Cooperative Virtual Cell Clustering for Green Cellular Networks

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***Abstract*—In this paper, a novel cell cooperation-based scheme is proposed as a means of energy saving in an overlapped coverage area of several cells. Different from the existing single-cell serving mode, our proposal utilizes virtual cell clustering (VCC) technique, which aggregates spare bandwidth from all adjacent cells, to reduce energy consumption while satisfying the service requirement simultaneously. For the maximum energy saving gain, a service partition procedure is then introduced with an optimization problem modeled in the scenarios under consideration. Evidences from numerical simulations further demonstrate that the proposed scheme outperforms the existing mode with a significant energy saving achievement.**

***Index Terms*—Green communications, energy saving, power efficiency, virtual cell clustering, partition factor**

I. Introduction

With the explosive growing demand of information and communication technologies (ICTs), the energy consumption in ICT industry has become a very serious issue from either economical or environmental perspective. For mobile telecommunications, due to the substantial power consumption of each Base Station (BS) and the rapid increase of the number of BSs for wide area coverage, the unprecedented high energy consumption is predictable, which in turn becomes a tremendous burden on the network operators' overall expenditures. Such an amount of energy consumption also causes a great environmental impact. It has been identified that ICTs are responsible for 2% of overall carbon emissions, of which mobile networks contributes to 0.2% totally with a expectation of continuous increase. Therefore, considerations from both aspects have motivated a trend of green communications to reduce the amount of energy consumption [1], which attracts lots of attentions from either academia or industry.

Since a fact that the radio access networks account for over 80% of the total energy consumption, especially the BSs, reducing the power consumed by BSs has a significant influence on the energy saving, and thus contributes to green communications. In view of this regard, plenty of efforts have been made in literature (see [2] and references therein), including the BS hardware design (e.g. power amplifier improvement), and balance between energy consumption and performance based on several system features, etc. Among these methods, heterogeneous wireless access networks deployment and sleep mechanism are two effective representative.

Traditionally, macrocells are used to provide wide area coverage in cellular networks. However, as cell size grows, more transmitted power is required to guarantee quality of service (QoS) of cell edge users, which results in an increase of overall BS energy consumption and thus calls for an energy efficient substitute. Several researches have already proved that small cell size contributes to the improvement of energy efficiency [3][4], which means that small-cell networks are available for deployment [5]. Recently, microcells, femtocells have been developed to fill the gap of coverage and meanwhile provide higher data rate as well as energy consumption reduction. In [6], Richter *et al.* investigated the efficiency of heterogeneous networks consisting of micro and macro sites, and found that higher user density required more small sites so as to achieve better energy efficiency, indicating the advantages brought by heterogeneous networks employment.

Due to user mobility and activities, traffic load in cellular networks have critical fluctuations in either spatial dimension or temporal domain. A great waste of energy will emerge if all BSs are always active with static coverage, since operating a BS consumes a considerable amount of energy. Hence, selectively making a BS into sleep mode based on its traffic load would be a good choice, which could evidently lead to a significant energy saving, as presented in [7-9] with diverse implementation individually. In addition, an extension of sleep scheme was proposed in [10] by Muhammad *et al.*, which switched on and off not only the BSs but also their resources according to the traffic load condition. The proposal enabled the cooperation of heterogeneous wireless networks in two scales, which resulted in a certain energy saving gain while satisfying user's QoS requirements. However, some overhead for cooperating BSs between different networks were required, including a complicated synchronization.

As analyzed in Section II, an energy inefficiency problem occurs under current single-cell serving mode, which is inharmonic in the trend of green communications. To tackle this, a novel scheme, which is based on cell cooperation (less overhead relatively), is proposed here. It exploits multiple cells diversity by utilizing virtual cell clustering (VCC) technique, which aggregates spare bandwidth from all adjacent cells to serve the user simultaneously. Due to the differences between the distances of user-to-BS and the individual spare bandwidth, a service partition procedure is introduced as well, and meanwhile an optimization problem is formulated to maximize the energy saving gain, which can be resolved through partial differentiation method. This proposal is proved effective most of the time, as shown in the following section, which could play positive role in green communications.

The reminder of this paper is organized as follows. Section II argues the inefficiency of current single-cell serving mode and then introduces our proposal based on cell cooperation. Gain achieved by our method with service partition under several scenarios are discussed in Section III. Numerical simulations are executed in Section IV to identify the aforementioned analysis. Finally, the concluding remarks are drawn.

II. Cell Cooperation For Energy Saving

Upon a typical cellular network coverage area as shown in Fig. 1, there are several BSs and a number of users requesting services. Take user A for instance, who is currently located in the area that overlapped by BS1 and BS2 (but nearer to the former).

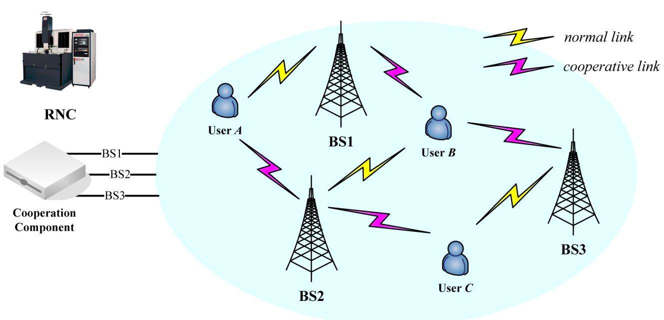

Fig. 1. Typical cellular radio network

In the so-called general single-cell serving mode, A is always served by BS1 via a normal link. Assuming that the distance between user A and BS1 is r and the transmitted power is $P_{TX,r}$, the data rate R can be thus calculated in AWGN-like (Additive White Gaussion Noise) channel through Shannon-Hartley formula by the following form:

$$R = \mu C = \mu W \log_2(1 + \frac{\alpha P_{TX,r}}{r^n n_0 W}) \tag{1}$$

$$\alpha = \frac{G_t G_r \lambda^2}{(4\pi)^2 L} \tag{2}$$

where μ is the coding efficiency determined by the coding technique (e.g. LDPC, Turbo Coding, etc.) and always lower than 1, n is the path loss exponent. α is the channel gain, which is a function of the transmitter antenna gain G_t and the receiver antenna gain G_r as well as the system loss factor L. n_0 represents the thermal noise density and W denotes the occupied bandwidth. λ is the wavelength in meters. Then, the required transmitted power for data rate R is

$$P_{TX,r}(R, W, r) = \frac{r^n n_0 W}{\alpha}(2^{R/\mu W} - 1) \tag{3}$$

The power efficiency, which is defined as

$$\eta = \frac{R}{P_{TX}}(bps/Watt) \tag{4}$$

is then transformed to be

$$\eta = \eta_0 \frac{R}{r^n(2^{R/\mu W} - 1)} \tag{5}$$

with $\eta_0 = \alpha / n_0 W$.

For constant R, $\eta \sim 1/r^n$, while in fixed distance r case, $\eta \sim R/(2^{R/\mu W} - 1)$, which means that the power efficiency is significantly decreasing when either the inter-distance or data rate grows, as illustrated in Fig. 2 (just follow the parameter settings in TABLE I). Thus, when a user is located at the boundary of a BS or requests a large service data rate, the power efficiency becomes fairly low, which results in a problem of inefficiency and conflicts to green communications.

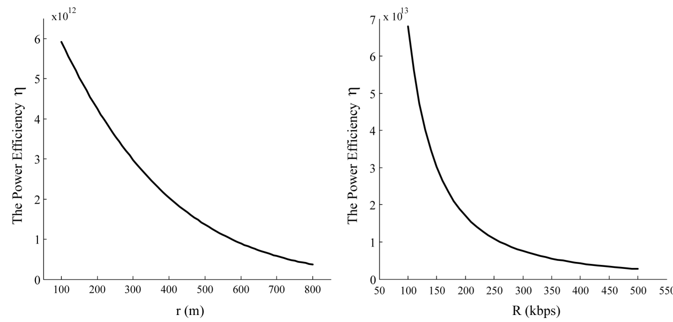

Fig. 2. The power efficiency η versus r and R

To tackle this problem, a more effective serving method should be introduced accordingly. A common idea is to use multiple bandwidth, which has been proved useful but lacking of operability due to the fact that bandwidth is really scarce, especially in a single BS. Notice a phenomenon that mobile terminals in future will be equipped with multiple radio interfaces for network access and could maintain multiple associations with different radio access networks through multi-homing techniques, which are naturally able to receive multiple transmissions from several adjacent cells simultaneously. In this regard, we propose a novel solution based on cell cooperation by using a virtual cell clustering technique in this paper, which could aggregate spare bandwidth from all adjacent cells. Although bandwidth in a solo BS is limited, it becomes respectable if collected from several BSs. Therefore, our method enhances the feasibility of implementation, while also achieving a significant energy saving and an improvement of the power efficiency, which can be proved in Section III and Section IV.

As seen in Fig. 1, a dedicated cooperation component is created as a central controller and placed in radio network controller (RNC), to which all the BSs connect via optical fibers. Then the component implement the serving procedure, as depicted in Fig. 3. When the user moves into the overlapped coverage area, which is also called interference region (i.e., the shadow region of Fig. 4), cooperation component firstly asks all adjacent BSs that have spare bandwidth (i.e., the available bandwidth minus the reserved one) to execute ranging function to this target user, and then feed back the inter-distance information together with the amount of spare bandwidth. According to these information collected, it calculates the potential of energy saving by cell cooperation as described in Section III. If a positive gain is achieved, the VCC method is implemented, while it remains in general serving mode otherwise. Note that the ping-pong phenomenon is not considered throughout this paper.

In VCC execution, cells with spare bandwidth are clustered as a virtual cell relative to the real cell in general mode, as well as all the spare bandwidth being aggregated together to serve the user. Due to the differences between the inter-distances of user and BSs, and individual spare bandwidth, a service partition procedure is additionally presented to maximize the energy saving, by using several division factors. Once optimized, BSs adjust their transmit power to serve the user according to the partition factors. The user A is then served through normal link and cooperative link together (see Fig. 1).

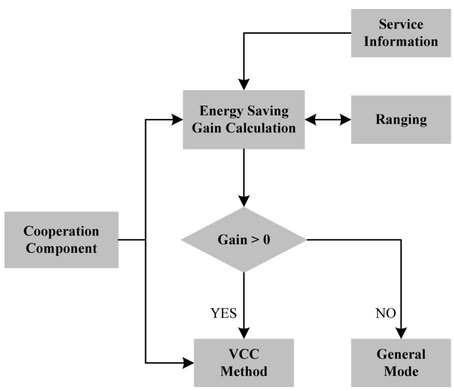

Fig. 3. The flowchart of VCC method

III. Gain Calculation

Comparing to the general mode, the energy saving gain by VCC adoption is analyzed in this section, to show the benefits from cell cooperation. Firstly, we discuss it in a simple case consisting of two overlapped cells, and then extend it to several BSs scenario.

It should be noticed that heterogeneous radio networks will be applied in future mobile communications for high-rate services and worldwide coverage [5-6], of whom the equipments for wireless access (e.g., BSs) are significantly different in energy consumption due to amplifier and feeder loss as well as cooling, etc. Our analysis will be more complicated if those differences are considered. Thus, for simplicity, homogeneous BSs are employed here, and we further denote the overall energy consumption with a expression of the total transmitted power multiplying a single factor. More precisely, we are more concerned about the total transmitted power.

A. Two BSs

As shown in Fig. 4, the distance between user and BS1, BS2 is assumed as r_1 and r_2, respectively. Without loss of generality, we set $r_1 \leq r_2$. Thus, in general mode, the user is always served by BS1 with a transmitted power $P_{t,1} = P_{TX,r}(R, W, r_1)$ and a power efficiency $\eta_1 = \eta(R, r_1)$.

Under VCC adoption, the user turns to be served by several cells simultaneously but with a different service part. Here, we define a partition factor β to represent the faction of data rate served by the nearest BS (i.e., BS1). Obviously, $\beta \in [0, 1]$. Besides, we assume that τW is the spare bandwidth of BS2. Then, the total transmitted power is written as

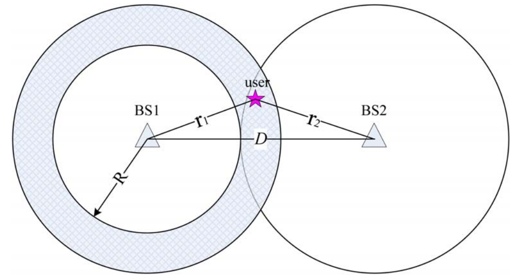

Fig. 4. Two BSs overlapped coverage

$$P_{t,2} = P_{TX,r}(\beta R, W, r_1) + P_{TX,r}((1-\beta)R, \tau W, r_2) \quad (6)$$

Substituting Eq.(3) into Eq.(6), we obtain

$$P_{t,2} = \frac{n_0 W}{\alpha}\left[r_1^n(2^{\beta R/\mu W} - 1) + r_2^n(2^{(1-\beta)R/\mu\tau W} - 1)\right] \quad (7)$$

with the power efficiency being

$$\eta_2 = \eta_0 \frac{R}{r_1^n(2^{\beta R/\mu W} - 1) + r_2^n(2^{(1-\beta)R/\mu\tau W} - 1)} \quad (8)$$

To exhibit the potential of energy saving achieved by our method, we define another performance indicator, the normalized energy saving gain (ESG) ψ, which is expressed as

$$\psi = \frac{P_{t,1} - P_{t,2}}{P_{t,1}} \quad (9)$$

which can be further simplified to be

$$\psi = 1 - \frac{(2^{\beta Rx} - 1) + \gamma^n(2^{(1-\beta)Rx/\tau} - 1)}{2^{Rx} - 1} \quad (10)$$

where the distance ratio $\gamma = r_2/r_1 \geq 1$ and $x = 1/\mu W$. Clearly, if $\psi > 0$, the energy saving is attained, revealing the superiority of our method, while the general mode performs better otherwise.

Eq. (10) is a concave function to β, due to the inequality that $\frac{\partial^2\psi(\beta)}{\partial^2\beta} \leq 0$, no matter what R or γ is. In Section IV, this proposition is graphically demonstrated (see Fig. 6).

For the maximum ψ, we can get an optimization problem, that is,

$$\max_{\beta} \psi, s.t., \beta \in [0, 1] \quad (11)$$

which can be solved through partial differentiation method. And we obtain the optimal partition factor β_{opt} with the maximum energy gain as $\psi(\beta_{opt})$:

$$\beta_{opt} = \left[\min\left\{\frac{1}{1+\tau} + \frac{\tau}{Rx(1+\tau)}\log_2\left(\frac{\gamma^n}{\tau}\right), 1\right\}\right]^+ \quad (12)$$

where $[\alpha]^+$ denotes the positive fraction of α, i.e., $\max(\alpha, 0)$.

B. N BSs

When the user steps into an area overlapped by several BSs, where the distance of user-to-BS is $r_1, r_2, ..., r_N$ and individual spare bandwidth is $\tau_1 W, \tau_2 W, ..., \tau_N W$, respectively, a virtual cell is clustered so as to serve it. Without loss of generality, $r_1 \le r_i, \forall i$ and thus $\tau_1 = 1$. Let $\beta_i (1 \le i \le N)$ be the partition factors of data transmitted by BS i. Then, the gain ψ achieved by VCC adoption can be expressed by

$$\psi = 1 - \frac{\sum_{i=1}^{N} \gamma_i^n (2^{\beta_i Rx/\tau_i} - 1)}{2^{Rx} - 1} \tag{13}$$

where $\gamma_i = r_i / r_1 \ge 1$ and $\sum_{i=1}^{N} \beta_i = 1$.

Our objective is to maximize the energy saving gain ψ, which is then transformed to be

$$\max_{\beta_i} \psi \Leftrightarrow \max_{\beta_i} Z \tag{14}$$

where $Z = \sum_{i=1}^{N} \gamma_i^n (2^{\beta_i Rx/\tau_i} - 1)$. By using optimization theory that

$$\frac{\partial Z}{\partial \beta_i} = 0, 1 \le i \le N \tag{15}$$

we obtain all the factors through the equations given by

$$\beta_{i,opt} = \left[\min \left\{ \frac{\tau_i}{\sum_{j=1}^{N} \tau_j} + \frac{\sum_{j=1}^{N} \tau_i \tau_j \log_2 \left(\frac{\tau_i \gamma_j^n}{\tau_j \gamma_i^n} \right)}{Rx \sum_{j=1}^{N} \tau_j}, 1 \right\} \right]^+ \tag{16}$$

IV. Numerical Study

In this section, we show the superiority of our proposal through numerical simulations. For simplicity, the scenario with two overlapped cells in free-space circumstance is considered here. System parameters are given in TABLE I, where the bandwidth of individual cell for cooperation is equally set to 150 kHz.

TABLE I
Parameter Settings

System Parameters	Value
Carrier frequency(f)	2.4 GHz
Path loss exponent(n)	2 (free space)
BS antenna gain(G_t)	15 dB
Receiver antenna gain(G_r)	-1 dBi
System loss factor(L)	1
Bandwidth(W)	150 kHz
Thermal noise(n_0)	-174 dBm/Hz
Coding efficiency(μ)	0.8

Fig. 5 depicts the general distribution of ESG achieved by VCC adoption when γ and β varies respectively with a service requirement $R = 300$ $kbps$. It's clear that the energy saving gain is attained comparing to general mode (the base zero-plane) in some cases. A more detailed simulation is implemented and presented in Fig. 6, where a larger γ or data rate leads to a greater ESG as well as a larger β_{opt}.

When the required data rate R ranges from 12 $kbps$ to 360 $kbps$, the energy saving gain is achieved under different

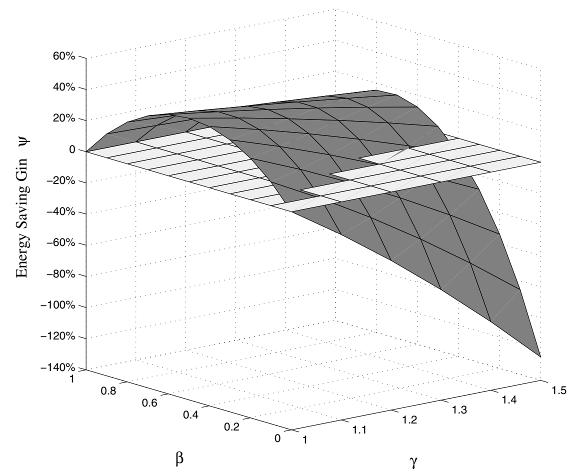

Fig. 5. ESG achieved by VCC adoption when β and γ varies

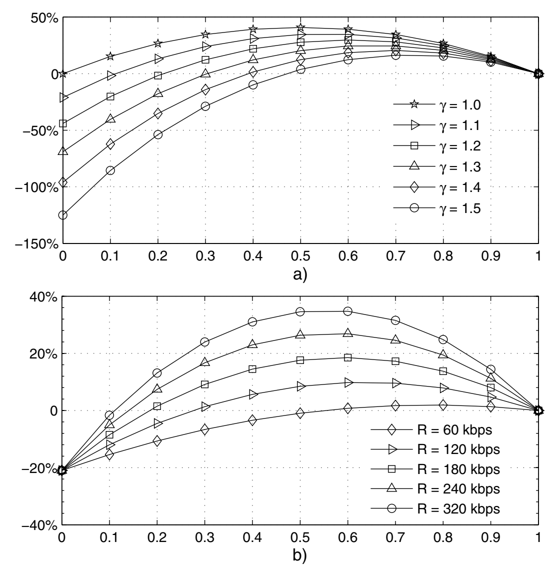

Fig. 6. ESG obtained versus β: a) $R = 300$ $kbps$; b) $\gamma = 1.2$

distance ratio γ respectively, as shown in Fig. 7. Whatever γ is, the gain is continuously increasing as R grows. Similarly, the smaller γ is, the greater gain is, which means that our method performs better when the distances between user and two BSs are nearly the same. Besides, in order to compare with general mode adoption, the power efficiency is calculated as well (shown in Fig. 8), where the simple line and the line with star represents the lower bound and upper bound of the achieved ESG, respectively. As shown therein, the power efficiency is always improved, indicating the superiority of our proposal. And as R increases, the advantages of our method are gradually exhibited.

The values of optimal partition factor β_{opt} under diverse γ as R grows is shown in Fig. 9. When $\gamma = 1$, meaning that the user is located in the middle of two BSs, a half separation

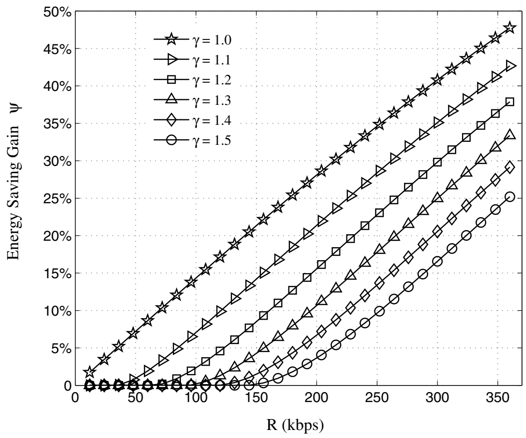

Fig. 7. ESG attained in VCC mode when R varies

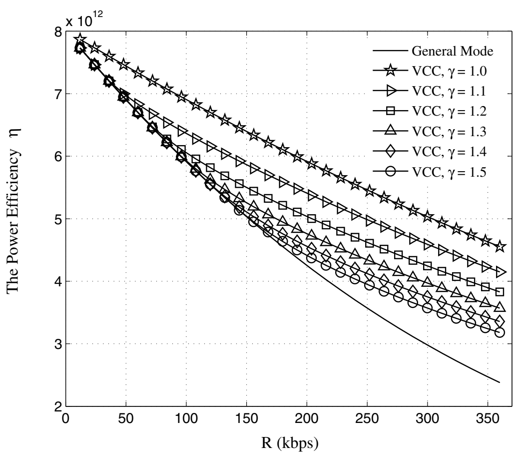

Fig. 8. Comparison of power efficiency with R varying

of data rate served individually would be excellent. Once γ grows, where an offset of distances happens, the nearest BS should share more responsibility for services. Moreover, when R is low, which dissatisfies the conditions, a value that belongs to $[0, 1]$ cannot be attained, indicating that general mode is a good choice prior to VCC mode. However, the converse situation happens as R increases as well as β_{opt} being derived in $[0, 1]$. In addition, when R is larger enough, β_{opt} approaches 0.5, which means the larger data rate R has gradually covered the differences of distance ratios.

V. Conclusion

In this paper, cell cooperation is investigated as a method of energy saving. Cells with overlapped coverage can cooperate to provide a significant energy saving gain via our proposed scheme, which employs virtual cell clustering technique to aggregate spare bandwidth from all adjacent cells to serve the user. Since there are some differences of the inter-distances and the number of spare bandwidth, a service partition procedure is introduced then. For a maximum energy saving gain, an optimization problem with respect to the division factors is formulated and further resolved. Our method exploits the potential of multiple cell diversity, thus resulting in energy efficiency improvement. Numerical results also identifies our proposal's superiority on energy saving.

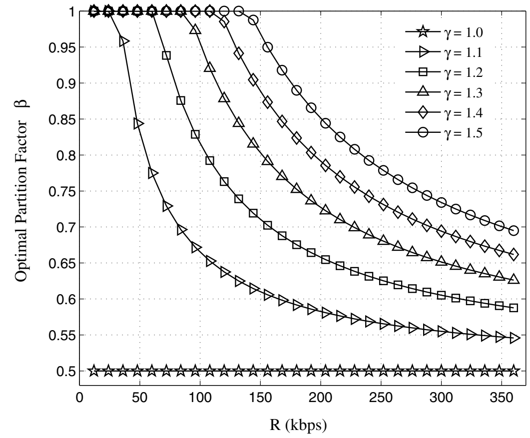

Fig. 9. Values of β when R grows

VI. Acknowledgement

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References

[1] Congzheng, H., T. Harrold, et al., "Green radio: radio techniques to enable energy-efficient wireless networks." IEEE Communications Magazine, Vol. 49, Issue 6, pp.46-54, 2011.

[2] Hasan, Z., "Green Cellular Networks: A Survey, Some Research Issues and Challenges." IEEE Communication Surveys & Tutorials, Vol.13, Issue 4, pp.524-540, 2011.

[3] B. Badic, T. OFarrell, P. Loskot, J. He, "Energy Efficient Radio Access Architectures for Green Radio: Large versus Small Cell Size Deployment", in *Proc.* of IEEE VTC-Fall'2009, pp. 1-5, 2009.

[4] Hansung Leem, Seon Yeob Baek, and Dan Keun Sung, "The Effects of Cell Size on Energy Saving, System Capacity, and Per-Energy Capacity", in *Proc.* of IEEE WCNC'2010, pp. 1-6, 2010.

[5] Hoydis, J., M. Kobayashi, et al., "Green Small-Cell Networks." IEEE Vehicular Technology Magazine, Vol. 6, Issue 1, pp.37-43, 2011

[6] Fred Richter, Albrecht J. Fehske, Patrick Marsch, and Gerhard P. Fettweis, "Traffic Demand and Energy Efficiency in Heterogeneous Cellular Mobile Radio Networks", in *Proc.* of IEEE VTC-Spring'2010, pp. 1-6, 2010.

[7] Zhisheng Niu, Yiqun Wu, Jie Gong, and Zexi Yang, "Cell Zooming for Cost-Efficient Green Cellular Networks", IEEE Communications Magazine, Vol. 48, Issue 11, pp. 74-79, 2010.

[8] M. Ajmone Marsan, L. Chiaraviglio, D. Ciullo, M. Meo, "Optimal Energy Savings in Cellular Access Networks", *GreenComm' 2009*, Dresden, Germany, June 2009.

[9] Louai Saker, Salah-Eddine Elayoubi and Tijani Chahed, "Minimizing energy consumption via sleep mode in green base station", in *Proc.* of IEEE WCNC'2010, pp. 1-6, 2010.

[10] Ismail, M. and Z. Weihua, "Network cooperation for energy saving in green radio communications." IEEE Wireless Communications, Vol. 18, Issue 5, pp.76-81, 2011