Research Article

Energy Efficient Operation of Cellular Network Using On/Off Base Stations

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To allow rapid growth of the number of base stations, reducing the energy consumption of the stations, as the main energy consumers in cellular networks, has become an important research topic. In this paper, we attempt to find an adaptive cell zooming method to reduce the energy consumption of base stations. The cell zooming mechanism was formulated as an optimization problem with consideration of varying traffic patterns and interference, as well as the service availability of the whole area. Simulations were then conducted to verify the performance of the proposed cell zooming method. The simulations considered varying traffic conditions, both timely and spatially, in traditional 19-cell configuration. The proposed scheme demonstrated reduction of energy consumption of up to 4.72 times for urban environments and 3.78 times for rural environments against traditional static cell operation.

1. Introduction

Currently, the telecommunications industry is responsible for about 2% of the global carbon dioxide (CO₂) emissions but could increase to 4% by 2020 given the projected growth in mobile multimedia communications. In January 2013, there were more than six million traditional base station (BS) sites worldwide, a number expected to exceed more than 11 millions by 2020. Furthermore, the global number of small cells, not counted in this figure, now exceeds the total number of traditional base stations. It is well known that the main source of energy consumption in cellular mobile network is the BSs, which are responsible for roughly two-thirds of the total CO₂ emissions of radio access networks [1]. Therefore, reducing the energy consumption of BSs, as the main energy consumers in cellular networks, has recently become an important research topic.

Over the past few years, the increasing energy demand has prompted considerable research on the subject of green communications. For example, the authors in [2, 3] proposed a mathematical model that calculates the total power consumption of a BS and turns off the BS’s power amplifiers according to traffic load. The authors in [4] focused on relays and MIMO systems for energy efficiency. They also discussed the importance of additional overhead for relays, considering both the additional time and energy used. For a comprehensive introduction to this field, the reader is directed to recent survey articles [5–10].

The typical cell planning mechanism currently in practice is to set the cell size according to the estimated traffic load measured at peak times. However, while the static cell planning is simple to operate, it may lead to poor performance when the traffic patterns do not conform to the estimation. So far, overprovision has widely been used to absorb the traffic fluctuations in several networks, such as 3G and long-term evolution (LTE). However, massive overprovisioning based on the traffic measured at peak times is inefficient in terms of operating costs. Cell breathing [11] is a well-known mechanism which allows overloaded cells to offload subscriber traffic to neighboring cells by changing the geographic size of their service area. This allows heavily loaded cells to decrease in size, while neighboring cells increase their service area to compensate. Thus, some traffic is handed off from the overloaded cell to neighboring cells, resulting in
load balancing. However, this mechanism marginally affects the energy savings of a base station. According to [12], when a BS is in working mode, the energy consumption of the processing circuit and cooling system make up approximately 60 percent of the total energy consumption. Therefore, merely controlling the transmission power of the radio equipment has a marginal effect on energy savings.

Recently, cell zooming mechanisms [13–15] have been brought to attention in the literature. In cell zooming scenarios, the challenge is to reduce the overall energy consumption while adapting the target of spectral efficiency to the actual load of the system and meeting the quality of service (QoS). In order to save energy, the cell zooming scheme reduces the number of active cells during periods when they are unnecessary due to low traffic. When some cells are switched off, the remaining cells usually zoom out to guarantee service availability of the whole area. Weng et al. [14] formulated the cell zooming mechanism as an optimization problem and also proposed an \((m,n)\)-off scheme for insufficient cell zooming.

In this work, we attempted to find a better cell zooming method according to the offered traffic load. As in [14], the cell zooming mechanism was formulated as an optimization problem with consideration of varying traffic patterns, interference, and the service availability of the whole area. Simulations were then conducted to verify the performance of the proposed cell zooming method. The results showed that the proposed scheme can reduce energy consumption in both urban and rural environments, while maintaining adequate throughput and providing full service coverage.

The rest of the paper is organized as follows. Section 2 describes the power consumption model of a base station and formulates the optimization problem of network power consumption. The proposed scheme is experimentally verified in Section 3. Finally, Section 4 presents the conclusions.

2. Problem Formulation

2.1. Power Consumption of a Base Station. The channel model considered herein is the COST 231-Walfisch-Ikegami model. This model distinguishes between line-of-sight (LOS) and non-line-of-sight (NLOS) cases. For LOS, the total path loss, \(\text{PL} \text{[dB]}\), is

\[
\text{PL}(d) = \alpha \log_{10} d + C_d
\]

for \(d \geq 0.02 \text{ km}\). Here, \(d\) is the distance between a user and a BS in units of kilometers, \(C_d\) is a coefficient of the other factors irrelevant of distance, and \(\alpha\) is the attenuation coefficient. For the LOS case, \(\alpha = 26\) and \(C_d\) is around 107.7, assuming the carrier frequency of 1.8 GHz. The radius of cell \(i\), \(\mathcal{R}_i\), can be determined from \(P_i(t) - \text{PL} (\mathcal{R}_i) = P_r\), where \(P_i(t)\) is the transmission power of the BS \(i\) [dBm] and \(P_r\) is the receiver sensitivity (e.g., -90 dBm). By (1), we can obtain

\[
\mathcal{R}_i = 10^{(P_i(t) - P_r - C_d)/\alpha}.
\]

A base station typically consists of several power-consuming components. Power consumption requirements for the air conditioner and backhaul link equipment are common for all sectors. However, some equipment is sector-specific, such as the digital signal processor, power amplifier, transceiver, signal generator, and AC-DC converter. The power consumption of each component of the base station is a constant value in Watts, except for the power amplifier, which depends on the coverage. The power consumption, \(P_{\text{amp}}\), of the power amplifier can be determined as follows [1]:

\[
P_{\text{amp}} = \frac{P_{\text{TX}}}{\eta},
\]

where \(P_{\text{TX}}\) is the input power of the antenna and \(\eta\) is the efficiency of the power amplifier. Once the power consumption of each of the different components of the base station is known, the power consumption, \(P_i\), of the entire base station can be calculated as follows [1, 16]:

\[
P_i = n_s \cdot \left( n_{\text{TX}} \cdot P_{\text{amp}} + P_{\text{trans}} + P_{\text{disp}} + P_{\text{gen}} + P_{\text{conv}} \right)
\]

\[
+ P_{\text{link}} + P_{\text{cool}}
\]

where \(n_s\) is the number of sectors in the cell, \(n_{\text{TX}}\) is the number of transmitting antennas per sector, and \(P_{\text{amp}}, P_{\text{trans}}, P_{\text{disp}}, P_{\text{gen}}, P_{\text{conv}}, P_{\text{link}},\) and \(P_{\text{cool}}\) are the power consumptions of the power amplifier, transceiver, digital signal processor, signal generator, AC-DC converter, backhaul link equipment, and air conditioner, respectively. The power consumption of the different components of a base station is summarized in Table 1.

### Table 1: Power Consumption of a Base Station Components

| Component          | Power Consumption |
|--------------------|-------------------|
| Digital Signal Processor | \(P_{\text{DSP}}\) |
| Power Amplifier     | \(P_{\text{amp}}\) |
| Transmitter         | \(P_{\text{trans}}\) |
| Signal Generator    | \(P_{\text{gen}}\) |
| AC-DC Converter     | \(P_{\text{conv}}\) |
| Link                | \(P_{\text{link}}\) |
| Air Conditioner     | \(P_{\text{cool}}\) |

2.2. Optimization of Network Power Consumption. The notations used in this paper are as follows:

- \(P_i(t)\): transmit power of the BS \(i\) [dBm],
- \(\lambda(t)\): traffic arrival rate per unit area [bits/second/m²],
- \(\mu_i(t)\): service rate of the cell \(i\) [bits/second],
- \(\rho_i(t)\): effective traffic intensity for cell \(i\),
- \(S_i\): the area served by cell \(i\), that is, \(S_i = \{(x, y) | (x-x_i)^2 + (y-y_i)^2 \leq R_i^2\}\) where \((x_i, y_i)\) is the location of BS \(i\),
- \(g_i(x, y)\): the transmission gain of the cell \(i\) at place \((x, y)\), the inverse value of the path loss, that is,

\[
g_i(x, y) = \left[ \alpha \log_{10} \left( \sqrt{(x-x_i)^2 + (y-y_i)^2} \right) + C_d \right]^{-1}.
\]

- \(P_N\): the power of noise.

As formulated by the authors in [14], given the traffic intensity and coverage constraints, we shall minimize the energy consumption of the whole network \(E_{\text{net}}\) for \(T\):

\[
\text{Minimize} \quad E_{\text{net}} = \sum_{i=1}^{n} \int_{t} P_i(t) \, dt
\]

subject to \(0 \leq P_i(t) \leq P_{\text{max}}\),

\[
\rho_i(t) \leq \rho_{\text{max}}(t),
\]

\[
\bigcup_{i=1}^{n} S_i = U,
\]

where \(P_{\text{max}}\) is the maximum power consumption for a BS, \(\rho_{\text{max}}\) is the maximum traffic intensity, \(S_i\) is the service area of cell \(i\), and \(U\) is the whole area.
### Table 1: Power consumption of a base station.

| Equipment                  | Mobile WiMAX | LTE  |
|----------------------------|--------------|------|
| Power Amplifier SISO       | $P_{amp}$    | 100 W| 300 W|
| $\eta$                    | 10%          | 6.67%|      |
| $P_{Tx}$                   | 10 W (40 dBm)| 20 W (43 dBm)|
| Power Amplifier MIMO       | $P_{amp}$    | 10.4 W| 10.4 W|
| $\eta$                    | 11.54%       | 11.54%|      |
| $P_{Tx}$                   | 1 W (30 dBm) | 1 W (30 dBm)|
| Transceiver                | $P_{trans}$ | 100 W| 100 W|
| Digital signal processing  | $P_{dsp}$    | 100 W| 100 W|
| Signal generator           | $P_{gen}$    | 384 W| 384 W|
| AC-DC converter            | $P_{conv}$   | 384 W| 384 W|
| Backhaul link              | $P_{link}$   | 80 W | 80 W |
| Air conditioning (cooling) | $P_{cool}$   | 690 W| 690 W|

### Table 2: Path loss models ($f_c = 1.8$ GHz, $h_B = 35$ m, and $h_U = 1.5$ m).

| Scenario     | Path loss [dB]                                      | Applicability range                                                                 |
|--------------|-----------------------------------------------------|------------------------------------------------------------------------------------|
| Urban areas  | $PL = 22 \log(d) + 28.0 + \log(f_c)$                | $10 \text{ m} \leq d < d_{BP}$, $d_{BP} = 4h_Bh_Uf_c/c$                          |
|              | $PL = 40 \log(d) + 7.8 - 18 \log(h_{BS}) - 18 \log(h_{UT}) + 2 \log(f_c)$ | $d_{BP} \leq d < 5000 \text{ m}$                                                 |
| Rural areas  | $PL_1 = 20 \log(40\pi df_c/3) + \min(0.03h_{UT}^{1.72}, 10) \log(d) - \min(0.044h_{BS}^{1.72}, 14.77) + 0.002d \log(h)$ | $10 \text{ m} \leq d < d_{BP}$, $d_{BP} = 2\pi h_Bh_Uf_c/c$                       |
|              | $PL_2 = PL_1(d_{BP}) + 40 \log(d/d_{BP})$          | $d_{BP} \leq d < 10,000 \text{ m}$                                               |

where

$$\rho_i(t) = \int \int S_i \frac{\lambda(t)}{\mu_i(t) P_i(t)} \sin(x, y) dx dy,$$

$$\sin(x, y) = \frac{g_i(x, y) P_i(t)}{\sum_j g_j(x, y) P_j(t) + P_N}.$$  

Our goal is to find $P = [P_1(t), P_2(t), \ldots, P_n(t)]$ minimizing $E_{net}$. Substituting (8) into (7) and collecting the $P_j(t)$ and $P_N$ terms, we get

$$\rho_i(t) = \frac{\lambda(t)}{\mu_i(t) P_i(t)} \left[ \sum_{j=1, j \neq i}^n \int \int S_i \frac{g_j(x, y)}{g_i(x, y)} dx dy \right] P_j(t)$$

$$+ \left[ \int \int S_i \frac{P_N}{g_i(x, y)} dx dy \right].$$

Using (9), the second constraint of (6) can be rewritten as

$$\rho_i(t) = \frac{\lambda(t)}{\mu_i(t) P_i(t)} \left( \sum_{j=1, j \neq i}^n A_{ij} P_j(t) + B_i \right) \leq \rho_{max}(t),$$

where

$$A_{ij} = \int \int \frac{g_j(x, y)}{S_i g_i(x, y)} dx dy,$$  

$$B_i = \int \int \frac{P_N}{S_i g_i(x, y)} dx dy.$$  

Note that $S_i$ is $\pi R_i^2$, so that it is the function of $P_i(t)$. Simply, inequality (10) can be rewritten as

$$A_i P^T + B_i \leq 0,$$

where

$$A_i = \left[ A_{i1}, A_{i2}, \ldots, \frac{\mu_i(t)}{\lambda(t)} \rho_{max}(t), \ldots, A_{in} \right].$$

An exhaustive search algorithm was applied to solve the optimization problem of (6)–(8). Optimization of the function $E_{net}$ was attempted over the time domain, $t$, and location domain, $(x, y)$. The exhaustive search algorithm computed the value of $E_{net}$ for all of $t$ and $(x, y)$, determining the optimum values.

### 3. Simulations

#### 3.1. Simulation Conditions

Simulations were conducted to verify the performance of the proposed cell zooming scheme. As shown in Figure 1, the system consisted of a network of 19 hexagonal cells, with six cells surrounding the center cell in the first tier and 12 cells surrounding the center cell in the second tier. The BSs were located at a constant distance of 1.2 km for urban topologies and 6.0 km for rural topologies. The carrier frequency, $f_c$, of each BS was set to 1.8 GHz, and the bandwidth was set to 20 MHz. As path loss models, (17) was considered. The models employed are summarized in Table 2. The background noise level was set to $-93$ dBm.
Table 3: Observed cell zooming scenarios under $0 \leq \lambda < 1.69$ Mbps/km$^2$ ($H = 25.2$ dBm for urban areas $H = 39.2$ dBm for rural areas).

| $P^1$ | $P^2$ | $P^3$ | $P^4$ | $P^5$ | $P^6$ | $P^7$ | $P^8$ | $P^9$ | $P^{10}$ | $P^{11}$ | $P^{12}$ | $P^{13}$ | $P^{14}$ | $P^{15}$ | $P^{16}$ | $P^{17}$ | $P^{18}$ | $P^{19}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $0$   | $0$   | $0$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $0$   | $0$   | $H$ |
| $P^{12}$ | $0$   | $0$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $0$   | $H$ |
| $P^{13}$ | $0$   | $H$   | $0$   | $0$   | $0$   | $0$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $H$   | $0$   | $0$   | $H$   | $0$   | $0$   | $H$ |
| $P^{14}$ | $0$   | $0$   | $H$   | $0$   | $0$   | $0$   | $0$   | $0$   | $0$   | $0$   | $0$   | $0$   | $H$   | $0$   | $0$   | $H$   | $0$   | $0$   | $H$ |

Table 4: Observed cell zooming scenarios with time-varying and geographically uniform traffic arrival.

| Traffic arrival (Mbps/km$^2$) | The number of BSs | Energy Consumption (KW) | Energy Consumption gain |
|-------------------------------|-------------------|--------------------------|-------------------------|
| Off                           | Zoom-in          | Zoom-out                 |
| Urban areas                   |                  |                          |
| $0$–$1.69$                    | $15$             | $0$                      | $4$                     | $11.35$ | $4.72$ |
| $1.69$–$8.38$                 | $14$             | $1$                      | $4$                     | $14.17$ | $3.78$ |
| $8.38$–$8.63$                 | $10$             | $6$                      | $3$                     | $25.45$ | $2.11$ |
| $8.63$–$49.36$                | $0$              | $19$                     | $0$                     | $53.62$ | $1$    |
| Rural areas                   |                  |                          |
| $0$–$0.037$                   | $15$             | $0$                      | $4$                     | $12.98$ | $4.14$ |
| $0.037$–$0.30$                | $14$             | $1$                      | $4$                     | $15.81$ | $3.40$ |
| $0.30$–$1.26$                 | $0$              | $19$                     | $0$                     | $53.76$ | $1$    |

Figure 1: Network topology for single-sector (19 cell) configuration with frequency reuse factor of 1.

and the receiver sensitivity was set to $-95$ dBm. The power consumption of each BS was calculated from (4) with the parameters specified in Table 1 (LTE case). The maximum transmission power was set to $25.2$ dBm for urban areas and $39.5$ dBm for rural areas. In order to reduce the computational complexity, only three power levels were examined: high power ($25.2$ dBm in urban areas and $39.5$ dBm in rural areas), low power ($7.7$ dBm in urban areas and $22.0$ dBm in rural areas), and switched-off power. Under these simulation settings, the range of a cell with the minimum power level was $700$ m in urban areas and $3.5$ km in rural areas. Therefore, even with the minimum power level, the networks had no coverage holes. Each BS could extend its coverage to $1.9$ km in urban areas and $9.6$ km in rural areas, at most.

3.2. Simulation Results. It was assumed that the service rate of BS $i$ is fixed to $\mu_i = 100$ Mbps. To evaluate the proposed algorithm with temporal load fluctuations, the traffic arrival rate, $\lambda$, was increased from $0$ to $49.36$ Mbps/km$^2$ (urban) and from $0$ to $1.26$ Mbps/km$^2$ (rural), and the possible cell zooming scenarios were observed. Figures 2(a)–2(c) show some cell zooming scenarios which minimized the network energy consumption, satisfying the traffic arrival rate without any coverage holes. For example, four possible cell zooming scenarios were observed under $0 \leq \lambda < 1.69$ Mbps/km$^2$, which are illustrated in Table 3.

Among the four possible scenarios shown in Table 3, the second cell zooming scenario, $P^{(2)}$, is illustrated in Figure 2(a). As shown in Figure 2(a), four active BSs (i.e., BS$_7$, BS$_8$, BS$_{11}$, and BS$_{17}$) can meet all of the required traffic demands, serving the whole network area without any coverage holes. Thus, the remaining 15 BSs can be allowed to sleep to reduce the energy consumption. In this scenario, the total power consumption in the network is $11.35$ KW, which is just $21.2\%$ of the traditional cell dimensioning scheme based on the estimated traffic load measured at peak times. The detailed energy consumption gain for each varying traffic load is summarized in Table 4. When the offered traffic load
in the urban area increased to 8.38 Mbps/km², the central cell turned on and zoomed in, while four neighboring cells (e.g., cell 9, 12, 15, and 18) zoomed out to meet the increased traffic demands, as shown in Figure 2(b). In this scenario, the total power consumption is 14.17 KW, which is still only 26.5% of the traditional cell dimensioning scheme. The proposed scheme is clearly better than a static cell dimensioning scheme, when the traffic load is at low or medium levels. When the traffic load rose above 8.63 Mbps/km² (urban) or 0.30 Mbps/km² (rural), the two schemes produced the same results, as shown in Figure 2(c) (i.e., the same power consumption).

To evaluate the performance of the proposed algorithm in cellular networks with spatial load fluctuations, selective cells with relatively higher load than other areas were generated. The simulation setting was as follows. First, cell 1 of the urban area was set at $\lambda = 43.30$ Mbps/km², with all others set to $\lambda = 8.30$ Mbps/km². In this case, the central cell needs to zoom in to have high capacity, and we get the same results as the earlier cell zooming scenarios with $1.69 \leq \lambda < 8.38$ Mbps/km². In this case, 1/3.78 or 1/3.40 of the energy consumption of the static cell dimensioning scheme was observed. The detailed energy consumption gain for each scenario is summarized in Table 5.

Second, urban cells 1, 2, and 3 were set to $\lambda = 43.30$ Mbps/km², while all others were set to $\lambda = 8.30$ Mbps/km². In this case, the highly congested cells (i.e., cells 1, 2, and 3) zoomed in to have high capacity, while cells 12, 15, and 18 zoomed out to serve the low traffic demands, as shown in Figure 2(d). It is notable that cells 8, 9, and 10 also zoomed in, although the load presented in those areas was relatively low. This is because there was no way to avoid possible coverage holes and interference without zooming in of cells 8, 9, and 10. For example, while zooming BS₈ out and switching BS₈ and BS₁₀ off may obtain better results for energy saving, it would not meet the traffic load requirement due to higher interference level among BS₈ and neighboring BS₁, BS₂, and BS₉. In this case, 1/2.11 (urban) or 1/2.01 (rural) of the energy consumption of the static cell dimensioning scheme was observed.
4. Conclusions

In this work, we attempted to find an adaptive cell zooming method according to offered traffic load. As in [14], cell zooming mechanism was formulated as an optimization problem, considering varying traffic patterns and interference, as well as the service availability of the whole area. Simulations were then conducted to verify the performance of the proposed cell zooming method. The simulations considered varying traffic conditions, both timely and spatially, in a traditional 19-cell configuration. The results showed that the proposed scheme achieved reduction of the energy consumption by up to 4.72 times for the urban environment and 3.78 times for the rural environment compared to traditional static cell operation, while maintaining adequate throughput and full service coverage. In this work, though only three power levels were used to reduce the computational complexity, we plan to apply the particle swarm optimization (PSO) algorithm to find an optimization solution for (6).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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References

[1] M. Deruyck, W. Vereecken, E. Tanghe et al., “Power consumption in wireless access networks,” in Proceedings of the European Wireless Conference (EW’10), pp. 924–931, April 2010.
[2] A. Chatzipapas, S. Alouf, and V. Mancuso, “On the minimization of power consumption in base stations using on/off power amplifiers,” in Proceedings of the IEEE Online Conference on Green Communications, pp. 18–23, September 2011.
[3] E. Oh, B. Krishnamachari, X. Liu, and Z. Niu, “Toward dynamic energy-efficient operation of cellular network infrastructure,” IEEE Communications Magazine, vol. 49, no. 6, pp. 56–61, 2011.
[4] G. Y. Li, Z. Xu, C. Xiong et al., “Energy-efficient wireless communications: tutorial, survey, and open issues,” IEEE Wireless Communications, vol. 18, no. 6, pp. 28–35, 2011.
[5] M. H. Alsharif, R. Nordin, and M. Ismail, “Survey of green radio communications networks: techniques and recent advances,” Journal of Computer Networks and Communications, vol. 2013, Article ID 453893, 13 pages, 2013.
[6] C. Han, T. Harrold, S. Armour et al., “Green radio: radio techniques to enable energy-efficient wireless networks,” IEEE Communications Magazine, vol. 49, no. 6, pp. 46–54, 2011.
[7] R. Bolla, R. Bruschi, F. Davoli, and F. Cucchietti, “Energy efficiency in the future internet: a survey of existing approaches and trends in energy-aware fixed network infrastructures,” IEEE Communications Surveys & Tutorials, vol. 13, no. 2, pp. 223–244, 2011.
[8] A. P. Bianzino, C. Chaudet, D. Rossi, and J.-L. Rougier, “A survey of green networking research,” IEEE Communications Surveys & Tutorials, vol. 14, no. 1, pp. 3–20, 2012.
[9] Z. Hasan, H. Boostanimehr, and V. K. Bhargava, “Green cellular networks: a survey, some research issues and challenges,” IEEE Communications Surveys & Tutorials, vol. 13, no. 4, pp. 524–540, 2011.
[10] K. Davaslioglu and E. Ayanoglu, “Quantifying potential energy efficiency gain in green cellular wireless networks,” IEEE Communications Surveys & Tutorials, vol. 16, no. 4, pp. 2065–2091, 2014.
[11] Y. Bejerano and S.-J. Han, “Cell breathing techniques for load balancing in wireless LANs,” IEEE Transactions on Mobile Computing, vol. 8, no. 6, pp. 735–749, 2009.
[12] J. Lorincz, T. Garma, and G. Petrovic, “Measurements and modelling of base station power consumption under real traffic loads,” Sensors, vol. 12, no. 4, pp. 4281–4310, 2012.
[13] M. A. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, “Optimal energy savings in cellular access networks,” in Proceedings of the IEEE International Conference on Communications Workshops (ICC ’09), pp. 1–5, June 2009.
[14] X. Weng, D. Cao, and Z. Niu, “Energy-efficient cellular network planning under insufficient cell zooming,” in Proceedings of the
IEEE 73rd Vehicular Technology Conference (VTC ’11), pp. 1–5, IEEE, Yokohama, Japan, May 2011.

[15] Z. Niu, Y. Wu, J. Gong, and Z. Yang, “Cell zooming for cost-efficient green cellular networks,” IEEE Communications Magazine, vol. 48, no. 11, pp. 74–79, 2010.

[16] M. Deruyck, W. Vereecken, E. Tanghe et al., “Comparison of power consumption of mobile WiMAX, HSPA and LTE access networks,” in Proceedings of the 9th Conference of Telecommunication, Media and Internet (CTTE ’10), pp. 1–7, June 2010.

[17] 3GPP, “Further advancements for E-UTRA physical layer aspects (release 9),” Tech. Rep. TR 36.814 V9.0.0, 3GPP, 2010.