Optimizing Cell Size for Energy Saving in Cellular Networks with Hybrid Energy Supplies

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***Abstract*—Green communications has received much attention recently. For cellular networks, the base stations (BSs) account for more than 50 percent of the energy consumption of the networks. Therefore, reducing the power consumption of BSs is crucial to achieve green cellular networks. In this paper, we optimize the energy utilization in cellular networks whose BSs are powered with both regular energy from the grid and the renewable energy. We minimize the on-grid energy consumption of BSs by adapting their cell sizes. The cell size optimization problem is NP-hard. We divide the problem into two subproblems: the multi-stage energy allocation problem and energy consumption minimization problem. We propose an energy allocation policy and an approximation algorithm to solve these subproblems, respectively, and subsequently solve the cell size optimization problem. Simulation results demonstrate that the proposed solution achieves significant energy savings.**

I. Introduction

In wireless cellular networks, energy consumption is mainly drawn from BSs (base stations). According to the power consumption breakdown [1], BSs consume more than 50 percent of the power of a cellular network. In addition, the number of BSs is expected to be doubled by 2012 [2]. Thus, reducing the power consumption of BSs is crucial to green cellular networks. Efforts on greening cellular networks can be classified into three categories. The first category is to design power saving communication protocols that adjust the transmit power of the transceivers according to the traffic intensity. Radio access networks are dimensioned for peak hour traffic, and thus the utilization of the base stations can be very inefficient during the off-peak hours. The most intuitive idea is to switch off the transceivers when the traffic load is below a certain threshold for a certain time period [3]. When some base transceiver stations are switched off, radio coverage and service provisioning are taken care of by the devices that remain active. The BS switching problem can be formulated as an optimization problem that minimizes the number of active BSs while meeting the traffic load in the access network. Several algorithms and schemes have been proposed to solve the problem [4]–[6]. The second category is to design heterogeneous radio access networks which utilize a diverse set of base stations to improve spectral and energy efficiency per unit area. The network deployment featuring high density deployments of small, low power base stations achieve higher network energy efficiency than the sparse deployment of few high power base stations do. Etoh *et al.* [7] pointed out that heterogeneous network deployment will bring up to 50 percent reduction of the total BS power consumption. Samdanis *et al.* [8] examined the energy efficiency of cellular networks with joint macro and pico coverage, and showed that the joint deployment can reduce the total energy consumption by up to 60% in an urban area. The third category is to design off-grid BSs and communication protocols to enable utilization of renewable energy in cellular access networks. Renewable energy such as sustainable biofuels, solar and wind energy are promising options to save the on-grid energy consumed by BSs and reduce the CO2 footprint. Zhou *et al.* [9] proposed the HO (Hand Over) parameter tuning algorithm for target cell selection, and the power control algorithm for coverage optimization to guide mobile users to access to the BSs with natural energy supply, thus reducing the power expense and CO2 emission.

Envisioning future BSs to be powered by multiple types of energy sources, e.g., the grid, solar energy, and wind energy, we propose to optimize the energy utilization in cellular networks whose BSs can be powered by both on-grid energy and renewable energy. In such cellular networks, BSs are powered by renewable energy if they have enough renewable energy storage; otherwise, the BSs switch to on-grid energy to serve mobile users. We minimize the on-grid energy consumption of the cellular network over a period of time consisting of several cell size adaptations by optimizing cell sizes of BSs. Mobile traffic exhibits both temporal and spatial diversity [10]. On the temporal diversity, traffic volume at individual BSs is highly dynamic over time, and it typically peaks between 10 AM and 18 PM, and bottoms between 1 AM and 5 AM. On the spatial diversity, traffic load intensity is quite diverse among the closely located BSs. As a result, the energy consumption on each BS is different. Thus, some of the BSs may run out of green energy and switch to on-gird energy supplies while the other BSs may have superfluous green energy stored in their batteries. Therefore, the consumption of green energy has to be balanced among BSs by adapting cell size in order to minimize the on-grid energy consumption. Thus, we decompose the cell size optimization problem into two subproblems: the multi-stage energy allocation problem and energy consumption minimization problem. We design an energy allocation policy to allocate the amount of renewable

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energy to each BS according to the energy demand of the BS as well as the energy storage in the BS. We solve the energy consumption minimization problem in two steps. First, we minimize the number of BSs that consume the on-grid energy. We prove that minimizing the number of BSs that utilize on-grid energy is an NP-hard problem. We thus propose an approximation algorithm to solve this problem with low computation complexity. Then, we check whether additional energy savings can be achieved by turning some of the BSs into the sleep mode. We calculate the per user energy consumption of each BS. If the per user energy consumption of a BS is larger than a predefined threshold, we test whether the energy consumption can be reduced by putting this BS into the sleep mode. If additional energy savings can be achieved, the BS is switched to the sleep mode. Through simulations, we show that our proposed solution can achieve significant on-grid energy savings.

II. Problem Formulation

Consider a cellular networks with N BSs and M mobile users. The BSs update their cell sizes every τ seconds by changing the power of their pilot signals. Mobile users select BSs based on the strength of pilot signals from BSs. We consider a duration of time consisting of L cell size updates. Let $\vec{P_i^0} = (p_{i,1}^0, p_{i,2}^0, \cdots, p_{i,n}^0)$ be the pilot signal power of BSs at the ith cell size update. Then, the user-BS association matrix at the ith cell size update, X_i, is determined by $\vec{P_i^0}$. Let $X_i(k,j) = 1$ when user k is associated with BS j; otherwise, $X_i(k,j) = 0$. Assume the BSs always have data transmission to mobile users during the τ seconds. The energy consumption of BS j during the ith interval can be expressed as

$$C_{i,j} = \sum_{k=1}^{M} X_i(k,j) P_{k,j} \tau + P_{i,j}^{fix} \mu_{i,j} \tau. \tag{1}$$

Here, $P_{k,j}$ is the dynamic power consumption of BS j for serving user k, $P_{i,j}^{fix}$ is the static power consumption when the BS is in the active status, and $\mu_{i,j}$ is an indication function which equals 1 when BS j is active at the ith duration; otherwise, $\mu_{i,j}$ equals 0. The BS is active when there is at least one user associated with it. Therefore, $\mu_{i,j}$ can be expressed as:

$$\mu_{i,j} = \begin{cases} 1, & \sum_{k=1}^{M} X_i(k,j) > 0 \ ; \\ 0, & Otherwise. \end{cases} \tag{2}$$

At the ith cell size update, the energy storage from a renewable source at BS j is $E_{i,j}$. The amount of energy storage depends on the energy consumption and generation of the previous interval. Therefore, $E_{i,j}$ equals to

$$E_{i,j} = \begin{cases} E_{i-1,j} - C_{i-1,j} + \alpha\tau, & E_{i-1,j} \geq C_{i-1,j} \ ; \\ E_{i-1,j} + \alpha\tau, & Otherwise. \end{cases} \tag{3}$$

Here, α is the energy generation rate which indicates the amount of energy generated from the renewable source per second. Denote $E_{0,j}$ as the initial renewable power storage at BS j. We assume the energy generation rate does not change in the duration of L cell size updates. The on-grid energy consumed by BS j during the ith interval is

$$G_{i,j} = \begin{cases} 0, & E_{i,j} \geq C_{i,j} \ ; \\ C_{i,j}, & Otherwise. \end{cases} \tag{4}$$

The CSO (cell size optimization) problem can be formulated as

$$\min_{(\vec{P_1^0}, \vec{P_2^0}, \cdots, \vec{P_i^0}, \cdots, \vec{P_L^0})} \quad \sum_{i=1}^{L} \sum_{j=1}^{N} G_{i,j} \tag{5}$$

$$subject\ to: \quad \lambda_{k,i} \geq \gamma, \quad k \in (1, 2, \cdots, M). \tag{6}$$

Here, $\lambda_{k,i}$ is the receiving SNR (signal noise ratio) of user k at the ith duration, and γ is the minimal SNR requirement. We assume all users have the same SNR requirement.

During L cell size updates, the mobile network may be in three different network states in terms of energy sources. The first network state corresponds to the case that all the BSs have sufficient renewable energy storage to serve all the users. The second network state is that some of the BSs rely on renewable energy while others draw energy from the grid to serve mobile users. The third network status corresponds to the case that all the BSs serve users by using on-grid energy because the renewable energy in BSs are depleted. In the first two network states, renewable energy is utilized to serve users. According to Eq. 3, the energy storage at the ith duration depends on the energy storage, consumptions and generations of the previous durations. Thus, the optimal cell size at the ith duration depends on the cell size in previous durations. Therefore, the CSO problem can be decomposed of two subproblems. The first subproblem is the MEA (multistage energy allocation) problem for individual BSs. The solution to this problem determines the amount of renewable energy to be allocated at individual BSs during each cell size update given energy allocation decision of other BSs. The MEA problem can be expressed as

$$\max_{(\beta_{1,j}, \beta_{2,j}, \cdots, \beta_{i,j}, \cdots, \beta_{L,j})} \quad \sum_{i=1}^{L} U_i(\beta_{i,j}, \beta_{i,\setminus j}) \tag{7}$$

$$subject\ to: \quad \sum_{i=1}^{l} \beta_{i,j} \leq E_{0,j} + l\alpha\tau, \quad l \in (1, 2, \cdots, L). \tag{8}$$

Here, U_i is the network utility in terms of energy savings at the ith cell size update. $\beta_{i,j}$ is the amount of renewable energy allocated to BS j at the ith cell size update. $\beta_{i,\setminus j}$ represents the renewable energy allocations of BSs except BS j. Therefore, the optimal energy allocation for individual BSs depends on the energy allocation strategies of all the other BSs and the energy demand at each cell size update duration.

The second subproblem is to minimize energy consumptions (MEC) at individual cell size update durations. The MEC problem can be formulated as

$$\min_{\vec{P_i^0}} \quad \sum_{j=1}^{N} G_{i,j} \tag{9}$$

$$\begin{aligned} subject\ to.: \quad & \lambda_{k,i} \geq \gamma, \\ & \beta_{i,j}^{'} \leq \beta_{i,j}, \\ & k \in (1, 2, \cdots, M). \end{aligned} \tag{10}$$

Here, $\beta_{i,j}^{'}$ is the renewable energy consumption, and it is a function of the pilot signal power of BS j at the ith cell size update, $p_{i,j}^0$. According to Eq. 4, the on-grid energy consumption $G_{i,j}$ is zero if the renewable energy storage [1] $E_{i,j}$ is larger than the energy cost $C_{i,j}$; otherwise, BSs consume on-grid energy. Therefore, to solve the MEC problem, the first step is minimize the number of BSs which consume on-grid energy.

Theorem 1. *The problem that minimizes the number of BSs powered by on-grid energy is NP-hard.*

Proof: The theorem can be proved by reducing any instance of the minimal dominating set (MDS) problem [11] to the considered problem that minimizes the number of BSs powered by on-grid energy. For the sake of brevity, we omit the detailed proof. ■

Therefore, the MEC problem is NP-hard, and thus the CSO problem is also NP-hard

III. The CSO Algorithm

In this section, we propose the CSO algorithm to solve the CSO problem with low computational complexity. Since the CSO problem consists of two subproblems: the MEA and MEC problems, we tackle the CSO problem by solving the subproblems. The solution of MEA determines the amount of renewable energy allocated at individual BSs during each cell size update. Based on this solution, optimal cell size adaptation is achieved by solving MEC. However, the solution of MEA also depends on the solution of MEC because the solution of MEA determines the amount of energy to be consumed at individual BSs during each cell size update. The best renewable energy allocation strategy is to allocate as much renewable energy as possible to individual BSs in meeting their energy demands, which are derived from solving MEC. Therefore, the idea of our algorithm is to start with an initial energy allocation to solve MEC, and then iteratively adapt the energy allocation based on the solutions of MEC.

A. The MEA Policy

Since the solution of MEA depends on that of MEC, we propose simple energy allocation policies to adapt the energy allocation at each stage to minimize overall on-grid energy consumption. We allocate each BS a certain amount of energy as an initial energy storage at the beginning of each cell size update. Based on the initial allocation, the MEC algorithm minimizes the on-grid energy consumption of each BS. Let $a_{i,j}$ and $d_{i,j}$ be the initial renewable energy allocation and the energy demand at BS j during the ith cell size update, respectively. Since on-grid energy is consumed only when the BSs are allocated with renewable energy below their energy demands, these BSs try to increase their renewal energy allocations to meet their energy demands, and to avoid consuming on-grid energy. For example, if $a_{i,j}$ is less than $d_{i,j}$, BS j will try to increase its renewable energy allocation by $d_{i,j} - a_{i,j}$. The amount of renewable energy that can be increased at BS j during the ith cell size update depends on the total renewable energy storage $E_{i,j}^t$ and the energy adaptation ratio,δ, which determines the percentage of the total renewable energy storage can be allocated to individual BSs at each cell size update duration.

Algorithm 1 The MEA Policy

```
for j = 1 to N do
    if (a_{i,j} < d_{i,j}) & (d_{i,j} - a_{i,j} < δE^t_{i,j}) then
        Return a_{i,j} = d_{i,j};
    end if
end for
```

B. The MEC Algorithm

Given the renewable energy allocation at individual BSs during each cell size update, we tackle the MEC problem in two steps. First, we minimize the number of BSs that consume on-grid energy because $G_{i,j}$ is positive only when BS j consumes on-grid energy at each cell update. Second, we maximize the number of BSs that can be switched into the sleep mode. Let $\rho_{i,j}$ be the energy drain rate (EDR), defined as $d_{i,j}/a_{i,j}$. Minimizing the number of BSs that consume on-grid energy is to minimize the number of BSs with EDR larger than 1. Therefore, the proposed algorithm first finds the BSs with EDR larger than 1, and reduces the cell sizes of these BSs by reducing their pilot signal power in order to reduce their energy demands. While reducing the energy demand of these BSs, EDRs of the other BSs will increase beyond 1. For example, in Fig. 1, both BSs have 10 units of power storage, and user 2 currently associates with BS 1. The energy demand on BS 1 is 11 which makes the EDR larger than 1. Therefore, BS 1 reduces its pilot power to enable user 2 switch to BS 2. As a result, the EDR of BS 2 will be larger than 1, and BS 2 will reduce its pilot power. Then, user 1 will switch back to BS 1. The ping-pong process hardly reaches the optimal solution. To address this problem, we introduce the concept

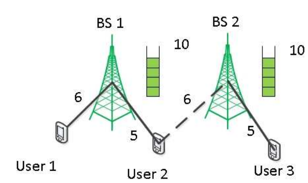

Fig. 1. Illustration of the problem in cell size adaptation.

of the energy dependent set (EDS).

[1]Here, $E_{i,j}$ equals $\beta_{i,j}$

Definition 1. Let $\rho_{i,j}$ be the EDR of BS j at the ith cell size update. $\mathbf{D}' = \{\kappa | \rho_{i,\kappa} > 1, \kappa \in (1, 2, \cdots, N)\}$. Let $\rho'_{i,j}$ be the EDR of BSs j after the pilot power reduction of the BSs in $\mathbf{D}'$. Then, EDS $\mathbf{D} = \{\kappa | \rho'_{i,\kappa} > 1, \kappa \in (1, 2, \cdots, N)\}$.

In order to reduce the EDRs of the BSs with EDRs larger than 1, the pilot signal power of the BSs in the EDS should be reduced together. The pseudo code of the proposed cell size adaptation (CSA) algorithm is listed as Algorithm 2 below.

Algorithm 2 The CSA Algorithm

Initialize $\vec{P_i^0}$ and $a_{i,j}, j \in (1, 2, \cdots, N)$;
Calculate and sort $\rho_{i,j}$ from largest to smallest;
Find the set $\mathbf{D}$ that $\rho_{i,j} > 1, j \in \mathbf{D}$;
for $m = 1$ *to* $|D|$ **do**
  while 1 **do**
    if $(p^0_{i,\mathbf{D}(m)}\ is\ minimal) | (\rho'_{i,\mathbf{D}(m)} == \rho_{i,\mathbf{D}(m)})$ **then**
      Break;
    else
      Find the EDS of BS $\mathbf{D}(m)$;
      Reduce pilot power of BSs in EDS;
      Calculate EDR $\rho'_{i,\mathbf{D}(m)}$;
    end if
  end while
end for
Return $\vec{P_i^0}$, and $\sum_{j=1}^{N} G_{i,j}$;

The proposed cell size adaptation algorithm does not enable the switch to sleep to save energy. Therefore, we further check whether some BSs can be put into the sleep mode based on the derived cell size coverage solution. We select the BSs whose per user energy consumption is larger than a predetermined threshold as the candidate BSs to be switched into the sleep mode. Then, we exam whether the energy consumption can be reduced by switching the BSs to the sleep mode. If the energy consumption can be reduced, we switch these BSs to the sleep mode; otherwise, we keep them in the active status.

C. The CSO Algorithm

We combine the MEA policy and the MEC algorithm to solve the CSO problem. Let $\vec{A_i} = (a_{i,1}, a_{i,2}, \cdots, a_{i,n})$ be the renewable energy allocation vector at the ith cell size update, and $\vec{A_0} = (a_{0,1}, a_{02}, \cdots, a_{0,n})$ be the initial energy allocation at each cell size update. The pseudo code of the CSO algorithm is listed as Algorithm 3 below.

Algorithm 3 The CSO algorithm

Initialize $\vec{P_i^0}$ with maximal pilot power;
Initialize $\vec{A_0}$;
for $i = 1$ *to* L **do**
  Set $\vec{A'_0} = 0$, and $\vec{A_i} = \vec{A_0}$;
  while $\vec{A_0} \neq \vec{A'_0}$ **do**
    $\vec{A'_0} = \vec{A_0}$;
    $[\vec{P_i^0}, \sum_{j=1}^{N} G_{i,j}]$ =CSA $(\vec{P_i^0}, \vec{A_i})$;
    Adapt $\vec{A_i}$ based on EMA;
  end while
  Select the set, $\mathbf{S}$, of BSs to sleep;
  if $|S| \geq 1$ **then**
    Adapt $\vec{P_i^0}$ to enable the sleep mode;
    Recompute $\vec{P_i^{0S}}$ and $\sum_{j=1}^{N} G^S_{i,j}$;
  end if
  if $\sum_{j=1}^{N} G^S_{i,j} < \sum_{j=1}^{N} G_{i,j}$ **then**
    Return $\sum_{j=1}^{N} G^S_{i,j}$ and $\vec{P_i^{0S}}$;
  else
    Return $\sum_{j=1}^{N} G_{i,j}$ and $\vec{P_i^0}$;
  end if
end for

IV. Simulation Results

Simulations are set up as follows. A total of 36 BSs are located in a 6 by 6 grid. The distance between two adjacent BSs is 2000 meters. Mobile users are uniformly distributed in the area, and move according to the random walk mobility model. The mobile users' data rate is 384 $kbps$. The carrier frequency is 2110 MHz, and the bandwidth is 5 MHz. We adopt COST 231 Walfisch-Ikegami [12] as the propagation model with 9 dB Rayleigh fading and 5 dB Shadow fading. For the BS power model, we assume the antenna feeder loss is 3 dB, the transmitter gain is 10 dB, and the power amplifier efficiency is 50%. For simplicity, we assume the interferences among BSs are well managed by frequency planning, and BSs have complete knowledge of the users' distances from BSs. We simulate the mobile network energy consumption during 10 hours by setting $L = 100$ and the cell size update interval to 0.1 hour. In the simulations, we compare our algorithm with the strongest-signal first (SSF) method which always associates a user to the BS with the strongest received signal strength.

Fig. 2 shows the on-grid energy consumption at different renewable energy generation rates. In this simulation, there are 400 mobile users in the mobile network. As the renewable energy generation rate increases, the on-grid energy consumption of the mobile network reduces. When the renewable energy generation rate is larger, more electricity is generated from renewable energy. Therefore, more BSs can serve mobile users using electricity generated by renewable energy instead of consuming on-grid energy. When the renewable energy generation rate is larger than 0.6 kWh/h, the CSO algorithm achieves zero on-grid energy consumption by optimizing the cell size of each BS while the SSF algorithm still consumes a significant amount of on-grid energy. When the renewable energy generation rate is low, the CSO algorithm saves more than 200 kWh electricity than the SSF algorithm. As the generation rate increases, the gap between the energy consumption of the CSO and that of the SSF narrows because the CSO algorithm has already achieved zero energy consumption, and the energy consumption of the SSF reduces owing to increased availability of renewable energy.

Fig. 3 shows the renewable energy consumption at different

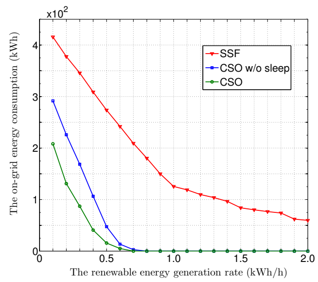

Fig. 2. The on-grid energy consumption with different generation rate.

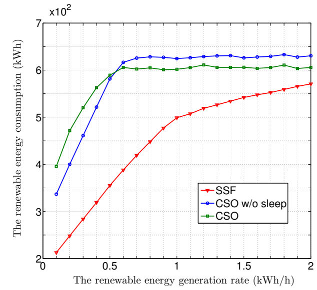

Fig. 3. The renewable energy consumption with different generation rate.

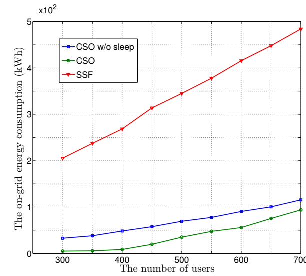

Fig. 4. The on-grid energy consumption with different number of users.

energy generation rates. When the energy generation rate is less than 0.7 kWh/h, the renewable energy consumptions of all the simulated algorithms are increasing as the renewable energy generation rate increases. This is because the larger the renewable energy generation rate, the more renewable energy can be used to serve mobile users. In addition, the CSO algorithm consumes more renewable energy than the SSF algorithm does because the CSO algorithm optimizes the cell sizes of BSs and maximizes the utilization of renewable energy in order to reduce the on-grid energy consumption. When the renewable energy generation rate is larger than 0.7 kWh/h, the renewable energy consumption of the CSO algorithm does not change much while that of SSF keeps increasing. This is because when the renewable energy generation rate is larger than 0.7 kWh/h, the on-grid energy consumption of the CSO algorithm is zero as shown in Fig. 2. That indicates all the users are served by renewable energy. Therefore, the renewable energy consumption of the CSO algorithm reflects the total energy consumption of the network, which is similar under different energy generation rates in the simulation.

Fig. 4 shows the total on-grid energy consumption versus the number of mobile users in the system. In this simulation, the renewable energy generation rate is 500 $Watts/hour$. We can see that the CSO algorithm can save up to 85% energy as compared to the SSF method because the CSO algorithm tries to minimize the number of BSs that consume on-grid energy as well as to put BSs in the sleep mode when possible. When the number of users increase, the energy consumption of CSO increases much slower than that of SSF because the CSO algorithm balances the energy demand among BSs, thus enabling more BSs to be powered with renewable energy. As shown in Fig. 4, the CSO algorithm saves more energy than CSO without sleep mode. This validates the effectiveness of the sleep mode on energy savings. As the number of users increases, the gap between CSO and CSO without the sleep mode narrows because when the number of users increases, less BSs can be switched to the sleep mode.

V. Conclusion

In this paper, we have proposed to reduce the energy consumption of cellular networks with hybrid energy supplies by optimizing the cell size. We decompose the cell size optimization problem into two subproblems: the multi-stage energy allocation problem and on-grid energy consumption minimization problem. We have proposed an energy allocation adaptation policy and the cell size adaptation algorithm to solve these subproblem and thus address the cell size optimization problem. The proposed solution has been demonstrated via extensive simulations to be able to save significant amount of on-grid energy.

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References

[1] C. Han, *et al.*, "Green radio: radio techniques to enable energy-efficient wireless networks," *Communications Magazine, IEEE*, vol. 49, no. 6, pp. 46 –54, Jun. 2011.

[2] "Community power using mobile to extend the grid." [Online]. Available: http://www.gsmworld.com/documents/gpfm_communitypower11whitepaperlores.pdf

[3] "3GPP R3-100162: Overview to lte energy saving solutions to cell switch off/on," in *3GPP RAN3 Meeting*, Valencia, Spain, Jan. 2010.

[4] S. Zhou, *et al.*, "Green mobile access network with dynamic base station energy saving," in *Proc of ACM MobiCom*, Beijing, China, Sep. 2009.

[5] E. Oh and B. Krishnamachari, "Energy savings through dynamic base station switching in cellular wireless access networks," in *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE*, Dec. 2010, pp. 1 –5.

[6] S. Bhaumik, G. Narlikar, S. Chattopadhyay, and S. Kanugovi, "Breathe to stay cool: adjusting cell sizes to reduce energy consumption," in *Proceedings of the first ACM SIGCOMM workshop on Green networking*, New Delhi, India, Sep. 2010.

[7] M. Etoh, T. Ohya, and Y. Nakayama, "Energy consumption issues on mobile network systems," in *Applications and the Internet, 2008. SAINT 2008. International Symposium on*, Turku, Finland, Aug. 2008.

[8] K. Samdanis, D. Kutscher, and M. Brunner, "Dynamic energy-aware network re-configuration for cellular urban infrastructures," in *GLOBECOM Workshops (GC Wkshps), 2010 IEEE*, Miami, FL, USA, Dec. 2010.

[9] J. Zhou, M. Li, L. Liu, X. She, and L. Chen, "Energy source aware target cell selection and coverage optimization for power saving in cellular networks," in *Proceedings of the 2010 IEEE/ACM Int'l Conference on Green Computing and Communications & Int'l Conference on Cyber, Physical and Social Computing*, Hangzhou, China, Dec. 2010.

[10] C. Peng, S.-B. Lee, S. Lu, H. Luo, and H. Li, "Traffic-driven power saving in operational 3g cellular networks," in *Proceedings of the 17th annual international conference on Mobile computing and networking*, Las Vegas, Nevada, USA, 2011, pp. 121–132.

[11] M. R. Garey and D. S. Johnson, *Computer and Intractability: A Guide to the Thoery of NP-Completeness*. New York, NY: W.H. Freeman and Company, 1979.

[12] "Evolution of land mobile radio (including personal) ccommunications: Cost 231." [Online]. Available: http://tools.ietf.org/html/draft-pantos-http-live-streaming-05