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Modeling sleep mode gains in energy-aware networks ☆

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ABSTRACT

Nowadays two main approaches are being pursued to reduce energy consumption of networks: the use of sleep modes in which devices enter a low-power state during inactivity periods, and the adoption of energy proportional mechanisms where the device architecture is designed to make energy consumption proportional to the actual load. Common to all the proposals is the evaluation of energy saving performance by means of simulation or experimental evidence, which typically consider a limited set of benchmarking scenarios.

In this paper, we do not focus on a particular algorithm or procedure to offer energy saving capabilities in networks, but rather we formulate a theoretical model based on random graph theory that allows to estimate the potential gains achievable by adopting sleep modes in networks where energy proportional devices are deployed. Intuitively, when some devices enter sleep modes some energy is saved. However, this saving could vanish because of the additional load (and power consumption) induced onto the active devices. The impact of this effect changes based on the degree of load proportionality. As such, it is not simple to foresee which are the scenarios that make sleep mode or energy proportionality more convenient.

Instead of conducting detailed simulations, we consider simple models of networks in which devices (i.e., nodes and links) consume energy proportionally to the handled traffic, and in which a given fraction of nodes are put into sleep mode. Our model allows to predict how much energy can be saved in different scenarios. The results show that sleep modes can be successfully combined with load proportional solutions. However, if the static power consumption component is one order of magnitude less than the load proportional component, then sleep modes become not convenient anymore. Thanks to random graph theory, our model gauges the impact of different properties of the network topology. For instance, highly connected networks tend to make the use of sleep modes more convenient.

1. Introduction

In networking, one of the main causes of energy waste is the fact that most of the devices do not consume energy proportionally to the work they sustain, but they consume much even when they are under-utilized [1]. On the contrary, network usage and traffic follow the typical human being activity patterns, with significant differences between peak and off-peak values and typical daily periodicities. Therefore, network devices result highly under-utilized for long periods of time during which they are mostly idle but consume a high amount of power. Many solutions are being studied to reduce this waste, or, equivalently, to make the network consumption proportional to the traffic load [2]. The proposed approaches can be divided into two

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main categories: (i) *Energy proportional approaches* work on the individual devices and try to achieve energy consumption proportionality by adapting the speed (and capacity) of the devices to the actual load, over relatively short time-scales [3]; (ii) *Sleep mode approaches* involve the network as a whole and approximate load proportionality by carefully distributing the traffic in the network so that some devices are highly utilized while others become idle and are put in sleep modes [4]. The two solutions can be merged so that energy proportional devices are present and sleep mode can be leveraged to possibly save additional energy.

In this context, several solutions have been proposed in the literature, including network management algorithms that optimize traffic routing so as to maximize the energy saving offered by sleep mode enabled devices (see Section 7 for more details). However, to the best of our knowledge, all previous works adopt simulation or actual testbed experiments as main means to assess energy saving performance, and typically few benchmarking scenarios have been considered. Furthermore, either energy proportionality or sleep modes approach is assumed, with few works only considering the combination of the two. In this paper, we instead aim at: (i) comparing and combining the two approaches, and (ii) proposing an analytical methodology to estimate their benefits. In particular, we aim at considering classes of topologies that we model as random graphs. This allows to generalizing results, and to gauging the impact of simple network properties such as node number and degree.

Given a family of network topologies, and given a model of the energy consumed by a device as a function of its load, is it better to purely rely on device energy proportionality capability, or, on the contrary, is it better to couple it with sleep mode solutions? And, also, which is the minimum energy proportionality that would make sleep mode ineffective? What is the impact of the network size, or topological properties on the benefits of energy saving feature? The answer to these questions is the goal of this paper.

When a device is switched-off the traffic passing through it has to be rerouted on different, typically longer, paths; thus, the beneficial saving achieved by switching off the device is mitigated by the increase of the consumption of the devices that remain on, due to the higher load they have to sustain. To investigate this trade-off, we consider a general model to represent network topologies ranging from backbone networks to metropolitan networks, and a general model for device power consumption.

Several power consumption models for devices have been proposed [5–8]. Basically, all these models assume that the energy consumption of network devices, i.e., nodes and links, is composed by a *constant* amount and a *variable* part that is an increasing function of the traffic that flows through the devices. We compute the total network energy cost as the sum of the fixed and variable cost of network devices which depends on the traffic they have to carry. In our previous work [9] this problem has been faced considering that only links offer energy saving capabilities. In this work we go a step further by considering a more general model that includes also the cost of nodes. We start considering the variable cost of devices scales linearly with the load. Then, we extend the model to generic cost functions which include linear and super-linear costs. The network and its topological characteristics are represented by random graphs; leveraging then on random graph theory, the load on network devices is computed from the knowledge of the shortest path between node pairs. Thus, the energy consumption of the whole network is easily derived.

Since we are not interested in proposing a novel algorithm to select which link and node can be put into sleep mode, we consider a generic policy, according to which some elements are turned off. This results in a change in the topological characteristics of the network, which is modeled as a new graph, whose energy consumption is evaluated using graph theory again. To the best of our knowledge, the only previous work that is similar to ours is [8]. Yet, only simple simulations have been used, so that the set and generality of presented results is limited. In our work, we present modeling results that corroborate the intuition of [8] and derive more general insights.

We present an extensive sensitivity analysis to show the impact of model parameters. We include both small-world and power-law graph models that are claimed to reflect actual network topology properties [10]. Our results show that:

- when the variable part of the cost model is small with respect to the constant part, as is typical of today devices, sleep modes are convenient;
- for future devices, whose consumption will probably be more load proportional, sleep modes might not be convenient anymore provided the static cost would be one order of magnitude smaller than the variable part;
- network topology characteristics have limited impact on energy saving. Yet, well-connected topologies show larger benefits in terms of energy saving margins when sleep-mode policies are in place.

This suggests that, given the today technological constraints that make the constant energy consumption of devices quite large, sleep mode enabled networks will allow to save more energy than purely energy proportional approaches for long time. Finally, we emphasize that, despite being simple, our model gives general insights of sleep modes effectiveness in actual telecommunication networks.

The rest of the paper is organized as follows. The system model and methodology is detailed in Section 2. The adopted network models are reported in Section 3. We present the evaluation of sleep modes in Section 4. The comparison of different switching off policies is reported in Section 5. A discussion about model assumptions is reported in Section 6. Section 7 reviews related work. Finally, Section 8 concludes the paper.

2. System model and methodology

In this section we provide a general overview of the methodology we use to evaluate sleep mode gains.