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An economic viability analysis on energy-saving solutions for wireless access networks

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ABSTRACT

As the energy bill for mobile operators rises with the continuing traffic growth, energy efficiency problems attract an increasing attention in the telecommunication industry. However, the investment for the implementation of any energy-saving solution could be so costly that it may not achieve the total cost reduction. Therefore, the economic viability of the proposed solutions is of substantial importance for the operators in the process of investment decisions. In this paper, we present a methodology for assessing the economic viability of energy-saving solutions. We conduct two case studies using the proposed methodology, and analyze the cost-benefit tradeoff for: (i) hardware upgrade enabling dynamic sleep mode operation at the base stations (BSs), and (ii) energy efficient network deployment minimizing the network energy consumption. Simulation results show that the hardware upgrade can save up to 60% of energy consumption particularly when the high data rate requirement forces low network resource utilization. Consequently, the solution is shown to be increasingly cost effective as the unit energy cost increases. Network deployment optimized for energy efficiency is shown to bring about further energy savings, but it demands denser deployment of BSs. Thus, it is not deemed as economically viable considering today's cost values.

1. Introduction

In recent years, with the explosive growth of mobile traffic, the energy consumption of wireless access networks has experienced a significant increase. Currently, information and communications technology (ICT) is responsible for 3% of worldwide electricity consumption, out of which wireless access networks contribute approximately 10% with 60 billion kilowatt-hour per year [1–3]. This situation poses a big challenge for mobile operators since the rising energy consumption together with growing energy prices directly leads to an increase in their operational expenditures (OPEX). In fact, operators' cost figures show that nowadays the energy cost of running a network constitutes almost 50% of overall OPEX [4,5].

A multitude of models and approaches have been recently proposed to increase the energy efficiency of these networks at all levels, including hardware design, network management, network deployment, and resource allocation [6–9]. A remaining issue is that most of these solutions require a new investment for the operators due to the need of hardware and software upgrade, or the deployment of new sites, etc. Therefore it is a non-trivial question if the proposed solutions, reducing the energy cost, can provide sufficient economic gain such that they provide return on investment. To the best of our knowledge, there is no study addressing this issue and analyzing the total cost of investment of the solutions. Considering the fact that the motivation of reducing the energy consumption of wireless access networks is driven not only by environmental concerns, but mainly by economic reasons, it is essential to assess the economic viability in order to identify whether or not the additional expenditures required for energy efficient solutions are compensated by the energy savings.

In this paper, we aim to answer the following question: *Under which circumstances an operator achieves a total cost reduction from an energy-saving solution?*. For this, we propose a methodology for assessing economic viability of energy-saving solutions for wireless access systems. It incorporates the net present value (NPV) of a given solution over the network lifetime in order to compare the energy saving benefit with the increment in overall expenditures with respect to the existing network where the solution is not implemented. Our methodology builds upon widely accepted economic models [10,11], and it is easy to apply to a variety of energy-saving solutions.

With the aid of the proposed methodology, we conduct two case studies and analyze the cost-benefit tradeoff of two popular energy-saving solutions, i.e., hardware upgrade and energy efficient deployment. We demonstrate in detail how our methodology can be utilized

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to assess the economic viability of a general energy-saving solution with these examples. Furthermore, the case studies give us insights into the important parameters to be considered for the network-level energy efficiency analysis.

For the case of the hardware upgrade solution, we assume that an operator decides to upgrade the existing BS transceivers in order to enable dynamic sleep mode operations, also called cell discontinuous transmission (DTX), in its network [7,8,12]. However, this fast traffic adaptability feature comes at the expense of increased CAPEX due to the necessity of a new hardware. In order to analyze this tradeoff between reduced energy cost and increased CAPEX, we first identify the annual energy savings with cell DTX considering the daily variation of the traffic and accordingly the variation of the cell loads in the network. Then, we analyze the break-even cost of the hardware upgrade below which the incremental increase in CAPEX is compensated by the reduced energy cost, and thus the solution provides total cost savings for the operator.

As for the energy efficient deployment solution, we assume that a greenfield operator deploys the network guaranteeing the minimum network energy consumption. Then, it is compared to the traditional CAPEX-optimized planning which requires the deployment of a minimum number of BSs to meet the network coverage and capacity requirements. In order to analyze this tradeoff between energy- and CAPEX-optimized planning, we first propose a simple algorithm to identify the optimum network deployment solutions taking into consideration the traffic-dependent cell load variations which directly impact perceived user data rate and annual energy consumption, based on our previous work [12]. We note that the solution approach adopted in this paper for defining the energy-optimized network deployment significantly differs from the ones in the literature that are mostly based on busy hour traffic conditions and full buffer traffic model assumptions [3,13,14]. Finally, based on the defined deployment solutions with respect to the considered objectives, and the proposed viability assessment methodology, we obtain the break-even cost of energy above which the energy oriented design presents total cost savings during the network lifetime.

2. A method for analyzing economic viability of energy efficient solutions

Assume that a mobile operator aims at finding solutions for minimizing the total network energy consumption while providing the required capacity. The resulted energy efficient solution might be a maintenance strategy such as to upgrade hardware and/or software, or to apply an traffic adaptive resource allocation scheme etc., for a given deployment. Moreover, the operator might also be interested in identifying greenfield deployment strategies that provide the minimum energy consumption in case of the rolling out the new technology in their network. However, it should be noted that even though these solutions will reduce operators' energy expenses, they might be obtained with an increase in the total cost due to required capital expenditures. In this regard, it is essential to analyze the total cost of investment of the solutions solely aimed at energy minimization considering the fact that operators' energy interest is driven mainly by economic reasons.

In this section, we first introduce a detailed total cost of investment model, and then present our economic viability analysis methodology.

2.1. Total cost of investment model

In this paper, a simple linear cost model is considered which is widely adopted in cost analyses of wireless access networks [10,11]. Based on this model, total cost of investment for the whole wireless infrastructure can be approximated as

$$C_{tot} = c\, N_{BS}, \ [€] \tag{1}$$

where c is the cost per base station including CAPEX, such as installation, radio equipment, and OPEX such as energy, site rentals, maintenance, etc. N_{BS} denotes the number of base stations needed to provide the desired service level in the network.

In order to incorporate the time aspect into the cost analysis, we need to capture two main points. The first point is that in the case of postponing the investment in the radio network, one can earn interest by depositing the money into a bank. This implies the fact that future costs are worth less [15]. Second, the price of the equipment will decrease over the years. To this purpose, we define the cost of a BS (c) by applying a discount rate, and express it in terms of its NPV as below:

$$c = \sum_{n=1}^{N} \frac{c_n}{(1+d)^{n-1}}. \quad [€/\text{unit}] \tag{2}$$

where d is the discount rate, c_n and N are the total cost in year n and the network lifetime, respectively. Here, price erosion can be included into the model by letting c_n diminish over the years. Note that c_n includes both the capital (c_n^{capex}) and the operational (c_n^{opex}) expenditures during the year under examination.

Under the assumption that capital expenditures occurs at the beginning of the deployment, the total cost of investment of deploying N_{BS} BSs during N years can be written as

$$C_{tot} = N_{BS}\left(c^{capex} + \sum_{n=1}^{N} \frac{c_n^{opex}}{(1+d)^{n-1}}\right). \quad [€] \tag{3}$$

Here c^{capex} denotes the capital expenditures of deploying a BS in the first year, i.e., $n = 1$.

For simplicity, we assume that all operational costs of a BS, excluding energy cost, i.e., c^o, are constant during the network lifetime, N years. Under this assumption, total OPEX of a BS in year n can be written as below:

$$c_n^{opex} = c^o + c_n^{energy}, \quad [€/\text{unit}] \tag{4}$$

where c_n^{energy} is the total energy cost per BS in year n.

Let $\mathbb{E}_n[C_{energy}]$ denote the average annual energy cost of the considered wireless access network with N_{BS} BSs in year n. Then, the total cost of investment presented in Eq. (3) can be expressed in detail as below:

$$C_{tot} = N_{BS}\left(c^{capex} + \sum_{n=1}^{N} \frac{c^o}{(1+d)^{n-1}}\right) + \sum_{n=1}^{N} \frac{\mathbb{E}_n[C_{energy}]}{(1+d)^{n-1}}. \quad [€] \tag{5}$$

Here, the average annual energy cost of a network in year $n \in N$, i.e., ($\mathbb{E}_n[C_{energy}]$), depends on the average annual energy consumption (E_n) in kWh and the unit energy cost (e_n) in €/kWh and is given by

$$\mathbb{E}_n[C_{energy}] = e_n \times E_n(N_{BS}). \quad [€] \tag{6}$$

Based on the given relationships, total cost of investment will have the following dependence on number of BSs:

$$C_{tot} = N_{BS}\left(c^{capex} + c^o \times \frac{(1+d)^N - 1}{d(1+d)^N}\right) + \sum_{n=1}^{N} \frac{e_n \times E_n(N_{BS})}{(1+d)^{n-1}}. \quad [€] \tag{7}$$

Note that we made several assumptions on capital and operational expenditures based on real-world scenarios in order to increase the applicability of the total cost of investment model for general use.