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Using bio-inspired algorithms for energy levels assessment in energy efficient wired communication networks

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ABSTRACT

Rapid growth of ICT (Information Communication Technologies) energy consumption involves the need for proposing new mechanisms to enhance their energy efficiency. Focusing on energy consumption of networking equipment, this paper presents a study to achieve a tradeoff between the amount of energy that could be saved in wired networks and the discrete number of energy levels to be implemented by line cards. We use bio-inspired computing based on GA (Genetic Algorithms) and PSO (Particle Swarm Optimization) in order to assess the most suitable network configurations in terms of energy savings for different-sized networks such as NSFNet, Géant and AT&T. Results show a comparison between both bio-inspired algorithms in which, although GA produces better results, PSO achieves a reduction in computation time with an optimality gap below 1.7%. From a practical point of view, a limited number, such as four energy levels, is enough to achieve significant reductions in energy consumption.

1. Introduction

ICT (Information Communication Technologies) account for between 2 and 10% of the world's electrical energy consumption. Nowadays, the power usage of the US network infrastructure is estimated at between 5 and 24 TWh/year (Nedevschi et al., 2008), with a cost of \$.5–2.4 B/year. Communication networks energy consumption is expected to globally grow beyond 200% in 2017 (Zhang et al., 2010). In particular, values around 35.8 TWh are estimated for Europe in 2020 (Global e-Sustainibility Initiative (GeSI), 2013), whilst routers will consume 9% of the Japanese electricity in 2015 (Nakamura, 2007).

Otherwise, ICT generate between 2 and 4% of the world's carbon dioxide (CO_2) emissions (Pickavet et al., 2008). From this percentage, 37% comes from communication networks and equipment (Mankoff et al., 2008), and these emissions are expected to double in 2020 if no initiatives are taken to reduce this footprint. However, a decrease in emission volume of 15–30% is required to keep the global temperature increase below 2 °C in that year (Pamlin and Szomolányi 2007). It is therefore a critical challenge which has to be solved by both industry and academia.

Fortunately, ICT are one of the most promising areas to achieve an important reduction of global energy consumption. Specifically, there are opportunities to save considerable amounts of energy in communication networks (IEEE, 2013; Chabarek et al., 2008; Gupta et al., 2004; Gunaratne et al., 2005; Roth et al., 2002; Nordman and Christensen 2005; Mahadevan et al., 2009). Though researchers initially focused on energy saving mechanisms within individual network equipment, reduction of energy consumption in the global Internet is recently receiving increasing attention. One possible classification to categorize methods which achieve energy savings in wired communication networks is presented in Chabarek et al. (2008). Three areas are considered: (1) network design and traffic engineering, (2) system design and hardware components optimization and (3) protocols design and global coordination.

Various authors focus on studying different energy saving mechanisms based on methods that determine the minimum set of resources that have to be used in order to support a given traffic demand. Two hardware-based techniques are used for this purpose: Sleeping (unnecessary components are put to sleep) and Rate Adaptation (components are adapted to particular network needs). Furthermore, it is widely assumed in literature that networking hardware will support energy saving features in the near future, through the possibility of providing a series of interfaces which can operate at different rates (Nedevschi et al., 2008; Vasic and Kostic 2010). If both concerns are combined, different energy saving mechanisms could be proposed by adapting the rate of line cards to the varying requirements in the network at every moment. In this way, significant reduction in terms of energy consumption could be obtained.

Our work therefore focuses on considering some modifications to network hardware components in order to achieve important energy savings in wired networks. Understanding the different

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energy functions used in the literature and the methods typically proposed to reduce power consumption in communication networks (see Section 7, Related work) allows us to make energy saving proposals based on the network components design. To the best of our knowledge, there is no prior work that aims to evaluate the most appropriate discrete number of energy levels to be implemented by line cards. In this manner, significant energy savings would be achieved without the need of high hardware requirements by avoiding the use of a large number of levels.

Thus, the main objective of this paper is to provide a practical answer to the number of energy levels that are enough to achieve most of the energy savings in wired communication networks. Although this problem has been initially addressed in Galán-Jiménez Gazo-Cervero (2013), in this paper we also focus on the method used to solve it. Genetic and Particle Swarm Optimization algorithms (GA and PSO) are used to evaluate the impact of different energy levels on energy saving. Through simulations over realistic network topologies, we obtain the energy saving percentage for diverse energy functions assuming that links can be configured at different energy levels. Therefore, considering the three areas defined in Chabarek et al. (2008) that allow networking equipment to save energy, this paper focuses on proposing modifications to network hardware components, instead of focusing on the other two areas, network design and protocols design, that are not the aims of this work.

The rest of the paper is organized as follows. Section 2 defines the problem we aim to solve, whereas the two energy-saving methodologies based on GAs and PSO are presented in Sections 3 and 4 respectively. An approach to reduce the number of evaluations in both bio-inspired algorithms is described in Section 5 and experimental results after simulations over different scenarios are presented in Section 6. Section 7 analyzes existing work related to energy saving mechanisms for wireless, wired and optical networks to make a final comparison between them and the proposed bio-inspired algorithms. Finally, some conclusions are drawn in Section 8.

2. Problem definition

2.1. Formulation

Given a network infrastructure $G=(V,E,R)$ of nodes $v \in V$, connected by a set of unidirectional links $e \in E$associated with a set of energy levels $r \in R$,and given also a traffic demand matrix $M_{(i,j)}, \forall i,j \in V$ with traffic demand $d_{(s,d)} \in M_{(i,j)}$ units of data from source node $s \in V$ to destination node $d \in V$, find a network configuration which minimizes the energy consumption required.

A directed link from node $i \in V$ toward node $j \in V$ is denoted by $e_{i \to j}$ and is associated to an energy level $r \in R$ during a time interval T, which represents the configured rate for the line card during that interval. Function $powerL(e_{i \to j},r,T)$ assesses instant power consumption in Watts of the line card corresponding to a directed link $e_{i \to j}$ which is configured in an energy level $r \in R$ during an interval T.

Therefore, instant power consumption is minimized for a set of time intervals, such that they provide an abutted sequence that together provides complete coverage over the daily cycle:

$$\min IPC(C,T) = \sum_{e_{i \to j} \in E} powerL(e_{i \to j},r,T), \forall e_{i \to j} \in E, \forall r \in R \quad (1)$$

with

$$powerL(e_{i \to j},r,T) = c_r T, \forall r \in R \quad (2)$$

where c_r refers to the instant power consumption of the line card which corresponds to link $e_{i \to j}$ during an interval T while it is configured in an energy level r. Thus, instant power consumption IPC of a network configuration $C \in G$ during a time interval T is determined by the sum of the instant power consumption of each active line card (1), which depends on the energy level in which they are configured (2).

2.2. Energy level definition

Given an energy function $f(x)$, we consider energy level to the pair (x,y), where x corresponds to link operation rate and y is the result of applying x over the energy function, with $f(x)=y$.

An energy level therefore maps the operation rate of a link to its energy consumption. The minimum number of energy levels a link can support is two: "sleeping" and "active". The former refers to an energy level in which the link does not process any type of traffic, similar to a standby mode. The "active" energy level refers to link nominal capacity, i.e. the maximum amount of information a channel can transport. However, a link can work using different energy levels by means of the hardware-based Rate Adaptation method. Furthermore, it is widely assumed in literature that networking hardware will support energy saving features in the near future through the possibility of providing a series of interfaces which can operate at different rates (Nedevschi et al., 2008; Vasic and Kostic 2010). An example is shown in Table 1, where a link can support five energy levels.

In our proposal, we assume that a link can support a particular number of different energy levels. In this way, energy can be saved to a greater or lesser extent by applying the energy functions described above depending on the operating rate associated to the energy level in which a link is configured. Links operating in a "sleeping" energy level save energy by not transporting data packets, but remain operational for the exchange of essential link integrity messages. They can leave their current energy level and enter another different energy level with a particular rate. This is the reason why links consume a low energy percentage: between 5 and 10% out of their consumption if they are configured with the maximum energy level (Rodgers, 2013). We also assume link asymmetry, i.e. the two unidirectional arcs of a link can be configured in different energy levels.

2.3. Energy distribution definition

Given a discrete number of energy levels, n, we define energy distribution, l, as the succession of n energy levels, r_i, which network links can be configured at. It is an increasing succession of operation rates which are associated to each of the energy levels:

$$l = \{r_0, r_1, r_2, \ldots, r_{n-1}\}, \forall r_i < r_{i+1} \in R \quad (3)$$

Thus, if we denote $rate_{\max}$ to the highest operation rate supported by network links, $r_i$values for a linear energy distribution are given by the next equation:

$$r_i = \frac{i}{n-1} rate_{\max} \quad (4)$$

Table 1
Example of energy levels supported by a link.

Energy level	***Rate***
0	Sleeping
1	10 Mbps
2	100 Mbps
3	1 Gbps
4	10 Gbps