An SDN Perspective to Mitigate the Energy Consumption of Core Networks – GEANT2

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An SDN Perspective to Mitigate the Energy Consumption of Core Networks – GÉANT2

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Abstract

The dense usage of networks in peak times forced network designers to over-provision resources to satisfy the needs during these specific times. Resources such as bandwidth, processing power, and memory are prepared oversized to handle high traffic loads, however, most of these devices are underutilised during the non-peak times and this unlocks the potential to optimise the energy consumption of the resources proportionally to its actual traffic utilisation. Due to the vertical integration of the control and data plane in the conventional network, managing the network is challenging. Software Defined Networking (SDN) is a novel networking approach, which provides a programmable and logically centralised control plane, separating the network control from the forwarding devices. Thanks to the features introduced by SDN, the decisions for the network such as routing and forwarding are made globally. In this paper, considering GÉANT network, we proposed a method by which we can remove up to 41% of the link during the peak time traffic and save energy consumption consequently.

INTRODUCTION

The telecommunication sector is growing rapidly. According to GSMA (Intelligence, G. S. M. A., 2017) by the end of 2016, 65% of the world's population had a mobile subscription – a total of 4.8 billion unique subscribers and by 2020, almost 73% of the world's population – or 5.7 billion people – will subscribe to mobile services. In addition, according to Elmirghani et al. (2014) the global wired Internet traffic will have an increase of a factor of 16, to reach 250 Exabyte per month. To keep the pace, Internet Service Providers (ISP) have to update their infrastructure to support this growing demand by enlarging the bandwidth, capacity of routers and switches. With exponential demand for telecommunication services, significant attention has been driven toward energy consumption of this sector from both the economic and environmental perspective. Studies show that Information and Communication Technology (ICT) has consumed more than 4.7% of worldwide energy (Gelenbe and Caseau, 2015; Van Heddeghem et al., 2014) and this will increase CO_2 emission consequently. According to several studies (Webb, 2008; Lambert et al., 2012), by 2020 the emission of CO_2 produced by the ICT sector could range from 2% to 10% of the total CO_2 emissions.

With the aim of obtaining the desired quality of service, having reliability in network architecture, and to sustain peak time traffic, the networking system is mainly designed based on over-provisioning and redundancy to assure Service Level Agreement (SLA). The switching capacity of the backbone networks is usually more than twice the peak hour traffic volumes (Bolla et al., 2011). Moreover, networks are dimensioned in a redundant manner to fulfill resiliency and fault-tolerance in case of software and hardware failure while the rest of the network is underutilized. On the other hand, the energy consumption of the devices is not proportional to the traffic loads but it grows linearly from E_0 to E_{max} (Mahadevan et al. 2009). Therefore, without energy consumption control policies, all the equipment in the network consumes energy to the maximum and consequently increases the global energy consumption of the network which is in opposition with green networking.

Management in the current network architecture is complicated, as each device has a vertical integration in which routing decisions are made in each single device that results in a distributed management. This heterogeneous network requires specific configurations for each device which is not easy and quick in large networks.

Software Defined Networking (SDN) (Open Networking Foundation, 2017) introduces a new paradigm to overcome the limitation of the conventional network. By separating the data plane and control plane, this architecture will enable programmability and provides central control over infrastructures. This eventually results in optimising functionality and performance. Moreover, this will help to have an agile and dynamic network which is always ready to be changed according to the demands while the network design and architecture remains untouched. Figure 1. demonstrates a comparison of these two architectures.

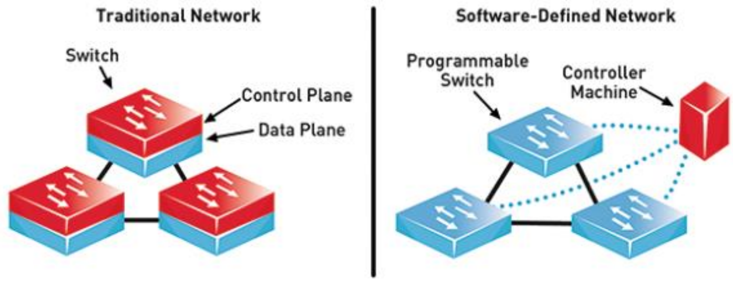


Figure 1.Traditional Network versus SDN

In this work, we evaluate the probability of saving energy in GÉANT core network from the SDN perspective. GÉANT project launched in November 2000, operating the European network for research and education community. It interconnects National Research and Education Networks (NRENs) across Europe. This project then followed by a second generation network, named GÉANT2, covering 30 national networks in 34 countries. The next GÉANT project (GN3) started in 2009 and continued for four years. The project entered its fourth phase named GN4-1 followed by a second version, GN4-2. GN4-2 is the current phase as part of the GÉANT 2020 Framework Partnership Agreement (FPA). The main objective is to provide an innovative and stable environment for the growth of the GÉANT network, ensuring that Europe remains in the forefront of research by providing the best possible infrastructure. Currently, the GÉANT network is the largest and most advanced research and education network in the world by gathering 38 NREN partners. It's connecting over 50 million end-users at 10,000 institutions across Europe. The backbone network is operating at speeds of up to 500Gbps and links to research networks in other world regions covering over 100 national networks worldwide. (Geant.net, 2017)

In this paper we formulate the network model and the energy consumption of the network and of each individual device. Later, we evaluate the potential of a real backbone network to decrease the energy consumption. We prove our assumption by describing and evaluating a scenario by real traffic data. In the last part the future work is explained.

RELATED WORK

In communication networks, energy efficiency can be achieved via two main approaches: (i) link rate adaptation and (ii) energy-aware routing (EAR). The first work on the Internet's energy consumption was evoked by Gupta and Singh (2003) in which they analysed the possible approaches to reduce the energy consumption in a network of computers. Bilal et al. (2013) did a survey on link rate adaptation. In this approach the probability of saving energy is high, however, it cannot be applied on current devices and it requires new hardware design. To be more specific, Dynamic Voltage Scaling makes the devices to be power-proportional and it is considered as a futuristic scenario. EAR is a classical approach for turning off the unused devices (Bolla et al., 2011; Bianzino et al., 2012; Giroire et al., 2010; Zhang et al., 2010; Cianfrani et al., 2012). In this approach a new routing algorithm must be considered which is capable of aggregating the traffic load over a specific number of network components and their links, allowing the other devices to be switched off. As the traffic level in a given network follows a well-known daily and weekly behavior (Qureshi et al., 2009), there is an opportunity to adapt the utilisation of the network according to the current request. However, there are a number of issues for this method that should be considered for the solutions. Firstly, the time required to shut down or activate a link is substantial. This problem is studied in IEEE 802.3az standard in which the sleeping/activating time can be decreased by up to 5μs for 10GBASE-T links (Christensen et al., 2010). Moreover, as traffic varies over time, EAR computes and applies a new routing configuration which results in network oscillation. In section IV, with the explanation of the solution we show that this approach is more efficient compared to other EAR solutions and decreases the number of decisions for each device.

Similar studies for optimising energy consumption of network in the SDN environment has been done. In Elastic Tree (Heller et al., 2010) the authors proposed a system in which the energy consumption is dynamically adopting in data center networks by using SDN. Their proposed solution functions in three modules; optimiser, routing and energy control. Optimiser finds the subset of the network, which is suitable for the incoming flows to be traversed. The routing module calculate the set of paths for the flows and then pushes routes into the network. In the last step, power control determines the power states and turns the device on /off according to the decisions of the previous steps. The work by Markiewicz et al. (2014) and Rahnamay-Naeini et al. (2016) also aims to reduce the energy consumption in SDN by powering down links or nodes. Markiewicz et al. (2014) consider a campus network and try to turn off as many nodes as possible according to the traffic load for different times of the day. Similar work by Rahnamay-Naeini et al.(2016) is trying to reduce as many links as possible by considering the value that is assigned to each link based on their energy consumption.

NETWORK MODEL

We propose a model representing the physical topology of a network with SDN by an undirected graph $G = (V, E)$ that *V* is a set of nodes $i \in \{1,2, \ldots, |V| = n\}$and *E* is a set of links *(i,j)* between two nodes. For a simple graph with nodes of *V*, the adjacency matrix is a square $V = |V| \times |V|$such that the element $A_{i,j} \in \{1,0\}$ has the value of 1 when a link exists between two nodes *i* and *j*, and 0 when there is no edge between the nodes. The diagonal elements of the matrix are zero, as the edges from a vertex to itself are not allowed in simple graphs. The weight of matrix

A is known as the capacity of each link and it is gathered in matrix *C* in which $C_{i,j}$represents the capacity of the link between node *i* and *j*.

The graph *G* represents the static part of the network, while the forwarding plane is the dynamic part of the network and interacts with the changing traffic. The traffic to be transmitted via network is defined by the exchange matrix $X = |V| \times |V|$ in which the $X_{i,j} \in R+$ is equal to the flow that needs to be transported from node *i* to node *j*. As each node for a common destination might have different (sub) flows, we discard this fact for simplicity and only the aggregated traffic will be considered.

The forwarding plane decides the output port of each node based on the destination and defines the overall path $P_{i,j}$between node *i* and node *j*. A path is an ordered set of nodes such that $P_{i,j} \in V$ and $P_{i,j} = \{v_1, v_2, \dots, v_l\}$ with $v_1 = i$, $v_l = j$ such that $v_i$is adjacent to v_{i+1}. And the second notation of the path is introduced by $Q_{i,j} \in E$ with $Q_{i,j} = \{e_{v1,v2}, e_{v2,v3}, \dots, e_{vl-1,vl}\}$.

To show the forwarding decisions of the nodes, the matrix $F = |V|^2 \times |V|$ is introduced such that $F_{(i,j),v} = 0$,if the flow from node *i* to node *j* will not be forwarded by the node $v \in V$,i.e. $\forall v \neq j, v \notin P_{i,j}$, otherwise $F_{(i,j),v}$ gives the node $v+1$ that is the node adjacent to the node v within the path $P_{i,j}$. In other words $F_{(i,j),v} = v+1$ that is the next hop from node *v*. Therefore, the path between node *i* and node *j* can be defined as follows;

$$P_{i,j} = \{i, F_{(i,j),i}, F_{(i,j),F_{(i,j),i}} \dots, j\}$$

Network Constraints

In a redundant topology, several paths can be designated, however, only paths satisfying the flow requirement can be chosen. Constraint (1) ensures that the capacity of the link has to be greater or equal to the flow throughput.

(1) $\forall e_{k,l} \in Q_{i,j}, C_{k,l} \geq X_{i,j}$

Since a single link might be participating in different paths, the capacity of the link can be shared for different flows. Constraint (2) ensures that a path can only be a good candidate if :

(2) $\forall v \in P_{i,j}, \sum X_{k,l} \leq C_{v,F_{(i,j),v}}$

Regarding the aforementioned constraint, to choose the next hop for a given path can be determined with the constraint (3) as follow;

(3) $\exists v' \in \{V - P'_{i,j}\}, C_{V,V'} - \sum_{(k,l) \in V^2,(k,l) \neq (i,j) \mid F_{(k.l),v} = v'} X_{k,l} \geq X_{i,j}$

Multi-commodity flow model is a classical routing problem in a network with multiple flows, which ensures the flow conservation at source, destination and in transit (Barnhart et al., 2009). This is guaranteed in constraint (4).

$$\exists\, e_{i,j} \in Q_{sd}, \qquad \sum_{e_{i,j} \in E} e_{i,j} - \sum_{e_{i,j} \in E} e_{j,i} = \begin{cases} 1, & i = s \\ -1, & i = d \\ 0, & i \neq s, d \end{cases}$$

Therefore, the Matrix *F* can be seen as the global forwarding table of the entire network.

Energy Consumption Model

Several researches were done to model energy consumption of the network devices. In Hossain et al. (2015), authors introduced a model for the energy consumption of Ethernet switches. However, this model is specifically for Ethernet switches and cannot be used for our scenario. Therefore, we assume a generic energy consumption model.

As mentioned earlier the energy consumption of a switch is not proportional to the traffic load (Mahadevan et al., 2009). However, the dynamic part contributing to the energy consumption of the switch is considerable. The fans, chassis, switching fabrics, etc., are considered as the fixed energy consumption of the switch, while working ports and their capacity are referred to the dynamic part. The Equation (1) describes the energy consumption of a switch:

(1)

$$\epsilon_v = \alpha + \sum_{(i,j)\ incident\ to\ v} \mu(C_{i,j})$$

Where α represents the fixed energy consumption, and μ is the energy consumption of the ports considering the link capacity from matrix *C.* And the overall energy consumption of the network can be derived from matrix *A* and Matrix *C* as follows (2) ;

(2)

$$\varepsilon_{tot} = \sum_{a_{i,j} \in A} a_{i,j} \left(\alpha + \sum_{(i,j)\ incident\ to\ v} \mu\big(C_{i,j}\big) \right)$$

METHODOLOGY

To analyse the possibilities for reducing energy consumption of core networks, we consider a set of scenarios with the GÉANT network. As explained earlier the GÉANT project operates the European network for research and education community. The latest network map of GN4-2 is shown in Figure 2. As can be seen, the links are operating at mediums with capacity of 1.2 Gbps, 10 Gbps and 100 Gbps.

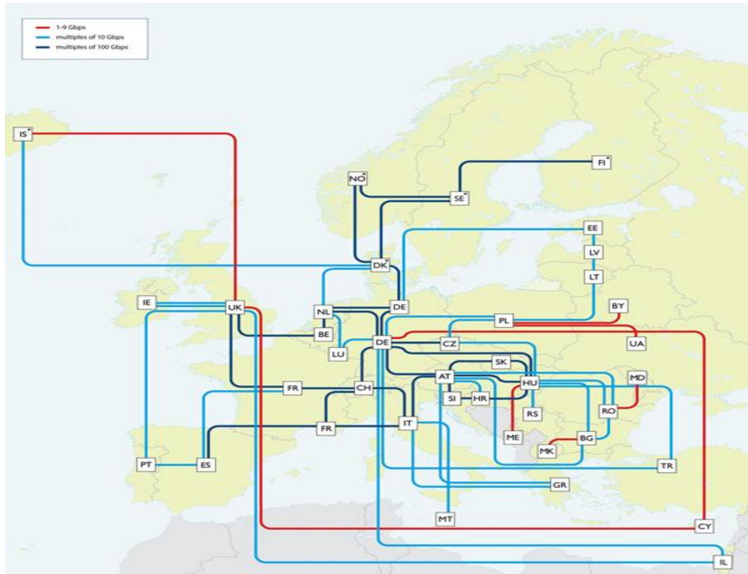


Figure 2. GÉANT Network (Geant.net, 2017)

We synthesise matrix X similar to the data sets available in SNDlib (Sndlib.zib.de, 2017), which represents the dynamic traffic of a subset of nodes with the granularity of 15 minutes. In this matrix all the nodes send traffic to other destinations. Figure 3 illustrates the graph of our scenario.

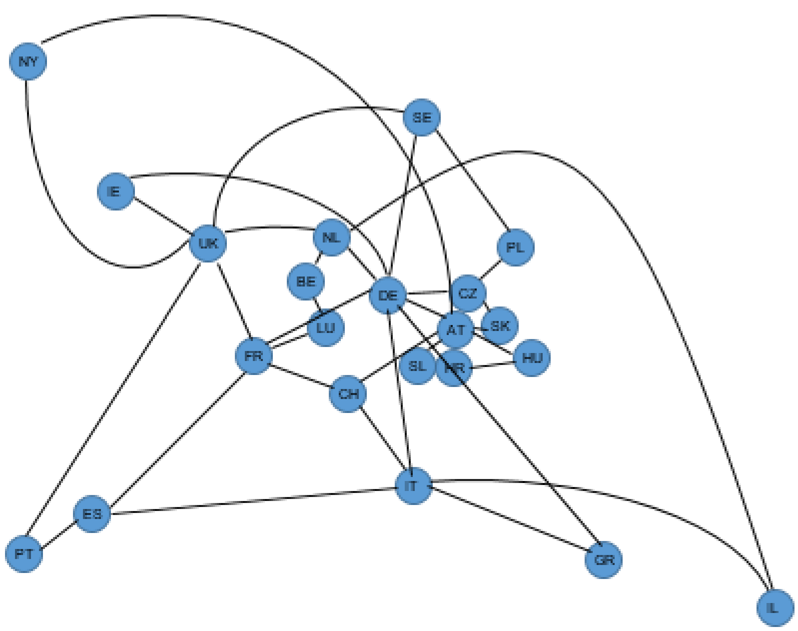


Figure 3. Graph of GÉANT Network

The method that we considered only focuses on the paths that were already used. We route the traffic by using the used path while satisfying the constraints (1), (2) and (3) mentioned in the previous section. Nevertheless, by violating any of the constraints a new path with enough capacity will be calculated to accommodate the flow, using the minimum number of resources. We name this approach Shared Path First (SPF). As an example, assume the first flow from AT to BE (Figure 4). For the first flow the shortest path will be chosen similar to Figure 4. And for the next flow from AT to FR, although a shorter path through CH exists, the path from BE to FR will be chosen. Moreover, while choosing this path, the network constraints are considered. Having the first flow, traffic from AT to BE, the selected path respects the constraints. As for the first constraint, each link has the capacity higher than the size of the flow. For the second constraint, the overall path consisting of several links can accommodate the traffic. Considering the second flow, traffic from AT to FR, both constraint (1) and (2) are ensured. However, since the medium is used by other flows the third constraint guarantees that the shared links have enough capacity to handle the traffic. Similarly, for all other flows this method is applicable.

RESULTS AND ANALYSIS

In order to evaluate the method in the GÉANT network, we considered 15 minutes of flow transmission for different times in night time and day time, which are expected to have different traffic loads. We compared SPF with the Dijkstra's algorithm to evaluate the final gain of the proposed model. According to the available dataset, to find the shortest path between each pair of nodes for the required flows all the edges in the network were utilised. However, with SPF we only route the traffic by using the used path considering the constraints, otherwise, a new path with enough capacity will be generated. By applying SPF we could save up to 41% of the links compared to the shortest path approach. Figure 5 demonstrates the adjacency matrix of the two mentioned approaches. The black boxes represent the active link between two nodes. We could fulfill the constraints and successfully transfer the flows by using only 21 out of 36 links. Since all the nodes were sending traffic it was not possible to turn off any node. From each node, there is a path to other nodes that are using the shared path only.

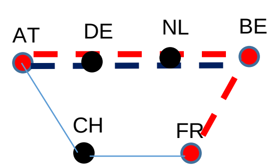


Figure 4. The traffic from AT - BE and AT - FR by using SPF

Path from AT to FR

Path from AT to BE

According to the Equation (2), the energy consumption model of each device consists of a static and dynamic portion. If we assume the dynamic part consumed ρ% of the static portion, the equation will be as follows, assuming that all the devices are using the same amount of energy;

(3)

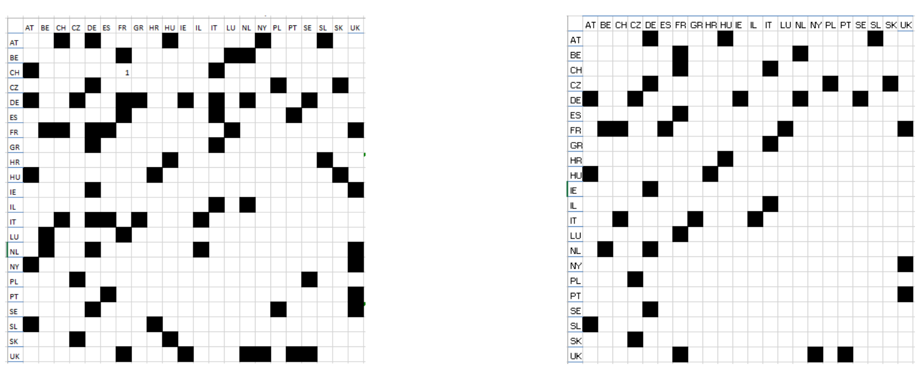
$$\varepsilon_{tot} = \sum_{a_{i,j} \in A} a_{i,j} \ (\alpha + \frac{\rho}{100} \ \alpha)$$

Considering sequential values of ρ as (1, 2, 5, 10, …), we can observe the impact of removing links on the overall energy gain percentage of the network (Figure 6). In fact, this graph shows the energy gain of the network by comparing two different algorithms, SPF and shortest path. The value of the gain has been normalised in this graph in following way:

$$\frac{\varepsilon_{Shortest} - \varepsilon_{SPF}}{\varepsilon_{shortest}}$$

As we can see, if we consider that each link considers 10% of the energy consumption of static part, SPF can have a power gain of a little over 10% over shortest path first. One important point to be noticed is that when we are considering a link, it is actually two interfaces of two different switches. While calculating the gain, we have also considered this particular information.

And finally, this gain is purely based on reducing the number of links. There are several other factors that should be considered. For example, for each flow a new path is calculated, SPF is not causing device oscillation since the new path is utilising the previous used links compared to shortest path first. However, this requires more research and it is out of the scope of this work.



(A) *(B)*

Figure 5. (A) Adjacency Matrix with Dijkstra's Algorithm

(B) Adjacency Matrix with Shared Path First

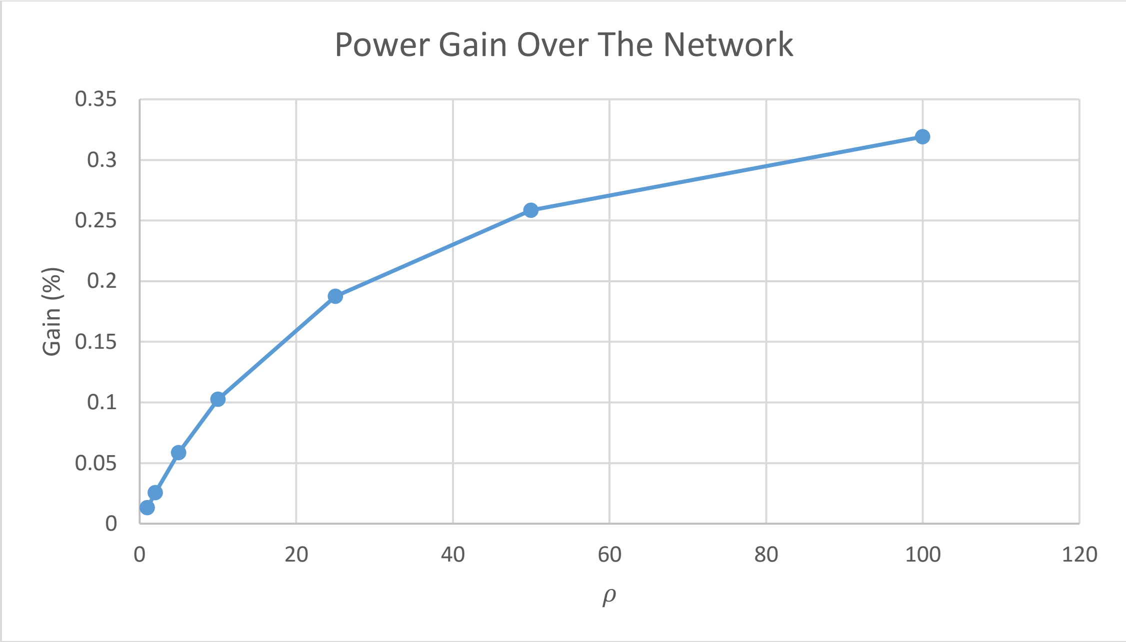


Figure 6. Power Gain of the network with SPF vs. Shortest Path

DISCUSSION

The obtained results are according to the traffic data set for different times of the network, when all the nodes were active. In this case, GÉANT network and in general all core networks, the probability of avoiding nodes in routing is low as each node has a critical position in the architecture and several sub-nodes are connected to it. Each main node has several sub-nodes and they are always active with sending or receiving data and there is no possibility to turn off any node. However, unlike the core network architecture, the campus network architecture and other enterprise networks have a specific pattern of traffic load due to working hours (Qureshi et al., 2009). Therefore, reducing energy consumption has a distinguishing probability by eliminating nodes and links.

Moreover, a specific energy consumption model for SDN switch can make a more precise decision. In addition, as the network is wide across Europe it is interesting to consider the energy consumption of supporting infrastructure such as repeaters and the effect of distance on energy consumption of the links.

Conclusion

In the traditional network architecture, redundancy and over provisioning are design techniques to ensure reliability and to improve the fault tolerance in special occasions, such as peak traffic times or in case of a hardware or software failure. This is due to vertical integration of the network while there is absence of a global vision of the network. By SDN, however, the global view provisioned can help to make decisions dynamically and adjust the consumption of resources in accordance with the demand. In this paper, we proved that by managing the routing and forwarding decisions in a network, the possibility of decreasing energy consumption is high. Specifically, in GÉANT network in peak traffic time we could save up to 41% of the links.

Since this problem is a Mixed Integer Linear Problem (MILP) (Giroire et al., 2010), a heuristic algorithm can be a solution to apply our proposed method to solve the problem of routing. In the related works (Rahnamay-Naeini et al., 2016; Heller et al., 2010; Markiewicz et al., 2014), authors solved this MILP to perform their approach of power saving. For future works, we will solve the problem with a heuristic algorithm and validate the results with a simulation tool.

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