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, due to both its potential economical benefits and to 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 is designed (i.e., the devices and links composing the network have been chosen), a periodical, on-line, process decides how the network resources will be utilized. This process is referred to as "network dimensioning". One of the most common practices for acting in a *green* fashion in network dimensioning is called *resource consolidation*. This technique aims at reducing the energy consumption due to underutilized devices over certain intervals 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 supported). 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 of this problem, which falls 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. Modeling the energy consumption of network components is, however, a hard task, mainly because of inconsistency, scarcity and aging of data. For these reasons, we decided to focus on two complementary models:

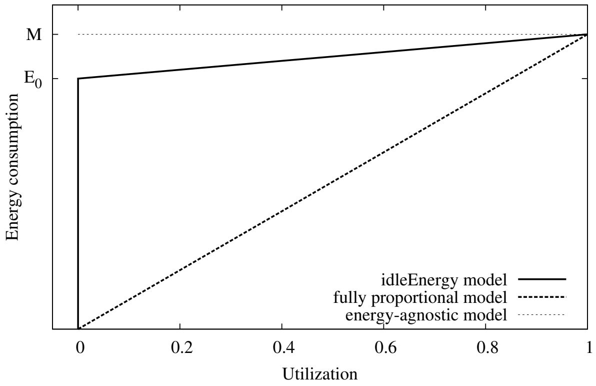

Figure 1: The used models for the network device energy consumption as parametrized function of the device utilization.

1. a more realistic model, in which an important minimum energy E_0 is consumed as soon as the device utilization is greater than 0, and a smaller term is further added, proportional to the utilization itself. This model will be referred to as "idleEnergy", it is illustrated in Figure 1;

2. a more idealistic model, in which devices energy consumption is always proportional 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 leads to a linear program with a subset of binary variables (0-1 ILP), which is NP complete, even if there exist mathematical tools allowing to obtain a solution in a reasonable time. The "fully proportional" model leads, instead, to a regular linear programming problem formulation, which can be solved in polynomial time.

The problem is 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 (network devices) and L the set of arcs (communication links) in the considered network; For any node or link a, l_a is the load of a and c_a represents its capacity (maximum load); f_{ij}^{sd} is the load induced on link (i,j) for routing traffic from node s to node d; Z is a "big" number (part of the "big-M method") used to relate 0-1 variables (on/off status) with continuous ones (loads); E_{0a} and M_a are the two parameters profiling the energy consumption of element a, as represented in Figure 1, and E_{fa} is the difference between the maximum energy consumption (M_a) and the idle energy consumption (E_0).

Switching off network elements and optimizing their utilization leads to energy saving, but can also reduce of the system robustness. Nowadays, the common practice in the operator networks, in order to guarantee robustness and a Quality of Service (QoS) level, is to limit the load of the network elements. To take into account this parameter, we finally introduced a variable α limiting the load on links to a certain fraction of their capacity. We evaluated the effect of this parameter value on the achieved energy saving.

For the evaluation of our solution we chose to use the GEANT topology [5]. In the GEANT network all nodes are sources and destination of traffic. This topology therefore constitutes a *worst case* scenario, as nodes can not generally be 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 solution on the basis of the percentage of energy that may be saved, with respect to the standard routing case.

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 idleEnergy model case, the energy savings are due to the switching off of network devices. In the fully proportional model case, energy savings are instead mainly due to the aggregation of the traffic upon the path involving the most energy efficient devices. Given the specific topology and traffic level we chose, it is impossible, in our scenario, to switch 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 savings due to the nodes and a considerable one due to the links. However, the link component represents a small contribution to the total energy expenditure in our model, therefore overall savings are 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, with respect to typical day traffic (i.e., over 24 hourly traffic matrices). We considered energy 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, thus 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 in 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/.