Base Station On/Off Strategies for Wireless Networks Powered with Energy Harvesting Sources

Javier Rubio, Antonio Pascual-Iserte, and Josep Vidal
Dept. Signal Theory and Communications - Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
Emails:{javier.rubio.lopez, antonio.pascual, josep.vidal}@upc.edu

Abstract—**In this paper, we present a procedure for switching on and off base stations (BSs) that are powered with solar panels and have finite batteries. In the scenario under consideration it is considered that the BSs are placed at the same site with fully overlapped coverage areas and using different frequencies. We propose a decision strategy where we assume perfect knowledge of the traffic profile and a second approach where a robust Bayesian strategy is considered in order to account for possible error modeling in the traffic profile information.**

I. Introduction

Switching off base stations (BSs) contributes to decrease interference and, in addition, to reduce energy consumption. If the BS is equipped with batteries and an energy harvesting source (e.g., solar panels) then, the energy savings are translated into a more efficient energetic dimensioning (i.e., reduction of the sizes of the batteries and solar cells). Usually, the energy dimensioning is devised assuming that BSs are always active, but this is not always necessary if a criterion for on/off switching is designed properly. Note, however, that switching off a particular BS affects the network topology. Traffic that was originally served by the BS to be switched off has to be either transferred to nearby BSs or dropped.

One important characteristic of the traffic profile, both for voice and data services, is that the rate of traffic generation is not constant throughout the day. This characteristic could be exploited to define a strategy based on the selection of the BSs to be switched off when the traffic load is low. The traffic served by the switched off BSs can be transferred to other BSs that remain active thanks to overlapping of their coverage areas. In case that these coverage areas did not overlap exactly, dynamic cell expansion solutions could be adopted, but this is out of the scope of this paper.

In this paper, we consider a scenario where the BSs are solely powered by an energy harvesting source consisting in solar cells and batteries. These scenarios are usually encountered in rural areas, where the access to the electricity network is not possible or too expensive. In order to have low-cost viable solutions for the deployment of the access network, these solar cells and batteries should be as small as possible to reduce the cost of the equipment, which would have a direct impact on the CAPEX. In concrete, we address the case where the set of BSs are located at the same site with overlapped coverage areas. The BSs share the same energy source, i.e., the same battery and solar cell.

In the literature, there are some works dealing with the problem of switching on/off BSs. For example, in [1], a strategy is developed to decrease the energy consumption by switching off BSs when the activity is low under the constraint of keeping the coverage unaltered. The strategies are developed within the framework of stochastic geometry and, therefore, are well suited for the case of having many BSs at random positions. In [2], a strategy is presented taking into account that the traffic profile is time varying and under the objective of minimizing the energy consumption of the network assuming that there are many BSs uniformly distributed within the area of interest. [3] defines different possible states for the BSs in order to develop a strategy based on that the switching between the states depends on the instantaneous traffic load. This is achieved by expanding the coverage areas of the BSs that remain active. In [4], [5], the authors propose a sleeping algorithm for the BSs assuming that the distances between the user equipments and their associated BSs are known. A more complex problem is analyzed in [6], where a scenario with several BSs from different operators are considered. This paper introduces the cost that has to be paid by an operator when its subscribers have to be served by another operator due to the fact that some BSs have been switched off.

It is important to remark that in the previous works, the decision to switch off BSs was based on the traffic demand. However, since in our work the BSs are powered with finite batteries, the decision to switch off BSs must be carried out under the criterion of minimizing the energy consumption.

II. System Description

Let us consider a system with two BSs placed at the same location, i.e., sharing the same cell-site[1]. Let us also consider that their coverage areas are fully overlapped and a different frequency is configured in each BS so that they do not interfere with each other. This setup is usually required in scenarios where there is a peak traffic demand in a specific location and there are not enough radio resources available to be allocated in a single BS to cope with such users' demands. As commented in the introduction, we assume that the BSs are provided with a finite battery and with solar panels that allow them to recharge their batteries.

As it is widely known, the evolution of the traffic throughout the day is not stationary, i.e., the traffic is high at particular peak hours and considerably low at nights. As a consequence, it may be reasonable to switch off one of the BSs if the required power of having the two BSs on is higher, and only one BS is enough to provide the demanded QoS.

Let us mention that in order to determine whether a BS should be switched off or not, we need to measure and compare the required power that is needed for both configurations, i.e., a single BS and two BSs, to serve the users with a specific traffic demand as the configuration of single BS is

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[1]The procedure described in this paper is valid not only for two BSs at the same location, but for any number of BSs placed at the same site. We consider only two BSs for the sake of clarity in the notation.

TABLE I
THRESHOLD COMPUTATION FOR SWITCHING ON/OFF BSS

1: Compute the mean power required by the two configurations (one and two BSs) for all possible traffic rates (λ_0) $P_{1\text{BS}}(\lambda_0)$ and $P_{2\text{BS}}(\lambda_0)$.
2: Let λ be the maximum traffic that can be supported with 1 BS fulfilling the maximum blocking probability constraint. If $P_{1\text{BS}}(\lambda) < P_{2\text{BS}}(\lambda)$, then $\lambda_{TH} = \lambda$. Otherwise, λ_{TH} is the value of λ for which $P_{1\text{BS}}(\lambda) = P_{2\text{BS}}(\lambda)$.
3: Switch off one of the two BSs in all time instants m where $\lambda_{TH} \geq \lambda_0$.

only admissible if with one BS we can provide the service required by the users with a blocking probability lower than a pre-established threshold related with the QoS.

We will assume throughout the paper that we know the daily traffic profile or that we have some estimation of it and, due to space limitations, we will consider that there is only one type of traffic (the extension to mixed types of traffic is relatively simple). The estimation of the required power can be obtained through measurement campaigns or with Monte Carlo simulations if the specifications of the deployment are known (e.g., type of BSs). The computation of such powers is out of the scope of this paper (see [7]). In any case, we observe from the simulations that for a traffic load greater than a given threshold, we need to have both BS on, and just one BS on otherwise. Once we know the average amount of power needed to run the network, we can perform the dimensioning of the energy units (number of required solar panels and batteries, see [8]).

III. Techniques for Switching Off

In the final version of the paper we will present two different techniques: one based on a deterministic threshold where we assumed that the traffic profile is complete known; and another technique based on a robust design in which traffic uncertainties are incorporated in the threshold design. Due to space limitations of this abstract, we only present a summary of the deterministic approach.

As we said we assume that the expected traffic demands are known. Accordingly, let $\lambda_0[m]$ denote the traffic load (with units of calls$/s$) corresponding to the m-th time instant within the day. In Table I we present the procedures to calculate the threshold λ_{TH} to be applied to $\lambda_0[m]$ for switching on/off a BS.

IV. Simulation Results

The setup under consideration is a real scenario which is being sized and planned at this moment in the European TUCAN3G project (www.ict-tucan3g.eu), taking data from some rural real locations in Perú. The considered batteries have the following specifications: 12 V, 100 Ah, and a capacity $C = 1200$ Ah $\times$ V. The solar panels have a nominal power $P_{\text{nom}} = 85$ W (for details of the energy dimensioning, see [7]). We have three types of BSs with different maximum radiated powers given by BS$_a$ = 16 dBm, BS$_b$ = 13 dBm, and BS$_c$ = 24 dBm. The traffic profiles and the traffic estimation forecast for the incoming years considered in the simulations can be found in [7]. The power consumption model of the BSs considered in this paper is based on [9].

Fig. 1 depicts the traffic profile for a specific location and the corresponding threshold for switching on/off one of the BSs. The type of BS considered is BS$_a$. As we can see, the two BSs are needed only a few hours during the day (30% of the total time). For the rest of the hours, only one BS is enough. Thus, potential energy savings can be obtained.

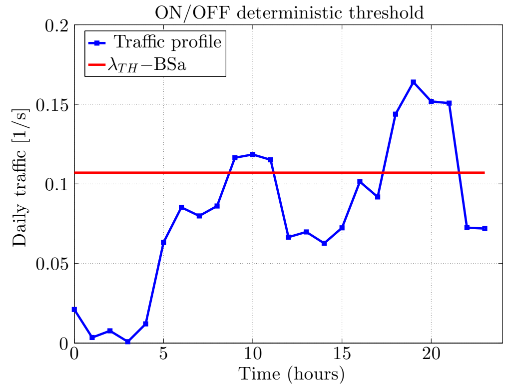
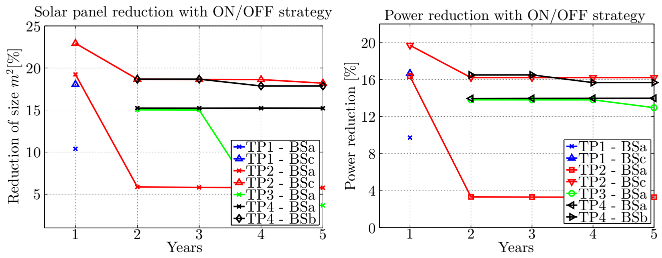


Fig. 1. On/off threshold example for a given traffic profile.



(a) Solar panel size reduction. (b) Power consumption reduction.

Fig. 2. Cost and energy savings for different traffic profiles and different types of BS within the first 5 years.

Fig. 2 depicts the reduction of the solar panel size and the reduction in consumed power in percentage compared to the case where two BSs are considered to be always active. The results are represented as a function of the estimated traffic evolution in 5 years for 4 different traffic profiles TP1, TP2, TP3, and TP4 and different types of BS (see details in [7]). Battery size is linearly proportional to the solar panel size and, thus, the experienced reduction is the same in both cases. As it can be observed, for some traffic profiles the amount of reduction is around 15-20% for the first years which directly translates into a CAPEX reduction.

References

[1] Y. S. Soh, T. Q. S. Quek, and M. Kountouris, "Dynamic sleep mode strategies in energy efficient cellular networks," in *IEEE International Conference on Communications (ICC)*, Jun. 2013.
[2] E. Oh and B. Krishnamachari, "Energy savings through dynamic base station switching in cellular wireless access networks," in *IEEE Global Communications Conference (GLOBECOM)*, Dec. 2010.
[3] W. Guo and T. O'Farrell, "Dynamic cell expansion: Traffic aware low energy cellular network," in *IEEE Vehicular Technology Conference (VTC)*, Sep. 2012.
[4] A. Bousia, A. Antonopoulos, L. Alonso, and C. Verikoukis, "Green distance-aware base station sleeping algorithm in LTE-advanced," in *IEEE International Conference on Communications (ICC)*, Jun. 2012.
[5] A. Bousia, E. Kartsakli, L. Alonso, and C. Verikoukis, "Dynamic energy efficient distance-aware base station on/off scheme for LTE-advanced," in *IEEE Global Communications Conference (GLOBECOM)*, Dec. 2012.
[6] A. Bousia et al., "Game theoretic approach for switching off base stations in multi-operator environments," in *IEEE International Conference on Communications (ICC)*, Jun. 2013.
[7] "ICT-601102 STP TUCAN3G, UMTS/HSPA network dimensioning," in *Deliverable D41, available online: http://www.ict-tucan3g.eu*, Nov. 2013.
[8] A. Rendón, P. Jeanneth, and A. Martínez, *Tecnologías de la Información y las Comunicaciones para zonas rurales. Aplicacioón a la atención de salud en países en desarrollo*, CYTED, first edition, 2011.
[9] "ICT-247733 EARTH, energy efficiency analysis of the reference systems, areas of improvements and target breakdown," in *deliverable report D23*, Jan. 2012.