Assessment of Practical Energy Savings in Cellular Networks

Diala Naboulsi, Marco Fiore, Carla-Fabianna Chiasserini

Assessment of Practical Energy Savings in Cellular Networks

Diala Naboulsi, Marco Fiore , Carla-Fabiana Chiasserini

TECHNICAL REPORT
N°
March 2014
Project-Teams

ISSN 0249-0803 ISRN INRIA/RT--FR+ENG

Assessment of Practical Energy Savings in Cellular Networks

Diala Naboulsi[*], Marco Fiore[†] [*], Carla-Fabiana Chiasserini[‡]

Project-Teams

Technical Report n° — March 2014 — 6 pages

Abstract: In this work, we tackle the problem of on-grid energy saving in cellular networks based on switch-on/off techniques for base stations and the usage of renewable energy. We aim to evaluate how much power can be saved in the network and dimension the renewable energy system according to the consumptions in real-world networks.

Key-words: cellular networks, energy consumptions, reduce consumptions

Funding for Diala Naboulsi was provided by a grant from the Rhône-Alpes Region.

[*] Université de Lyon, INRIA, INSA-Lyon, F-69621, Villeurbanne, France, diala.naboulsi@insa-lyon.fr
[†] CNR – IEIIT, Corso Duca degli Abruzzi 24, 10129 Torino, Italy, marco.fiore@ieiit.cnr.it
[‡] Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy, chiasserini@polito.it

RESEARCH CENTRE
GRENOBLE – RHÔNE-ALPES

Inovallée
655 avenue de l’Europe Montbonnot
38334 Saint Ismier Cedex

Evaluation des Economies d’Energie Pratiques dans les Réseaux Cellulaires

Résumé : Dans ce travail, nous abordons le problème d’économisation des consommations d’énergie dans les réseaux cellulaires sur le réseau électrique en appliquant des techniques d’endormissement pour les stations de bases et en utilisant de l’énergie renouvelable. On vise à évaluer combien de puissance on peut économiser dans le réseau et à dimensionner le système d’énergie renouvelable en fonction des consommations dans les réseaux réels.

Mots-clés : réseaux cellulaires, consommation d’énergie, réduction de consommation

1 Introduction

The last few years have witnessed a tremendous growth in cellular traffic. Currently, more than 4 million base stations (BSs) are deployed to fulfill users demands in the world, consuming very large amounts of energy. Alongside environmental concerns, the growing fuel prices are amplifying the expenses on the operator side, making the reduction of energy consumption an inevitable step. BSs are responsible for more than 50% of the total power of a wireless cellular network, they are switched on during all times and consume a lot of energy even when they are underutilized.

Our work focuses on reducing the energy consumption in cellular networks over the electrical grid by using BSs powered by renewable energy, and applying at the same time a switch on/off strategy for BSs. Such a solution is expected to be very convenient especially in regions where significant amounts of renewable energy can be produced. This approach is starting to be explored, as in [1]. However, the study in [1] only considers the coverage of users appearing in the network at a specific snapshot and does not propose techniques that allow to detect them. In our work, instead, we focus on providing geographical coverage of the network. Moreover, the evaluations in [1] are conducted over a simplistic scenario, whereas in our work, we use real-world data including a real deployment of BSs and real users consumptions data.

Clearly, our problem is constrained not just by the full coverage but also by the limitations on the radio resources. Accounting for both kinds of constraints simulataneously results in an NP-hard optimization problem, thus, we split it into two sub-problems, one for each kind of constraints. We conduct our work over three steps: i) we first evaluate the minimum required energy to provide a geographical coverage over the studied region; ii) we check the time intervals of a day when such a solution allows us to fulfill users demands; iii) we dimension the green energy system according to the daily energy needs of the BSs. In the following section, we detail steps i) and ii).

2 Model

2.1 Geographical coverage subproblem

We define $\mathcal{A} = \{1, ..., m\}$ as the set of areas that should be covered in the studied region, and $\mathcal{B} = \{1, ..., n\}$ as the set of deployed BSs. We denote the power consumption of a BS j by P^c_j. If BS j is off, P^c_j is equal to 0; while, if the BS is on, P^c_j accounts for the constant consumption due to the electronics plus a term related to the transmission power. P^c_{ij} is a constant representing the minimum required consumed power by BS j that permits it to provide coverage to a user at the farthest edge of area i. To derive the power consumption thresholds P^c_{ij}, we first evaluate the required transmission power P^t_{ij} of the BS j to serve area i, by applying the Walfish-Ikegami empirical propagation model [2], and then computing P^c_{ij} by applying the power consumption model proposed in [3]. Both models are briefly presented in the next section. We use x_{ij} to represent the association between area i and BS j, such that x_{ij} is equal to 1 if area i is covered by BS j, and 0 otherwise. We calculate the minimum consumed power needed to provide a full coverage of the network by solving the following optimization problem. Our decision variables are the continuous variables, $P^c_j\ \forall j \in \mathcal{B}$, and the binary variables $x_{ij}\ \forall i \in \mathcal{A}, \forall j \in \mathcal{B}$.

$$\min \sum_{j \in \mathcal{B}} P^c_j$$

$$P^c_j \geq P^c_{ij} x_{ij} \quad \forall i \in \mathcal{A}, \forall j \in \mathcal{B} \tag{1}$$

$$\sum_{j \in \mathcal{B}} x_{ij} \geq 1 \quad \forall i \in \mathcal{A} \tag{2}$$

$$P^c_j \leq P^c_{max} \quad \forall j \in \mathcal{B} \tag{3}$$

Constraint (1) allows an area $i \in \mathcal{A}$ to be covered by a BS $j \in \mathcal{B}$, if the power consumed by the BS is higher than the constant P^c_{ij}. Constraint (2) imposes that each area should be covered by at least one BS. Constraint (3) sets an upper bound P^c_{max} on the consumed power, such that the maximum possible transmit power is not exceeded.

2.2 Resource allocation subproblem

Once we obtain the BSs power configuration from the previous step, we check the time intervals for which the solution allows us to handle the expected user demand. We do so by solving the following subproblem, in which we aim to optimize the allocation of resources. The set of y_{ij} is the set of integer decision variables each representing the number of radio resources that shall be allocated by BS j to serve users in area i. y_{ij} are time-dependent, and we consider them over a meaningful time interval. For simplicity we drop the time notation in the model.

$$\min \sum_{j \in \mathcal{B}} \sum_{i \in \mathcal{A}_j} y_{ij}$$

$$\sum_{i \in \mathcal{A}_j} y_{ij} \leq R_j \quad \forall j \in \mathcal{B} \tag{4}$$

$$\sum_{j \in \mathcal{B}_i} y_{ij} W Log_2(1 + SNR_{ij}) \geq f_i \quad \forall i \in \mathcal{A} \tag{5}$$

Constraint (4) insures that the limit on the number of radio resources for each BS, R_j, is not exceeded. $\mathcal{A}_j$ is the set of areas covered by BS j. Equation (5) imposes the constraint on the radio resources allocated for each area, according to Shannon's theorem, such that the demand in the area can be managed. $\mathcal{B}_i$ is the set of BSs that can cover area i. W is the bandwidth for one radio resource, for simplicity it is considered constant. f_i represents the total throughput demands in area i. SNR_{ij} is the Signal-to-noise ratio perceived by a user in area i with respect to the signal received from BS j. The left part of constraint (5) provides the sum of theoretical throughputs that can be attained, based on Shannon's formula in area i. Constraint (5) can be modified depending on the technology. As introduced, it holds for the case of 4G networks, where we can consider that Shannon's capacity can be reached.

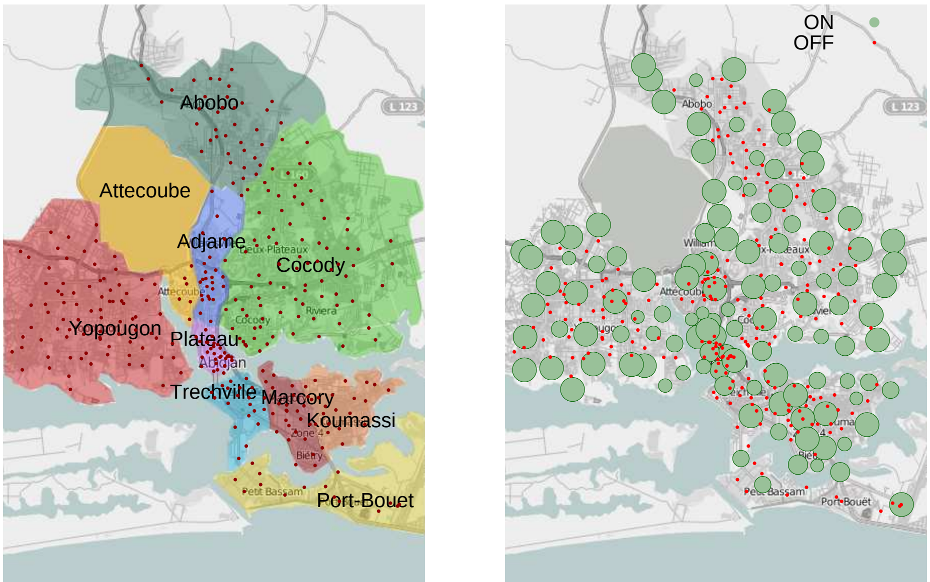
Our subproblems still suffer from complexity, due to the high number of integer and binary variables, especially in large-scale evaluations. However, as interactions occur on a local level, we approximate the solution by solving the subproblems on clusters of areas.

3 Scenario and results

3.1 Scenario

We derive our results over the 2G network of Orange in Abidjan. Abidjan is divided into ten neighborhoods, known as communes. Fig. 1(a) shows the position of BSs, together with the communes. These communes have highly different building characteristics that affect the signal propagation: As an example very tall buildings dominate over the commune of Plateau, while the commune of Abobo is mostly formed by buildings of one or two floors. This led us to parameterize, in our evaluations, each commune separately.

For the signal propagation, we adopt the Walfish-Ikegami model [2], which provides the average path loss, taking into account the properties of the vertical plane between the transmitter and the receiver. We assume that a region i can be associated to a transmitting BS j, if the user at the farthest edge of the area receives a minimum power of -100 dBm. The parameters of the model are chosen adequately for each commune according to the average characteristics of the environment. Concerning the power consumption, we apply the model for macro base stations from [3]. Moreover, the values of P^c_j belong



(a) (b)

Figure 1: (a): Geographical distribution of BSs over the communes of Abidjan. (b): Geographical distribution of switched-on/off BSs.

to a set of values $\{0, P_1, ..., P_6 = P^c_{max}\}$ [4]. We consider a maximum possible consumed power $P_6 = P^c_{max} = 947W$, corresponding to a maximum allowed transmission power of 20 W. Finally, we obtain our results by dividing each commune into small areas of 100 m by 100 m forming the set $\mathcal{A}$.

3.2 Results

In this poster, we provide early results on the geographical coverage subproblem, in subsection 2.1. We present in Fig. 1(b) the results derived over the scenario described above. In this figure, we represent the BSs that can be switched-off with red points, while the switched-on BSs are drawn with green circles whose radius is proportional to their consumed power. We can see that different communes require different densities of switched-on BSs, resulting from the characteristics of the signal propagation and the initial density of BSs. We compare the total consumed power when the switch-on/off strategy is applied, to the total consumed power when all BSs are on, obtained by solving the same optimization problem, as before, with the additional constraint: $P^c_j \geq P_1, \forall j \in \mathcal{B}$. This constraint imposes that each BS is switched on. We note that we respectively refer to the strategies as "on-off" and "all-on". Fig. 2 shows the normalized gain G in the power consumption for each commune, together with the absolute power value for both strategies. The gain we obtain in each commune varies from 39% to 72%.

4 Conclusions

Our results show how much energy can be saved in a real-world cellular network with a switch-on/off technique for BSs under geographical coverage constraints. Energy savings of more than 70% can be reached, when very low traffic demands exist. Also, we observed that this value changes with respect to the BSs density and the signal propagation environment characteristics. We are currently extending our

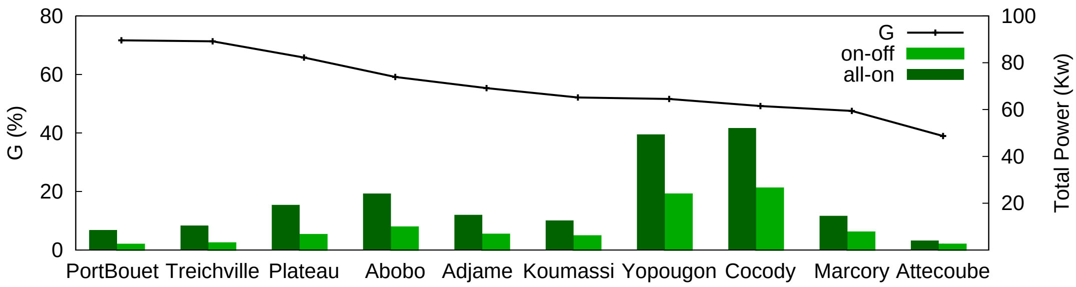


Figure 2: The obtained gain (G) when switch on/off strategy is applied, with respect to the all-on strategy, and the total power consumption per commune for each case.

results by focusing on the resource allocation optimization subproblem and the renewable energy system dimensioning. In the future, we would also like to consider other scenarios.

References

[1] T. Han, and N. Ansari. “On Optimizing Green Energy Utilization for Cellular Networks with Hybrid Energy Supplies." IEEE Transactions on Wireless Communications, Vol. 12, No. 8, August 2013.

[2] Cost 231 Final Report, http://www.lx.it.pt/cost231/

[3] O. Arnold, F. Richter, G. Fettweis, O. Blume. “Power consumption modeling of different BS types in heterogeneous cellular networks." IEEE Future Network and Mobile Summit, June 2010.

[4] “Digital Cellular Telecommunication System (phase 2)"; Radio Transmission and Reception, ETSI, 3GPP TS 05.05, Ver 8.20.0, Release 1999.

Contents

1 Introduction **3**

2 Model **3**
2.1 Geographical coverage subproblem 3
2.2 Resource allocation subproblem 4

3 Scenario and results **4**
3.1 Scenario 4
3.2 Results 5

4 Conclusions **5**

**RESEARCH CENTRE
GRENOBLE – RHÔNE-ALPES**

Inovallée
655 avenue de l'Europe Montbonnot
38334 Saint Ismier Cedex

Publisher
Inria
Domaine de Voluceau - Rocquencourt
BP 105 - 78153 Le Chesnay Cedex
inria.fr

ISSN 0249-0803