Energy-Awareness in Network Dimensioning: a Fixed Charge Network Flow Formulation

Aruna Prem Bianzino, Claude Chaudet, Dario Rossi, Jean-Louis Rougier
Institut TELECOM, TELECOM ParisTech, CNRS LTCI UMR 5141, Paris, France
{bianzino, chaudet, drossi, rougier} @telecom-paristech.fr

1. INTRODUCTION

Reduction of unnecessary energy consumption is becoming a major concern in wired networking, in reason of both the potential economical benefits and its forecast environmental impact. These issues, usually referred to as “green networking”, relate to embody energy-awareness in the network elements and processes.

Once a network has been designed (i.e., the resources that will compose it have been chosen), a periodical, on-line, process decides how the network resources will be used. This process is referred to as “network dimensioning”. One of the most common practices for acting in a *green* fashion in network dimensioning consists in *resource consolidation.* This technique aims at reducing the energy consumption due to devices underutilized at the considered interval of time. Given that the traffic level in standard networks approximately follows a well-known daily and weekly behavior [4], there is an opportunity to aggregate traffic flows over a subset of the network devices and links, allowing others to be switched off temporarily or be placed in sleep mode (if available). This solution shall preserve connectivity and Quality of Service (QoS), for instance by limiting the maximum utilization over any link. In other words, the required level of performance will still be guaranteed, but using an amount of resources that is dimensioned for the current network traffic demand rather than for the peak demand (or more). Flow aggregation may be achieved, for example, through a proper configuration of the routing weights.

2. PROBLEM FORMULATION

This approach has been evoked in [3] as a hypothetical working direction, and in [2], with the proposal, and the evaluation, of some greedy heuristics, based on the ranking of nodes and links with respect to the amount of routed traffic in the energy-agnostic configuration. In our work, we instead model the problem of the optimization of the total energy consumption of a network as a function of the utilization level of the network devices. We analyze the Integer Linear Programming (ILP) formulation for this problem, falling into the set of Fixed Charge Network Flow (FCNF) problems. We found that the complexity of the solution largely depends on the model used for the Energy consumption of the network devices. Also, it is known that modeling the energy consumption of network components is an hard task, mainly because of inconsistency, scarcity and oldness of data. For these reasons, we decided to use two complementary approaches:

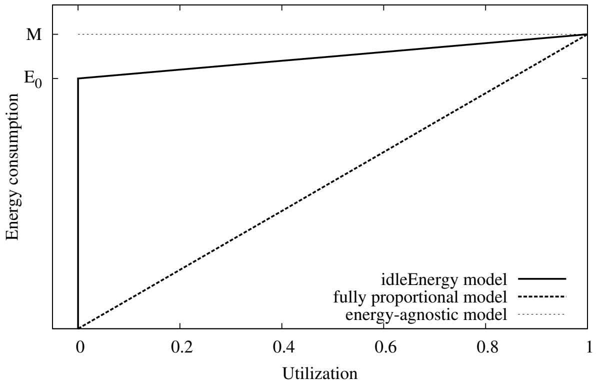

Figure 1: The used models for the network device energy consumption as parametrized function of the device utilization.

1. a more realistic approach, where device energy consumption presents a strong idle component E_0 as soon as the device utilization is greater than 0, and a smaller component proportional to the utilization itself (this model will be referred to as “idleEnergy”, it is illustrated in Figure 1);

2. a more ideal approach, where device energy consumption behaves proportionally to their utilization (this model will be referred to as “fully proportional”, it is illustrated in Figure 1 and was originally described in [1] as the ideal case of “proportional computing”).

The “idleEnergy” model brings to a rather complex solution, even if there exist mathematical tools allowing to obtain a solution in a reasonable time. The “fully proportional” model brings, instead, to a formulation of the solution as a linear problem, and to a consequent strong reduction of the solution complexity with respect to the one of the "idleEnergy" formulation. The problem is mathematically defined by the following LP formulation:

$$\min \frac{1}{2} \sum_{(i,j)\in L} \Big(\frac{(l_{ij}+l_{ji})E_{fij}}{c_{ij}} + x_{ij}E_{0ij} \Big) + \sum_{n\in N} \frac{l_n E_{fn}}{c_n} + x_n E_{0n}$$

subject to:

$$\sum_{i,s,d\in N} f_{ij}^{sd} - \sum_{i,s,d\in N} f_{ji}^{sd} = \begin{cases} r_{sd} & \forall s,d,i=s \\ -r_{sd} & \forall s,d,i=d \\ 0 & \forall s,d,i\neq s,d \end{cases}$$

$$\sum_{s,d\in N} f_{ij}^{sd} = l_{ij} \leq \alpha c_{ij} \quad \forall i,j \in L$$

$$l_n = \sum_{(i,n)\in L} l_{in} + \sum_{(n,i)\in L} l_{ni} \quad \forall n \in N$$

$$Zx_{(ij)} \geq l_{(ij)} + l_{(ji)}$$

$$Zx_n \geq l_n$$

where N is the set of nodes and L the set of links in the considered network; l_a is the load of the network element a and c_a its capacity; f_{ij}^{sd} is the amount of the flow from node s to node d that has been routed on the link (i,j); Z is a "big" number (used as part of the "big-M method"); E_{0a} and M_a are the two parameters profiling the energy consumption of the network element a, as previously defined in Figure 1, and E_{fa} is the difference between the maximum energy consumption (M_a) and the idle energy consumption (E_0).

For the evaluation of our solution we chose to use the GEANT topology [5]. Since in the GEANT network all nodes are sources and destination of traffic, this constitutes a *worst case* scenario, as nodes can not be generally turned off. This is a good candidate for representing a lower bound benchmark for the evaluation and comparison of different algorithms. Moreover GEANT is a real network offering public data on both its *topology* as well as its *traffic matrices*, which ensures a certain degree of realism in the evaluation. We took as a reference the routing performed using IGP-WO optimized weights, and enabling Equal Cost Multi Path. IGP-WO is the standard practice in the operators networks, which we will refer to as "standard routing case". We evaluated our algorithm on the basis of the percentage of energy that may be saved, with respect to the standard routing case.

Switching off network elements and optimizing their utilization brings to energy saving from one side, but also to a reduction of the system robustness from the other side. Nowadays, the common practice in the operators' network to guarantee robustness and a Quality of Service (QoS) level, is the limitation of the charge of the network elements. In order to obtain a realistic solution, we introduced in our formulation a parameter α representing this limitation of the network element charge. We evaluated the effects of this parameter on the achieved energy saving.

3. RESULTS

Our preliminary results show that it is possible to obtain an optimal solution to this problem in a reasonable time, employing standard computational power, and considering realistic and fairly complex topologies.

Observing the results for the two considered energy models, we can see how in the first case (idleEnergy model) the energy saving is consequence of switching off network devices, while in the second case (fully proportional model) energy saving comes as consequence of aggregating the traffic into the path involving the most energy efficient devices. Given the specific topology and traffic level we chose, it is not possible switching off nodes, since every node is source and destination of traffic requests, but is possible switching off links. As a consequence, we can achieve a small energy saving due to nodes and a considerable one due to links. However, it should be noticed that the link component represents a small contribution to the total one in our model, so that the overall saving is modest: saving account to about 0.2% in the case of the idleEnergy model, and about 4% in the case of the fully proportional model, as evaluated on a typical day (i.e., over 24 hourly traffic matrices). Notice that we considered consumption figures typical of Ethernet links, which are two to four order of magnitude smaller than the one used for the nodes. We point out that the situation may considerably change when taking into account optical interconnections over real distances of thousands of kilometers, requiring periodical signal regenerators, involving much higher energy consumptions.

From the comparison of the two proposed energy models, we can also notice how a network involving devices whose energy consumption is fully proportional to their utilization allows achieving much higher energy saving with respect to one involving more energy-agnostic devices, as expected. This is due to the fact that in the second case, the main opportunity to reduce the energy consumption is switching off network elements, which strongly depends on the considered scenario.

In future work we plan to consider topologies that including multi-homed nodes end transport nodes (i.e., nodes that do not represent sources or destination of traffic requests), and to compare the optimal solution with the existing heuristics, in terms of achievable energy saving, of the robustness of the solution, and of the solution complexity. We are also interested considering different energy profiles for the network elements, as they may result from different network technologies.

Acknowledgments

This work was funded by Eureka Celtic TIGER2 project.

4. REFERENCES

[1] Barroso, Luis André and Hölzle, Urs. The case for energy-proportional computing. *IEEE Computer*, 40(12):33–37, December 2007.

[2] L. Chiaraviglio, M. Mellia, and F. Neri. Reducing power consumption in backbone networks. In *Proceedings of the IEEE International Conference on Communications*, June 2009.

[3] M. Gupta and S. Singh. Greening of the internet. In *ACM SIGCOMM*, pages 19–26, August 2003.

[4] Qureshi, Asfandyar, Et al. Cutting the electric bill for internet-scale systems. In *ACM SIGCOMM*, August 2009.

[5] The GEANT Project. http://www.geant.net/.