Computer Communications 000 (2016) 1–13

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Low-Carb: A practical scheme for improving energy efficiency in cellular networks

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ARTICLE INFO

Article history:
Received 16 July 2015
Revised 18 August 2016
Accepted 21 August 2016
Available online xxx

Keywords:
Energy management
Energy conservation
Energy efficiency
Load management
Cellular networks

ABSTRACT

Electricity cost constitutes a significant fraction of the total operations costs in a cellular network. We present Low-Carb, a practical scheme which reduces the power consumption in such networks. Low-Carb achieves this by coupling *Base Transceiver Station (BTS) power savings* with *Call hand-off*—two features widely available to cellular operators. Motivated by the observation that most callers are in the vicinity of multiple BTSs, Low-Carb allows calls to hand-off from one BTS to another so that BTS power savings can be applied to a maximal number of BTSs throughout the cellular network. The resulting reduction in energy consumption is shown to be governed by an optimization problem. We also provide optimal and heuristic solutions to this problem. We use BTS locations and traffic volume data from a large live GSM network to evaluate the power savings possible using our proposed approach. Our results indicate that performing coordinated call hand-off and BTS power-savings, a GSM 1800 network operator with about 7000 sites nation-wide can reduce annual electricity consumption by up to 35.36 MWh. This is at least 9.8% better than the energy savings achievable by using BTS power savings alone.

1. Introduction

Cellular networks consume several tens of TWhs (terawatt-hours) of electrical energy worldwide every year [1], exacerbating the rising ecological concerns. Beyond these concerns, the corresponding cost of electricity makes up a significant proportion of the overall operational cost of a cellular service provider. In European markets, for example, the electricity cost is estimated to be around 18% of the operational costs [2]. This fraction is even higher in developing regions due to the shortage of grid electricity and the use of small-scale generation powered by diesel fuel. Thus, cellular operators are keen on reducing the power consumption of their networks.

Cellular networks in the energy-starved developing countries are pre-dominantly based on Global System for Mobile communication (GSM). For instance, more than 98% of the cellular subscribers in Nigeria are using GSM [3]. Similarly, almost 91% of Pakistan's 131 Million cellular subscribers are using GSM [4]. The 3G/4G subscribers in Pakistan are mostly concentrated in the large cities. The large rural population is still covered by legacy GSM networks. Transition of these rural cellular networks to 3G/4G is expected to be slow due to the high cost of handsets and low demand for higher bandwidth services. Furthermore, upgrade from GSM to 3G/4G/5G requires equipment upgrade and licensing costs. Since profits are low in today's cut-throat competition, upgrade to 3G/4G/5G in developing countries is expected to be slow. Thus, GSM networks are here to stay for a considerable period of time. Therefore, in this paper, we focus on energy efficiency of legacy GSM cellular networks.

This paper presents Low-Carb[1], a practical scheme which uses *Base Transceiver Station (BTS) Power Savings* and *Call Hand-off* to reduce the consumption of electricity in a GSM cellular network. Using deployment and traffic data from a cellular provider in a large metropolitan area in a developing region, we show that Low-Carb can save about 10% in the amount (and cost) of electrical energy. This translates into millions of dollars in annual savings, just for this one service provider.

Low-Carb achieves this saving in energy consumption by reducing the power consumption at BTSs, which account for 60% to 80% of a cellular network's total power consumption [1,5,6], by making them more energy proportional. Fig. 1 shows the normalized load

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[1] Short for Lower Carbon footprint.

http://dx.doi.org/10.1016/j.comcom.2016.08.009
0140-3664/

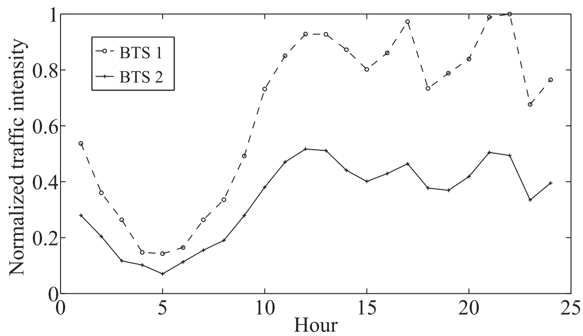

Fig. 1. Traffic load variations at two neighboring BTSs during a single day from our data set. For most of the day, the instantaneous load is a fraction of the peak traffic load.

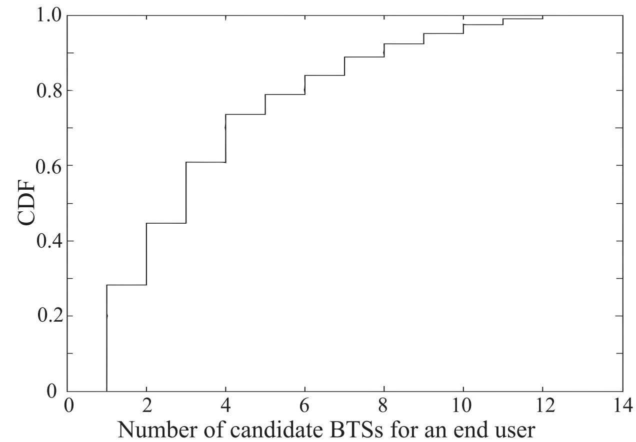

Fig. 2. CDF (cumulative distribution function) of the number of potential serving BTSs for a call in our dataset (large metropolitan area).

of consumer traffic at two neighboring BTSs in our data set. Observe that while the traffic load peaks for a short period of time, it mostly stays at a fraction of its peak[2].

However, the radio circuitry at BTSs is provisioned in accordance with the peak load. This radio circuitry lacks energy proportionality, i.e., its power consumption does not scale in proportion to the traffic load. As a result, a BTS also lacks energy proportionality and consumes power at about the same level as it would at the peak load [6]. This leads to wasted energy, which Low-Carb aims to reduce—by varying the power consumption at a BTS in accordance with its traffic load.

If the instantaneous power consumed at a BTS can be made proportional to the instantaneous workload, savings in power consumption will ensue. For the provider data available to us, a fully energy proportional BTS subsystem of a cellular network would save between 44% – 52% of electrical energy depending on the BTS model. Thus, there exists potential to save electricity cost in a cellular network by reducing the energy consumption at low workloads. Low-Carb exploits this potential in two ways: (i) by shutting down part of the radio circuitry, and (ii) by rerouting calls from one BTS to a nearby BTS.

1.1. Description of Low-Carb

Coarse-grained energy proportionality in BTSs may be achieved in one of the following two ways:

- BTSs may be turned off when traffic is low and turned on later when traffic load increases [1,7–11]. However, operators are often reluctant to switch on/off entire BTSs due to coverage and equipment lifetime concerns (see Section 2.2).
- *Frequency dimming* [12] proposes to turn off a fraction of the radio circuitry when traffic is low, such that the traffic may be handled by the circuitry that stays on. Most vendors' BTSs support such a feature, which we term as *BTS power savings* in this paper. Our conversations with cellular operators reveal that they regularly use this feature. Low-Carb also makes use of this feature.

Traffic traces collected from a large network operator indicate that if some calls are handed off between neighboring BTSs, the number of BTSs that can be put in BTS power savings mode can be increased. Thus, Low-Carb proposes to hand-off calls between neighboring BTSs, without making a negative impact on the network quality of service, such that the *BTS power savings* can be applied to a maximal number of base stations throughout the cellular network. In comparison to uncoordinated *BTS power savings*, as used in current cellular network deployments, Low-Carb offers additional power savings as it may allow a larger number of radio circuits to be deactivated.

The underlying assumption in Low-Carb is that calls can be handed off to neighboring BTSs without being dropped and without exceeding their traffic capacity. This is possible because (a) traffic load in cellular networks exhibits significant variation over time and space and (b) most callers often receive sufficiently strong signal from *several* nearby BTSs [6,13]. This coverage diversity is evident in Fig. 2, which shows the CDF of the number of BTSs available to an end-user in our dataset of live traffic. Observe that the results show that about half of the callers have 3 or more candidate BTSs available at all times Thus, some calls may be handed off from one BTS to a nearby BTS in order to increase energy savings over those possible through BTS power savings alone.

1.2. Contributions

This paper makes the following contributions:

1. We formulate Low-Carb as a mathematical optimization problem to maximize energy savings in a cellular network, by using call-handoff and BTS power savings in a coordinated manner.
2. We propose a heuristic algorithm for solving the Low-Carb power optimization problem in polynomial time.
3. We use real datasets from a large GSM network operator to evaluate Low-Carb.
4. We evaluate the sensitivity of Low-Carb electricity savings to various system parameters.
5. Turning off TRXs to save energy consumption results in an associated increase in call blocking probability. We find quadratic fits to fairly accurately determine the increase in call blocking probability as a function of the achievable savings in electricity consumption.

The rest of the paper is structured as follows. In Section 3, we discuss related works. The formulation of Low-Carb optimization problem is presented in Section 4. Experimental setup and the results are presented in Sections 5 and 6, respectively. In Section 7, we offer concluding remarks.

2. Background and motivation

2.1. BTS radio resources in GSM

In a GSM network, the cell covered by a BTS is typically split into three *sectors*. A BTS is equipped with several transceivers

[2] Operational cellular networks have been widely observed to exhibit traffic load variations both over time and space [6].