

Contribution to the Optimization of the Energy Consumption in SDN Networks

Lagasane Kra¹, Yaké Gondo², Bi Tra Gooré¹, Olivier Asseu^{1,3}

¹Institut National Polytechnique F. Houphouët Boigny (INP-HB), Yamoussoukro, Côte d'Ivoire

²Université Félix Houphouët Boigny (UFHB), Abidjan, Côte d'Ivoire

³Ecole Supérieure Africaine des TIC (ESATIC), Abidjan, Côte d'Ivoire

Email: oasseu@yahoo.fr

How to cite this paper: Kra, L., Gondo, Y., Gooré, B.T. and Asseu, O. (2018) Contribution to the Optimization of the Energy Consumption in SDN Networks. *Journal of Sensor Technology*, 8, 59-67.
<https://doi.org/10.4236/jst.2018.83005>

Received: September 4, 2018

Accepted: September 26, 2018

Published: September 29, 2018

Copyright © 2018 by authors and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

With the advent of new technologies such as IoT (Internet of Things) and Big Data, the increase in users and their different communications have led to a significant increase in energy consumption in network equipment. A new networking technology called SDN (Software Defined Network) is born. It aims to make network management easier. The SDN consists of decoupling the control plane that is the brain, the data plane or the muscles of the network. It allows the programmability of network devices and also the redirection of flows. One or more centralized controllers use algorithms to act remotely on network devices. Because of its operation, this new technology offers opportunities to improve network performance and optimize energy consumption. In this paper, we will use this technology (SDN) to suspend links or routers when they are not used while taking into account the congestion that degrades the quality of service in the network. We have formulated this problem as a linear integer program and proposed algorithms to process it in normal period and peak period. We have used the OMNET ++ simulator to evaluate our algorithms. Thus, our approach showed that 87.5% of ports and 33.33% of links could be shut down to save energy.

Keywords

IoT, SDN, Big Data, Optimization, Peak Period, Normal Period, Heuristic Algorithms

1. Introduction

Communication networks are progressively evolving in terms of size and performance. There are two types of network equipment: active devices such as

routers, switches, etc. (information transmission devices) and passive devices such as cables, fiber optics, etc. (interconnection equipment). Of the two types of equipment, only assets are energy intensive. The evolution of the networks leads to an increase of these equipments in quantity and in performance. The increase of these and their performance increases the consumption of the electrical energy they need for their operation.

A study conducted in 2009 [1] shows that information and telecommunications technologies (ICTs) alone consume 2% to 10% of global energy consumption. Hubs, switches and routers consume 6 Twh/year in the USA [2]. Therefore the search for a mathematical model for the consumption of energy in the communication networks becomes a real concern for the companies of the moment. In traditional networks, when a packet arrives on a port of a switch or router, it applies the routing or switching rules that are registered in an operating system. Generally, all packets that have the same destination follow the same path. In high-end models, hardware is able to recognize the type of application and apply the specific rules to it. But this programming is rigid. It can only be changed manually by the administrator, which obviously takes time [3].

The advent of Software Defined Network (SDN) technologies appears to be a good alternative for acting remotely and dynamically on equipment in order to model energy consumption.

In SDN technology, it is a centralized controller that will be responsible for routing packets in the network via SDN protocol (openflow) by programmability by injecting routing rules provided by the application layer (Figure 1).

In this paper, we use this paradigm to act on network devices by enabling or disabling router ports when they are not working. A new strategy has been developed which takes into account the peak periods (dense traffic) and normal (low traffic) minimizing energy while avoiding congestion. The authors of [4] have in their minimized approach with high delays leading to packet losses.

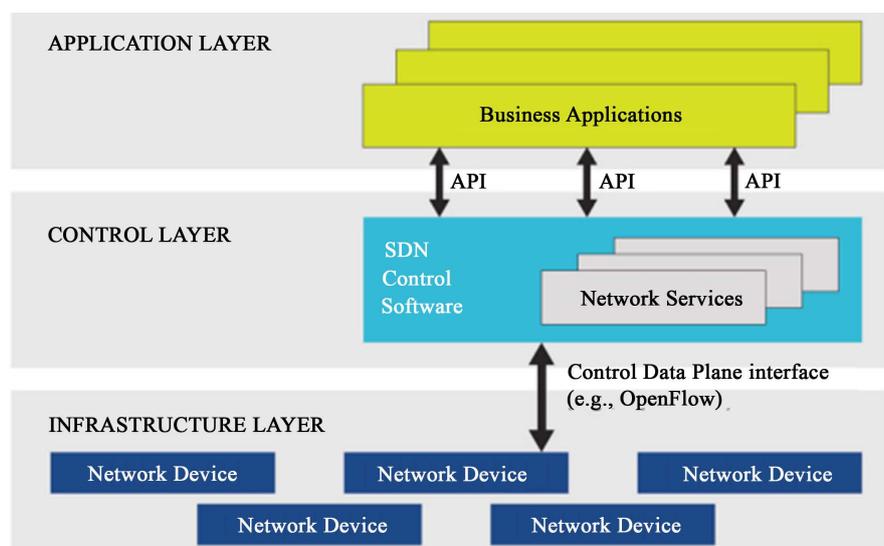


Figure 1. SDN architecture [3].

Our model is based on that of these authors [4]. We have implemented an energy minimization model based on a new strategy. Our work will revolve around the following points:

Section 2 will cover previous work. Section 3 describes the mathematical model of our approach. We present in Section 4, the resolution approach. In Section 5, we will evaluate the performance of the model. Section 6 concludes our article.

2. Previous Work

In this section, we will present some previous work that has addressed the issue of energy consumption in networks. We also formulate some basic assumptions that our future mathematical model must respect.

2.1. Mathematical Model Research Reduce Energy Consumption Optimally

The consumption of energy has been treated by some researchers [4] [5] [6] [7] [8]. In [4], the authors have minimized under three constraints using on/off technology in conventional wired networks, the consumption of energy in the networks (delay, packet loss and jitter). A saving of 40% was obtained. But at each extinction, a delay variation led to packet losses in case of heavy traffic. The authors of [5] [8] minimized the energy in SDN networks using the “compression” approach of the routing table. According to the authors, the devices that can implement the SDN rules uses TCAM (Content-addressable Ternary Memory). This memory in which are recorded the rules, is expensive and greedy in energy. So you have to compress the routing table. Compression maximizes rule space, increasing the number of paths. The consumption of a high-capacity link and that of an unsolicited link is low, some flows can be redirected to other links. As a delay solution, the authors have defined the default rule for forwarding packets to the default port without contacting the SDN controller. An energy saving has been observed but with degradation of the quality of service in terms of congestion in the network. As for the works of [6] and [7], the authors have shown that it is the number of ports of the routers on the network that consume. Consumption modeling would reduce router interfaces when they are not in use.

We orient our work in this way while finding a mathematical model of energy minimization in the SDN network which satisfies the “QoS” in terms of delay of transmission and loss of packets.

2.2. Basic Assumptions

- ✓ Each port has the same rate of energy consumption.
- ✓ Each port can handle multiple services so it can redirect traffic.
- ✓ Choose in the graph, the path or paths that seem to offer more energy saving.

Our future mathematical model will be obtained through a set of processes that will involve theories such as graphs; trees etc.

3. Modeling the Problem

This section will cover the description of our mathematical model.

We formulate our problem as a linear integer program in contributing to the optimization of energy consumption in SDN networks. Let N be a network and $n(t)$ a sub-network of N ($n(t) \subseteq N$). We defined a dynamic approach based on two situations of graph theory:

1) The activation and deactivation of the ports of the routers for a given time t . we note the change in energy consumption.

2) We will assume that a router cannot be turned off and therefore must remain awake.

Once switched on, at each given instant t , a link is established between a router i and a router j . It will therefore be a question of maximizing a number of ports to be deactivated in order to have energy savings under “QoS” constraints. In our approach, we will enable or disable router ports using a smart approach.

The number of ports to disable $\ell(t)$ is defined as:

$$\begin{aligned} \ell : [0, +\infty[&\rightarrow N \\ t &\mapsto \ell(t) \end{aligned}$$

Consider λ_{\max} , the total number of ports on a router. This parameter λ_{\max} is fixed and depends on the types of routers. If the total number of ports on a router is 8, how much should I disable and how, to hope to save the maximum energy?

Let us consider the function f the consumption of energy in the sub-networks. We express the model of our approach in mathematical form called objective function of the solution of the problem that is to say (1) and (2).

Which amounts to:

$$f(n(t), t) = \sum_{i \in n(t)} f(i, t, \ell(t)) + \sum_{i, j \in n(t)} f(k(i, j, t)) \quad (1)$$

A link is the junction between two routers interfaces. $i, j \in N$ having a maximum load capacity of $C(i, j)$ packet traffic per second. The links can be in the following state 0 or 1. Let k be the link state variable: 0 state where the router is off and 1 state where the router is on.

The objective function to be minimized becomes:

$$f(n(t), t) = \sum_{i \in n(t)} f(i, \ell(t), t) + \sum_{i, j \in n(t)} f(k(i, j, t)) \quad (2)$$

where $f(i, \ell(t), t)$ is the energy consumption of the router i whose $\ell(t)$ ports were deactivated at time t and $f(k(i, j, t))$ represents the energy of the link i, j at time t .

$f(i, t, \ell(t))$ is the function to be explained. Power gain function of router i : “ g ”. The function g is a linear and increasing function with respect to the number of ports deactivated at time t .

Let $g_i(t, \ell(t))$: the energy gain of the router i such that:

$$\max_i \ell(t) \leq \lambda_{\max}, \text{ with } g_i(t, \ell(t)) = a\ell(t) + b$$

where $a > 0$.

$$\text{if } \max_t \ell(t) \leq \lambda_{\max}, \text{ then } f_i(t, \ell(t)) = C_i - (a\ell(t) + b) \quad (3)$$

This is the final expression of our function “energy consumption” of router. Otherwise $f_i(t, \ell(t)) = 0$ where C_i is the total consumption of the router i and $f(i, t, \ell(t)) = f_i(t, \ell(t))$.

We deduce that if all ports are disabled, $g_i(t, \ell(t)) \approx C_i$.

We showed above that our function is linear in $\ell(t)$. It is thus refined in the form of:

$$f(n(t), t) = \sum_{i \in n(t)} (C_i - (a\ell(t) + b)) + \sum_{i, j \in n(t)} f(k(i, j, t))$$

Now every affine function is convex and therefore admits a minimum. Our model then becomes:

$$\min(f(n(t), t)) = \min\left(\sum_{i \in n(t)} (C_i - (a\ell(t) + b)) + \sum_{i, j \in n(t)} f(k(i, j, t))\right) \quad (4)$$

With $C_i =$ chassis consumption (C_{ch}) + consumption of ports (C_p) on. From where:

$$C_i = C_{ch} + C_p$$

The explicit objective function becomes:

$$\min(f(n(t), t)) = \min\left(\sum_{i \in n(t)} ((C_{ch} + C_p) - (a\ell(t) + b)) + \sum_{i, j \in n(t)} f(k(i, j, t))\right) \quad (5)$$

Under constraint of:

$$q(f(t), R(F(t), n(t), k(t), t)) \leq Q(f(t)), \forall f(t) \in F(t)$$

$$\text{and } \sum f(t) \leq C_{i,j}, \forall f(t) \in F(t)$$

$$k \in \{0, 1\}$$

Summary of the ratings:

$f(n(t), t)$	Power consumption in the subnet
λ_{\max}	Total number of ports on a router
C_i	Overall energy of the router
$a\ell(t) + b$	Gain of energy obtained during the deactivation of the ports
$f(k(i, j, t))$	The state of ports in s/networks at time t
q	Quality of service perceived by the user
$R(t)$	Set of all requests at the moment t
$f_{s,p}(t) \in F(t)$	Observed request of a user at the instant t from a point s to p
$R(F(t))$	Routing of all requests at time t (see the routing algorithm)
$n(t) \subseteq N(t)$	The subnet included in the network at time t
$Q(f(t))$	Quality of service set to not exceeded for all requests observed

We have found our mathematical model which minimizes, so a method of resolution proves necessary.

4. Resolution Approach

In this part, we proposed a resolution method of our mathematical model.

Solving the problem consists of:

- ✓ Solve by integer linear programming $f_i(t, \ell(t)) = C_i - (a\ell(t) + b)$
- ✓ Solve by the **Kruskal** algorithm by looking for the maximal tree the function $f(k(i, j, t))$

4.1. Principle of Resolution

We are going to build a network (lowest total weight covering tree) from which we will obtain our possible energy savings. The ports to be shut down will consist of those of the adjacent routers. For our simulation, we will use a network of 7 routers each with 8 ports and 9 links. All extinctions of adjacent ports cause those of these links (**Figure 2**).

Our tree covering the lowest total weight becomes (see **Figure 3**).

Total weight: $12 + 12 + 12 + 4 + 4 + 5 = 49$.

4.2. Port Extinction/Ignition Algorithm

Our demand-side extinguishing strategy must select all ports that are not affected by the request and dynamically shut them down.

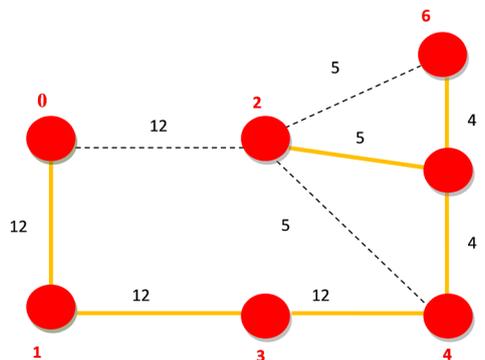


Figure 2. Network with link capabilities.

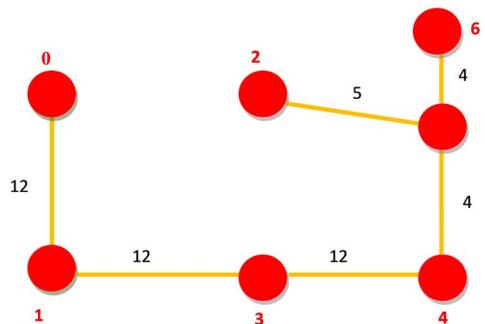


Figure 3. Architecture obtained by the Kruskal algorithm.

In our approach, when a router is turned on, it establishes a link with its neighbors and so on in the network.

Our 7-router network has 8 ports each, only one port is turned on and the (n – 1) ports are off with its links. The circuits are to be avoided in the choice of favorable paths (having the lowest weight).

The Modified SPRING Protocol (**MSP**), is responsible for the extinction of ports and links unsolicited by the request (see Algorithms below).

Algorithm 1: Centralized SDN:<RerouteAndRouterOff>

Data: List-of-Ports:[(0-4),(2-6)..] and the new roads / *Supplied by<SelectPortstoOff>and <ComputeNewRoutes>respectively */

```

1 Begin
2 The controller gives all adjacent nodes the new routes to use for the virtual paths;
3 The controller sees the network as a whole and informs neighboring routers to turn
off all enabled ports except one;
4 Routers 0,1,3 ... send an (ACK) to the controller after the task is executed;
5 The SDN controller identifies the lit ports and turns off the others;
6 All routers apply the change to the forwarding tables for redirection by other ports;
7 Nodes 0,1, 2 ... stop sending IGP packets;
8 Ports (0-1, 2-5 ...) stop and enter sleep mode to be turned off;

```

Algorithm 2: Main loop

```

1 Whileenergy efficient traffic engineering is
active do
2 List-Of-Ports = <SelectPortsToOn>();
3 if<ComputeNewRoutes>(All-Ports-that-are-ON U
List-Of-Ports) then
4 <turn off the links to avoid circuits>;
5 List-Of-Ports = <SelectPortsToOff>();
6 if<ComputeNewRoutes>(All-Ports-that-are-ON\
List-Of-Ports) then
7 <RerouteAndRouterOff>(List-Of-Ports);

```

This **Figure 3** (maximum tree of minimum weight) is obtained thanks to the Kruskal algorithm. The ports of the adjacent routers are stopped using a modification of the SPRING or Segment Routing algorithm as well as the links (see algorithms) [9]. Note that SPRING is designed for SDN.

The resolution approach having been found, we will evaluate the performance of our model.

5. Evaluation and Performance

In **Table 1** below, we present our results.

Table 1. Evaluation of our approach.

Number of routers with 8 ports	Ports off	% Ports off	Number of links	Links off	% Links off
7	49	49/56 = 87.5	9	3	3/9 = 33.33

In our model, we explained high (see 4.1) that the extinct ports are those of adjacent routers. Once the port is off, it drives the one of its links. The SDN is a technology based on the programmability of remote equipment via a centralized controller in the network. The SDN controller, thanks to its global view of the network, is responsible for the extinction of the ports and links, if they are not used by means of a modification of the algorithm SPRING.

Our **Table 1** is obtained from **Figure 2** and **Figure 3**. We applied the Kruskal algorithm to obtain the tree with the lowest weight. This allowed us to have 3 disabled links out of 9. However, we used a network of 7 routers each having 8 ports from which $7 \times 8 = 56$ total ports in the network. When the routers are turned on, only one port on each router is enabled and the $n - 1$ ports are off. In our case, there are 7 ports off on each router i , so 49 (7×7) in total in the network (see **Table 1**).

6. Conclusions

Our mathematical model in SDN networks minimizes energy consumption. Any router chosen, disabling some ports would give a strong energy saving by this model. Our model is flexible and gives us a double energy saving in ports and links. In the ports, an extinction of 87.5% is possible to make savings and 33.33% in the links to also make savings.

In this article, we found our mathematical model; however, improvements are possible and will be the subject of our future work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Chiaraviglio, L., Leonardi, E. and Mellia, M. (2009) How Much Can Internet Be Greened? 2009 *IEEE Globecom Workshops*, Honolulu, HI, 30 November-4 December 2009, 1-6.
- [2] Bruce, N. and Christensen, K. (2005) Reducing the Energy Consumption of Networked Devices. *IEEE 802.3 Tutorial*, San Francisco, 19 July 2005.
- [3] Doherty, J. (2016) *SDN and NFV Simplified: A Visual Guide to Understanding Software Defined Networks and Network Function Virtualization*. Addison-Wesley Professional, Boston.
- [4] Gelenbe, E. and Silvestri, S. (2009) Optimisation of Power Consumption in Wired Packet Networks. In: Bartolini, N., Nikolettseas, S., Sinha, P., Cardellini, V. and Mahanti, A., Eds., *Telecommunications Engineering*, Springer Berlin Heidelberg, 717-729.
- [5] Havet, F., Huin, N., Moulhierac, J. and Phan, K. (2015) Green Routing and Compression of SDN Rules. *ALGOTEL 2015-17th French Meeting on the Algorithmic Aspects of Telecommunications*, Beaune, June 2015.
- [6] Giroire, F., Mazauric, D. and Moulhierac, J. (2011) Energy Efficient Routing. *Francoophone Meetings on Algorithmic Aspects of Telecommunications (AlgoTel)*, Cap

Esterel, 2011.

- [7] Reviriego, P., Sivaraman, V., Zhao, Z., A-Maestro, J., Vishwanath, A., Sanchez-Macian, A. and Russel, C. (2012) An Energy Consumption Model for Energy Efficient Ethernet Switches. 2012 *International Conference on High Performance Computing & Simulation (HPCS)*, Madrid, 2-6 July 2012, 98-104.
<https://doi.org/10.1109/HPCSim.2012.6266897>
- [8] Giroire, F., Moulhierac, J. and Phan, T.K. (2014) Optimizing Rule Placement in Software Defined Networks for Energy-Aware Routing. 2014 *IEEE Global Communications Conference*, Austin, TX, 8-12 December 2014, 2523-2529.
<https://doi.org/10.1109/GLOCOM.2014.7037187>
- [9] Carpa, R., Glück, O., Lefèvre, L. and Mignot, J.-C. (2017) STREETE: Traffic Engineering for Energy-Efficient Core Networks. *Conference Compas 2015*, Lille, June 2015.