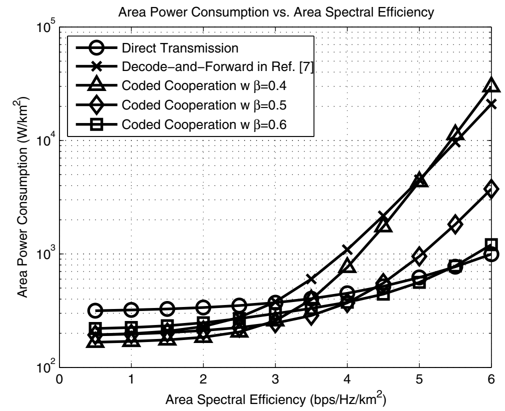
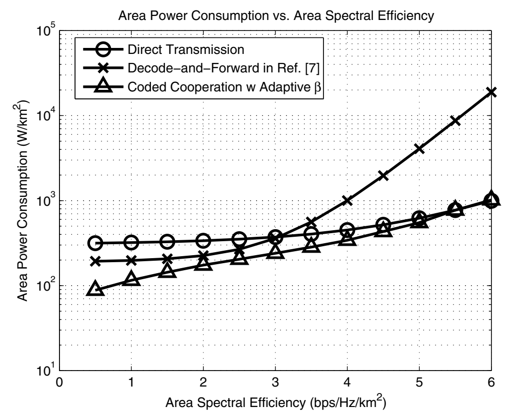


Fig. 3. Area power consumption versus number of relays.



(a) Area power consumption versus target area spectral efficiency for coded cooperation with different β.



(b) The optimal area power consumption versus target area spectral efficiency for coded cooperation with adaptive β.

Fig. 4. Area power consumption versus area spectral efficiency.

better energy efficiency than the direct transmission, while coded cooperation has better energy efficiency than direct transmission for $\kappa \geq 0.3$ and consumes less and less energy as κ increases from 0.2 compared with DF. The optimal position of relays for coded cooperation is about $\kappa = 0.6$.

2) Area Power Consumption vs. Number of Relays: Figure 3 shows how the number of relays affects the area power consumption when $R = 0.8km, \kappa = 0.6, \beta = 0.5$ and $\mathcal{C}_T = 1bps/(Hz{\cdot}km^2)$. Likewise, the area power consumption of direct transmission is unrelated to the number of relays. For the other two schemes, it is obvious that coded cooperation is more energy efficient than DF all along and their curves are both convex with a minimum point that corresponds to the optimal energy efficient relay number denoted as K_{opt} ($K_{opt} = 8$ for coded cooperation and $K_{opt} = 10$ for DF). When $K < K_{opt}$, as K increases, the distance between relays and users shortens, and the power consumed decreases accordingly. When $K > K_{opt}$, the improvement on energy efficiency brought from K becomes less, while large number of relays leads to linear increase of idling power instead and the power consumption curve rises slowly again.

3) Area Power Consumption vs. Area Spectral Efficiency: Figure 4(a) shows how the area power consumption changes by increasing the target area spectral efficiency $\mathcal{C}_T$ when $R = 0.6km, \kappa = 0.5$ and $K = 8$. It can be observed that all curves are rising as $\mathcal{C}_T$ increases and DF is not efficient when $\mathcal{C}_T \geq 3bps/(Hz \cdot km^2)$. However, for coded cooperation, different values of parameter β have different power consumption curves. The less value of β is, the faster the curve rises with the increasing $\mathcal{C}_T$. Since β can be adjusted by varying the coding rate, we can dynamically modulate the resource allocation between BS and relay to acquire a better power consumption. Specifically, for each $\mathcal{C}_T$, we adjust β until the best energy efficiency obtained and get a optimal power consumption curve accordingly showed in Figure 4(b). By dynamic adjusting β, it is guaranteed that coded cooperation always consumes less energy than direct transmission which is unachievable for DF.

B. Deployment of Relays

In this section, we investigate how the relay deployment strategy affects the area power consumption by comparing our system model with the model in [7]. Besides, we also study the impact on the area power consumption of different factors such as cell radius and inter-layer distance.

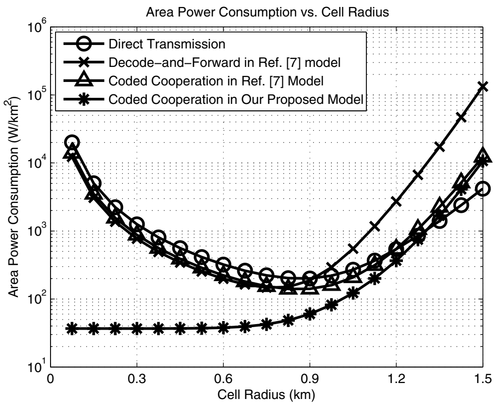


Fig. 5. Area power consumption versus cell radius for different system models.

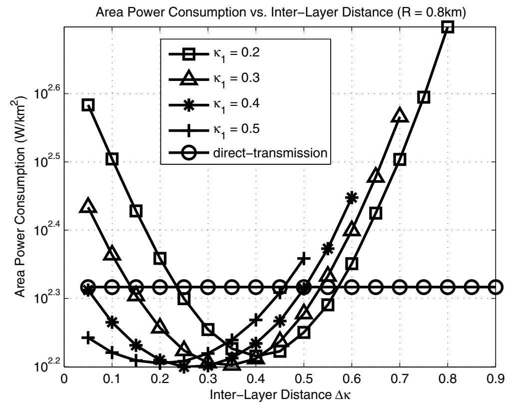


Fig. 6. Area power consumption versus inter-layer distance.

1) Area Power Consumption vs. Cell Radius: Figure 5 shows how the cell size affects the area power consumption when $K = 8, \beta = 0.6, \kappa_1 = \frac{1}{3}, \kappa_2 = \frac{2}{3}, K_1 = K_2 = 4$ and $\mathcal{C}_T = 1bps/(Hz \cdot km^2)$. From the figure, we can see that the optimal cell radius of direct transmission is about 0.9km which is the same as the one of coded cooperation using the system model in [7], while the optimal one for DF is about 0.8km. However, in our system model, coded cooperation has no optimal radius but it has maintained very low power consumption until $R = 0.6km$. When $R > 0.6km$, the power consumption curve also rises with the increase of cell radius like other curves, while it has the best energy efficiency until $R = 1.3km$. It can be concluded that in our system model, relays are distributed more uniformly and users can select relays from different layer according to their positions which can decrease the power consumed obviously. When the cell radius becomes larger, due to β is fixed to 0.6 that means the resource allocation is fixed, so the coded cooperation will consume more energy than direct transmission finally. We can further improve the energy efficiency by adjusting the parameter β using similar method in IV-A3.

2) Area Power Consumption vs. Inter-layer Distance: Figure 6 shows how the inter-layer distance affects the area power consumption while changing κ_1 in our two-layer relaying system when $K = 8, \beta = 0.6, K_1 = K_2 = 4$ and $\mathcal{C}_T = 1bps/(Hz \cdot km^2)$. We denote the inter-layer distance, i.e., the distance between the first layer and the second layer, as $\Delta\kappa = \kappa_2 - \kappa_1, (0 \leq \Delta\kappa \leq 1)$. From the figure, we can see that for different κ_1, there is always an optimal $\Delta\kappa$ with the lowest power consumption. Besides, for each curve, there is a certain range of inter-layer distances where coded cooperation has better energy efficiency than the direct link transmission and it makes the deployment of relays more flexible.

V. Conclusions

In this paper, we analyzed the area power consumption of a single relay-assisted cellular system using coded cooperation as the transmission scheme. We proposed a novel deployment strategy for relays in the cell which is generalized, realistic and simple. Accordingly, a relay selection procedure was proposed and the area power consumption under a target area spectral efficiency was derived. Our simulations revealed the impact of various system parameters on the power consumption and the better energy efficiency achieved by coded cooperation via dynamically adjusting the resource allocation compared with direct transmission and DF relaying, which sheds useful insights into the choice of system parameters and the resource allocation to deal with the tradeoff between the energy consumption and the spectral efficiency well.

References

[1] Z. Hasan, H. Boostanimehr, and V. Bhargava, "Green cellular networks: A survey, some research issues and challenges," *Communications Surveys & Tutorials, IEEE*, vol. 13, no. 4, pp. 524–540, 2011.

[2] V. Mobile, "Virtual centre of excellence in mobile and personal communications-mobile vce-core-5 research area: Green radio." [Online]. Available: http://www.mobilevce.com/infosheets/GreenRadio.pdf

[3] eMobility report, "White papers produced during sra revision period 1," Nov. 2008.

[4] D. Calin, H. Claussen, and H. Uzunalioglu, "On femto deployment architectures and macrocell offloading benefits in joint macro-femto deployments," *Communications Magazine, IEEE*, vol. 48, no. 1, pp. 26–32, 2010.

[5] F. Richter, A. Fehske, and G. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks," in *Vehicular Technology Conference Fall (VTC 2009-Fall), 2009 IEEE 70th*. IEEE, 2009, pp. 1–5.

[6] A. Fehske, F. Richter, and G. Fettweis, "Energy efficiency improvements through micro sites in cellular mobile radio networks," in *GLOBECOM Workshops, 2009 IEEE*. IEEE, 2009, pp. 1–5.

[7] J. Xu and L. Qiu, "Area power consumption in a single cell assisted by relays," in *Green Computing and Communications (GreenCom), 2010 IEEE/ACM Int'l Conference on & Int'l Conference on Cyber, Physical and Social Computing (CPSCom)*. IEEE, 2010, pp. 460–465.

[8] T. Hunter, S. Sanayei, and A. Nosratinia, "Outage analysis of coded cooperation," *Information Theory, IEEE Transactions on*, vol. 52, no. 2, pp. 375–391, 2006.

[9] A. Agrawal, "Heterogeneous networks a new paradigm for increasing cellular capacity." [Online]. Available: http://netseminar.stanford.edu/seminars/01_29_09.pdf

[10] M. Alouini and A. Goldsmith, "Area spectral efficiency of cellular mobile radio systems," *Vehicular Technology, IEEE Transactions on*, vol. 48, no. 4, pp. 1047–1066, 1999.