GMNet: An SDN Based Energy-Aware Routing Model for MPLS Networks

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Abstract

Reducing the energy consumption is an important subject on many areas due to increasing energy cost and environment protecting issues (Green House Gases emissions etc.) recently. Especially, the Internet has become a major source of *power consumption due to the rapid growth of network users and new applications (e.g. VoIP, IPTV etc.) that results in large amounts of traffic. In this paper, an energy-aware routing and resource management model is proposed for Multi-Protocol Label Switching (MPLS) networks. The proposed model, Green MPLS Network model (GMNet), is based on a central control unit that manages the whole traffic with Software-Defined Networking (SDN) approach. The controller is responsible for energy-aware routing and resource management on a network with pre-established paths. The experimental results verify the achievements of the proposed model under various traffic conditions.

Key words: Software Defined Networking; the controller; energy-aware routing; MPLS; energy efficiency

1. Introduction

In the last decade, saving energy has become an important and common endeavour both for industries and humankind. Therefore, national and international foundations and industries work on reducing the power consumption to protect the environment and to decrease the costs. Especially, some studies have focused on saving energy in the Internet because according to these studies, the ratio of Internet power consumption accounts for up to 10% of the worldwide energy consumption [1,2,3]. These studies are related to adapting link rates, turning off unused network elements (routers, NICs, links and ports) and servers (e.g. energy efficient CPU, cooling system and server design). The Internet consists of many network elements to provide redundancy for protecting Internet from failures, packet drops and delays. Some network elements are rarely used or not used at all under the various traffic loads due to the redundancy. In order to reduce power consumption, low traffic loads can be aggregated and unused network elements can be turned off.

In the Internet, both aggregating the traffic loads and routing decisions require up-to-date neighborhood information (traffic, topology etc.) that is distributed and updated hop by hop via routers. Therefore, adding new network elements or deciding new routes takes relatively long time [4]. In the updating process, if out of date (expired) neighborhood information is used by a router, routing decisions may not be computed accurately and it results in inefficient usage of network. Another problem of the Internet is the complex and vendor specific control layer of the network elements that decide routing and distribute network information. Due to various types

* Power & Energy interchangeably used in this paper.
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and brands of routers, network management and distribution of neighborhood information have become almost impossible [1,5].

In order to handle aforementioned problems, there are several studies that decouple control planes of routers in a network to a single controller [4,5,6,7]. With the advantage of decoupling all control planes to one controller, we can get rid of complex routing algorithms and vendor specific configuration problems. The idea of gathering all control planes to single controller is a novel idea called Software Defined Networking [4,6]. Today, the Open Networking Foundation (ONF) is founded by many universities and industrial companies for establishing and standardizing the SDN concept. They continue to standardize the specifications of the SDN [5]. Their first accepted standardization, OpenFlow architecture, has been introduced in [7]. OpenFlow based studies show that controlling the overall network with a centralized controller is applicable and effective [5,8]. Moreover, the SDN based controller is robust on failures. It prevents network from out of order delivery and route oscillations. It can also control and measure the overall network directly for energy saving and load balancing. In this paper, we propose an SDN based approach on MPLS networks for energy saving. The proposed model aims to minimize the number of active network elements. As a central agent, the controller manages the traffic based on pre-established Label Switching Paths (LSPs). Our algorithm minimizes the number of active LSPs, which in turn, results in lower energy consumption.

The rest of the paper is organized as follows. Section II reviews the related work for greening of the Internet. Section III presents proposed model for communication of users and applications with minimum energy costs. Section IV presents simulation results. Section V concludes the paper and lists future works.

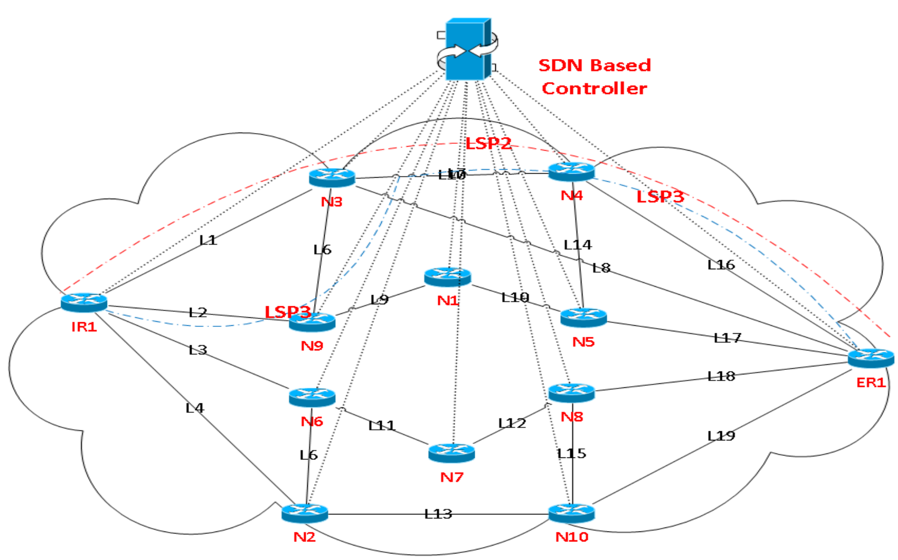

Figure 1. Experiment Topology of our design for one IR-ER pair.

2. Related Work

There are many studies related to reducing energy consumption of the Internet's network elements. They exploit two design features of the Internet. First, there are much more than needed network elements to provide redundancy for failures in the Internet. Hence, some of the network elements are not used or less frequently used under light traffic loads. Second, network elements have high link capacities to prevent bandwidth overprovisioning under high traffic loads. Based on aforementioned design features, two well-known approaches are proposed to reduce energy consumption of the Internet. The idea of first approach is to consolidate traffic into several paths and powering down network elements which are located on unselected paths [11]. The second approach is to adapt data link rates to their offered traffic loads [10] (rate adaption). Adapting link data rates can reduce the energy consumption of links and ports by decreasing their high link capacities. Many studies show that powering down approach provides more energy saving than rate adaption [12,13]. Therefore, in this paper we propose a novel algorithm based on the second approach.

Powering down approach has been first introduced in [14]. This work and the increasing energy consumption of Internet's network elements have triggered many researchers to search for new methods applying power down approach on the Internet. Several problems may arise in case of turning a router off completely. For example, route oscillation, forwarding loops in IBGP and time consuming update procedure in OSPF are some of the well-known issues. Due to these problems, some studies focus on turning off other network elements such as, links, ports and NICs [15,16,17]. However, [18] shows turning links/ports off saves only up to 8% of total router power consumption. [12,13,14] are the researches that turn off router completely to accomplish higher energy savings. A router's energy consumption stems from usage of a power supply, NICs, CPU and ports. Powering down a router means to turn off the router chassis, CPU, ports and all its components. In [16] and [17] authors show that making online routing decision is an NP-hard problem and can be accomplished in a few hours for a medium-sized network. Hence, [16] and [17] propose to use pre-established paths that are formed offline to avoid long path computation time.

3. GMNet Model

The most important features and trends in the results should We propose Green MPLS Network (GMNet) model that uses pre-established multi-paths (LSPs) to minimize power consumption of MPLS networks. We assume that LSPs are pre-established by a standard protocol

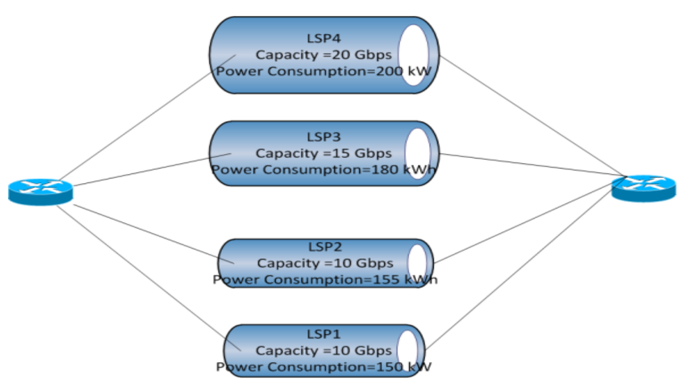

Figure 2. The capacities and power of LSPs

such as Resource Reservation Protocol- Traffic Engineering (RSVP-TE) or Constraint Based Label Distribution Protocol (CR-CDP). We also assume that several MPLS LSPs are pre-established between each ingress-egress router (IR-ER) pair as shown in Figure 1. All the accepted requests having the same IR-ER are aggregated and forwarded through the associated LSPs depending on their capacities and energy consumption. After flow aggregation, unused LSPs and routers are turned off for energy saving. SDN based controller executes all algorithms and manages all LSPs and routers. In this section, we explain our algorithms and the design issues of the SDN based controller to demonstrate how we provide energy saving in MPLS networks.

Algorithm 1. The pseudo code of Turning On/off LSPs Algorithm

Algorithm 1 Function Turning On/Off LSPs (TOOL)

```
Require: D^ji, Indice, Track, Level, LSPCounter
k = LSPCounter
Track(Level) = k
TrackVar = Level + 1
while k <= numberofLSPs do
    if C_k^ij < D^ji then
        remainder = D^ji - C_k^ij
        resultRemain(Indice, 1) = remainder
        k = k + 1
        Function TOOL(remainder, Indice, Track, TrackVar, k)
    else
        remainder = D^ji - C_k^ij
        resultRemain(Indice, 1) = remainder
        if remainder > 0 then
            Indice = Indice + 1
            Function TOOL(remainder, Indice, Track, Level, k)
        else
            c1 = 1
            c2 = Level
            while Level >= c1 do
                resultcapacity(i, j, Indice, Track(c2)) = C_Track(c2)^ij
                AllSolutionsIndice(i, j, Indice, Track(c2)) = 1
                c1 = c1 + 1
                c2 = c2 - 1
            end while
            Totalcost(Indice) = ∑ OpennedNodes + Links
            Indice = Indice + 1
        end if
        k = k + 1
    end if
    Track(Level) = k
end while
MAIN()
for i = 1 to Number of IRs do
    for j = 1 to Number of ERs do
        Track[numberofLSPs] = 0
        function TOOL(D^ji, 1, Track, 1, 1)
        minCostIndice(i, j) = Min(Totalcost)
        Open(AllSolutionsIndice(minCostIndice(i, j), :) == 1)
        Close(AllSolutionsIndice(minCostIndice(i, j), :) == 0)
    end for
end for
AllTotalcost = sum(the cost of opened routers and links)
```

3.1. Turning On/Off LSPs

The key factor to gain energy saving is turning on/off LSPs. According to the studies presented in [16,17], the most energy efficient paths are the ideal paths. They maximize energy saving by aggregating the flows into the most energy efficient paths. If these paths encounter a traffic above the desired utilization value, they activate some other paths that are more energy efficient than the other residual paths.

Choosing the most energy-efficient path may not always result in the most energy saving. For instance, assume four LSPs LSP1, LSP2, LSP3 and LSP4 ranked by energy consumption as depicted in Figure 2. Assume that the current traffic load is 10 Gbps and only LSP1 is active. Then, the new traffic load becomes 18 Gbps. In this case, LSP1 cannot satisfy the new traffic load and LSP2 will be opened because it is the second most energy efficient LSP. As it is seen in Figure 2, LSP4 consumes more power than the other LSPs (LSP1 and LSP2), but LSP4 satisfies incoming traffic load. Using LSP4 instead of LSP1 and LSP2 will save more energy. Therefore, our proposed algorithm takes both capacity and power consumption of each LSPs into account when deactivating/activating LSPs. To determine which LSPs to be turned off/on, we take the combinations of LSPs into account. Our algorithm can find the optimal solution in 2^L-1 (L=number of LSPs). It finds the solutions by comparing each tunnel step by step (one by one, two by two…) until all combinations are examined. The algorithm looks for solutions as depth first search method. Therefore, it can find optimal path in 2^L-1 iterations. Turn On/Off LSPs algorithm pseudo-code is shown in Algorithm [1].

Consider the scenario shown in Figure 1 in which the LSPs share some of their links and nodes. Turning on two LSPs may not mean the entire network will consume as much energy as two LSPs. We consider the total power consumption based on power consumption of active nodes and links. For example, the energy consumption of LSP2 and LSP3 will be calculated by summing energy consumed in node 3, 4, 9 and their connections to each other.

The traffic load information is crucial to estimate the future traffic in terms of energy saving. Additionally, knowing the traffic inclination, whether it is temporary or stable, is a key factor to decide which LSPs will be opened/closed. As a result, atomic or delayed updates based on traffic inclination affect power consumption ratio. Therefore, predicting future traffic has a crucial effect on energy saving. The previous and current traffic information or their combination can be used to forecast the future traffic. But, this will be considered as a future work.

3.2. Load Balancing

Load-balancing is one of the crucial factors to provide efficient usage of network elements and to increase network utilization. Thus, we have to balance the traffic loads of active LSPs between each IR-ER pair. After deciding which LSPs will be turned on/off, we have to distribute traffic to the active LSPs with respect to Equation (1). For instance, suppose the traffic load between an IR-ER pair is 90 Mbps and this load needs to be distributed across two active LSPs. The capacities of LSP1 and LSP2 are 100 and 50 Mbps respectively. The traffic loads have to be distributed across the two LSPs with the portions of 60 Mpbs and 30 Mbps. How the controller distributes the traffic loads to the LSPs is explained in the next section.(T_k^{ij} =Traffic k^{th} of LSP in i^{th} IR- j^{th} ER pair, C_k^{ij} =Capacity of k^{th} LSP in i^{th} IR- j^{th} ER pair, l= total LSP in i^{th} IR- j^{th} ER pair)

$$\text{new } T_k^{ij} = \sum_{k=1}^{l} T_k^{ij} * (C_k^{ij} / \sum_{k=1}^{l} C_k^{ij}) \qquad (1)$$

3.3. SDN Based Controller Design

The whole Autonomous System (domain) is managed by a controller that is similar to the idea of Bandwidth Broker (BB) [19,20]. In the literature, the first implementation and scalability analysis of BB signaling protocol are proposed by us [19,21,22]. In this paper, we design the controller based on BB idea presented in our previous works. We added energy saving features into our previous study.

In the traditional Internet, getting the traffic information and controlling network elements online is impossible due to propagation and transmission delays. However, the SDN based approach overcomes these issues by the help of direct connections to network elements as shown in Figure 1. Routers can send their traffic variations to the controller instantly similar to the idea of OSPF. Whenever the traffic changes above a specified threshold (e.g. 10%), SDN controller starts to execute the load balancing algorithm. After load balancing algorithm performed, send new load balancing parameter to each ingress router. The controller does not need to turn on new LSPs if the traffic load can be handled by active LSPs after load balancing process and therefore it reduces power consumption of the network. However, the traffic load of an LSP can exceed the specified link utilization threshold (e.g. 90%). In that case the controller performs Turning On/Off LSPs algorithm.

Turning routers on/off immediately can cause route oscillations and out-of-order packet delivery. Out-of-order packet delivery causes a corruptive effect on TCP connections (85-90% of the connections in the Internet is based on TCP). Hence, the controller turns on/off routers after aggregating flows to opened LSPs gradually by active feedbacks. Aggregating traffic loads will be done in a flow-by-flow manner for decreasing packet loss.

We use a flow-based hashing approach in order to avoid out-of-order packet delivery. In this approach, hashing is applied on source and destination IP addresses and possibly other fields of the IP header. As it is mentioned in [23], the traffic will be first distributed into N bins by using module-N operation on the hash space. The SDN control element performs a modulo-N hash over the packet header fields that identify a flow. In the first step, suppose that the total traffic rate is F bps, each bin approximately receives the amount of F/N bps. The next step is to map N bins to active LSPs. The number of bins assigned to an LSP is determined based on its load portion [6]. For instance, assume that the total traffic load is 150 Mbps, and this load needs to be distributed across three LSPs with the portions of 75 Mbps, 45 Mbps and 30 Mbps in an IR-ER pair. In this scenario, if we have 150 bins, the ingress router will assign 75 bins to the first LSP, 45 bins to the second LSP and 30 bins to the third LSP. As a result, ingress router is responsible for load balancing but the load portions are decided by SDN controller.

4. Discussion

We evaluate our model in terms of energy saving, scalability and load balancing (traffic engineering) in a limited link utilization. For the experiments, we use our design topology shown in Figure 1. Traffic loads are aggregated into pre-establish paths. These LSPs are pre-established by a standard protocol such as RSVP-TE or CR-CDP and the establishment process is not considered. All links are unidirectional. The power consumption of each node is the same.

Representing the current Internet traffic behavior with any of the existing traffic models is almost impossible [24]. Therefore, we use real traffic loads from production networks for our experiments [9]. CAIDA which has advanced tools to collect and analyze the data based on source and destination addresses and traffic-type for different time intervals. To generate traffic according to the traced data, we normalize the traced data rate and map it to our test bed. It means the traffic behavior of each source node changes according to the traced data characteristics during the experiment.

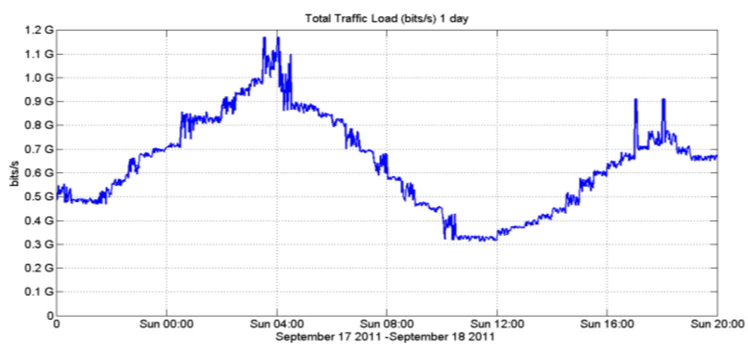

Figure 3. The total traffic matrix in one day is taken from

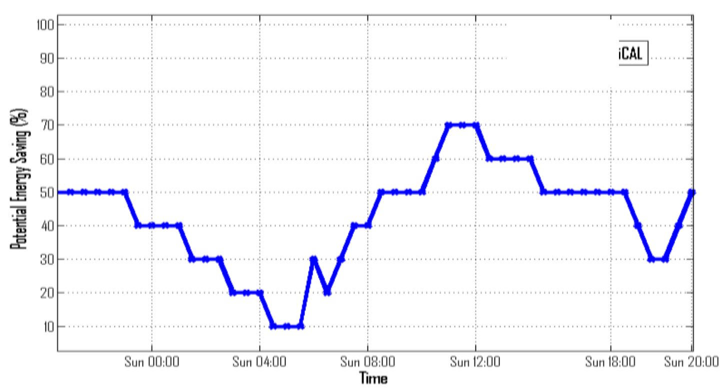

Figure 4. TOOL energy saving results under [9].

In our experiment topology, we set the capacities of each link to 0.8 Gbps. We design this topology to show how our model reduces the power consumption in one IR-ER pair. There are 9 LSPs passing through ten core routers. In Figure 3, the traffic loads of experiment are presented.

The energy saving with our model is shown in Figure 4. Our model can save up to 70% energy under various traffic loads. It also shows how our model achieves the optimal energy saving.

Conclusions

In this paper, we propose a method to reduce power consumption via turning routers off by applying SDN based approach on MPLS networks. We present Load Balancing and Turn On/Off LSPs Algorithms executed by a central SDN controller to save more energy. According to the evaluation results, up to 70% energy savings can be achieved. The proposed algorithms can be implemented on any MPLS networks at any time, since they do not consider how LSPs are pre-established. Therefore, our proposed algorithm differs from other approaches that use pre-established paths.

In our experimental topology, we use fixed-size LSPs. Some links may be shared by multiple LSPs. While traffic conditions change, to resize current active LSPs accordingly may be a good idea compared to shutting/opening LSPs to save more energy. Resizing active LSPs dynamically will provide us not to open new LSPs and that will result in reduced energy consumption. Implementing and adding LSP Resize Algorithm into the SDN controller design will be our first future work.

SDN Controller executes Load Balancing and Turn On/Off LSPs Algorithms in case of a traffic variation detected above a specified threshold value (e.g. 10%). The traffic variation is the difference of traffic loads between our algorithm's current and previous runs. As it is mentioned in Section III, saving more energy is applicable by estimating whether the traffic load inclination is permanent or not. Therefore, various estimation methods for understanding the traffic inclination direction will be examined for our second future work.

In this study, we do not take into consideration how LSPs are pre-established. The design issues of LSPs and network topology may affect our model performance. Therefore, our third future work will be about pre-establishing procedure of LSPs based on power consumption of network elements and traffic matrix information.

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