Link Sleeping Optimization for Green Virtual Network Infrastructures

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Abstract—**Power consumption in Information and Communication Technology (ICT) is 10% of total energy consumed in industrial countries. According to the latest measurements, this amount is increasing rapidly in recent years. In the literature, a variety of new schemes have been proposed to save energy in operational communication networks. In this paper, we propose a novel optimization algorithm for network virtualization environment, by sleeping reconfiguration on the maximum number of physical links during off-peak hours, while still guaranteeing the connectivity and off-peak bandwidth availability for supporting parallel virtual networks over the top. Simulation results based on the GÉANT network topology show our novel algorithm is able to put notable number of physical links to sleep during off-peak hours while still satisfying the bandwidth demands requested by ongoing traffic sessions in the virtual networks.**

Keywords-component; green networks, link sleeping; energy efficiency, virtual networks, network virtulization

I. Introduction

Currently, telecom operators and Internet Service Providers (ISPs) are considering energy efficiency in their networks as a high priority. This incentive is inspired by the growth in energy prices, the continuing expansion of the customer population, the spreading of broadband access, and the expanding services offered [1]. Power consumption in information and communication technology is rapidly increasing by 6% rate a year, while it is already 10% of the energy consumed in industrial countries [2]. In case no green technology will be deployed in communication networks, Global e-Sustainability Initiative (GeSI) predicts 35.8TWh energy consumption for European telecom operators in 2020, while they have already consumed 21.4TWh in 2010 [3].

With the evolved new business model in which service providers (SPs) are separated from Infrastructure/network providers (InPs), network virtualization has been regarded as a promising technology for flexibly utilizing shared network resources across multiple SPs. As far as energy efficiency is concerned, none of existing research works have considered power saving in the network virtualization environment. Besides, since network virtualization has been regarded as a promising technique for efficient usage of shared network resources, the corresponding solutions to energy saving in this type of networks becomes essential.

Common approaches for power saving in operational networks include reconfiguration of the idle network devices and pushing them to sleep mode [2, 12] during off-peak time. Sleep mode denotes the configuration of a device when it is inactive and consuming minimal level of power, however it can be re-activated as soon as required. In this paper, we specifically consider sleeping link optimizations in the network virtualization environment. Given the physical network topology (operated by the InP) and a set of virtual network topologies, the objective is to minimize the power consumption in the physical network, while still satisfying bandwidth demands from individual virtual networks (VNs) on the top. In this regard, a heuristic offline algorithm is proposed, which tries to push maximum number of physical links into sleep mode over the off-peak period, while still guaranteeing the off-peak traffic demand of all involved VNs. The algorithm marks a physical link as a potential candidate for sleeping in case the direct connected nodes are not isolated and there is at least one alternative path with guaranteed off-peak bandwidth support for all of involved VNs.

We use a simple network topology to illustrate the high-level idea of the algorithm in turning links into sleep mode over the off-peak hours for energy saving. Figure 1.A shows a small physical network topology based on which multiple VNs can be provisioned. In Figure 1.B the mapped topology of two virtual networks, with their *peak-time* bandwidth demands over the physical network is shown on per virtual link basis. Based on the required peak-time traffic demand, the corresponding bandwidth reservation is made on each virtual link for the two VNs. For simplicity in illustration, the bandwidth reservation in Figure 1.B is bi-directional, e.g. 5Mbps peak-time reservation from node 3 to 4 and 4 to 3 respectively fro VN 1. Each line model denotes one virtual network. During *off-peak* time the traffic demands over the two VNs become lower, in which case there is an opportunity to put a subset of physical links to the sleep mode. As an example here, the off-peak demand is considered as 40% of peak bandwidth for all the links. To enable link sleeping, customer traffic across the virtual links which are mapped onto the sleeping physical links need to be rerouted via alternative virtual paths where there are available reserved bandwidth resources for the same VN. For instance, Figure 1.C shows a resulting reduced topology to be used during off-peak time. The physical links (1-3, 4-5, and 4-6) are set into sleep mode while all the nodes still have full connectivity for all the previously involved virtual networks and their off-peak bandwidth demands are guaranteed through other active links. Besides, Figure 1.D shows the re-routed traffic for the slept links over the defined replaced path. The replaced paths for links 4-6, 4-5, and 1-3 are 1, 2, and 3 respectively. For instance, the removal of link 1-3 requires that the off-peak traffic demand (2Mbps*40%) for VN1 to be rerouted via the virtual path of 1-2-4-3 which consists of feasible links that can accommodate the rerouted demand. Concerning the active link 3-4 for VN2 as another example, the overall demand by taking into account rerouted traffic onto it includes: 5Mbps*40% (reduced traffic demand between nodes 3 and 4), 4Mbps*40% (rerouted VN2 demand upon the removal of link 4-5), 3Mbps*40% (rerouted VN2 demand upon the removal of link 4-6). As a result the total bandwidth consumption on the link is 2+1.6+1.2=4.8Mbps which does not exceed the allocated 5Mbps for that VN.

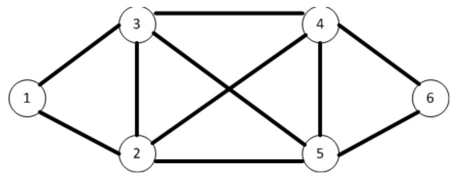

Figure 1.A. Physical network topology.

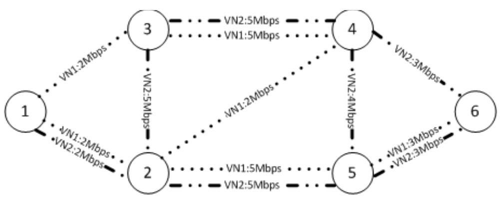

Figure 1.B. Peak time, mapped virtual networks topology.

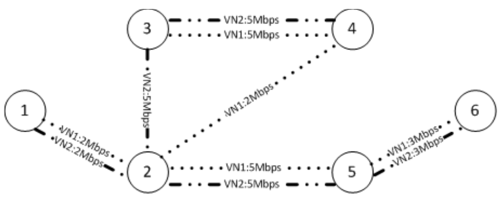

Figure 1.C. Reduced topology during off-peak time.

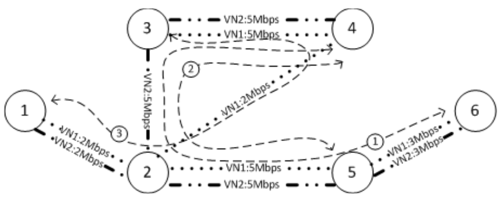

Figure 1.D. Alternative paths for slept links in VNs.

We conducted performance evaluation based on the GÉANT network topology with varied simulation scenarios. The simulation results with randomly generated virtual networks show our proposed algorithm is able to turn active notable number of physical links into sleep mode for energy saving over off-peak hours, but without violating the assurance to bandwidth demand from customers during the period.

II. Related Works

Power saving in communication networks has been targeted in several researches over the recent past years. The authors of [5] aimed to reduce power consumption over entire network infrastructure rather than single section of network. [4] proposed an approach to reduce energy consumption in wide-area networks by turning off a set of nodes and links over off-peak time. [6] selects line cards to be pushed to sleep mode in an IP-over-WDM networks. The authors of [2] presented another approach in support of sleep mode in distributed/centralized Generalized Multiprotocol Label Switching (GMPLS) networks. Greedy Green MPLS Traffic Engineering (GGMTE) has been investigated to discuss energy saving with link sleeping in multiprotocol label switching (MPLS) networks. All of these researches are trying to reduce power consumption in communication networks in different approaches. However, none of them are concerning about power saving in network virtualization environment, and as we are aware there is no published research on this issue.

In network virtualization environment, an allocation process maps a virtual network request, which is coming from a customer, to the substrate network topology. This process is handled by VN provider. At first, a VN request, which typically has nodes and link constraints [9] and is coming in a graph format [10], is given to the VN provider. Afterwards, the VN provider will discover matched candidates over substrate network based on requested constraints, and then choose the best one using optimization algorithms [11]. Finally, the VN provider allocates/reserves virtual resources from the substrate network [11].

III. Problem Formulation

The algorithm objective is to reduce power consumption in network virtualization environment over off-peak hours, while still offering bandwidth support to ongoing traffic sessions over the VNs. This can be achieved by setting maximum number of physical links into sleep mode, over off-peak hours. The description of the network optimization for energy saving is the following:

Given:
- i) Physical network topology.
- ii) A set of virtual network (VN) topologies.
- iii) Maximum allocated bandwidth for virtual links of each VN during peak-time period.
- iv) Off-peak traffic demands for each VN.

Find: The set of links in the physical topology which are capable to be set into sleep mode during off-peak time.

Subject-to:
- i) Full-connectivity of each VN topology.
- ii) The residual VN topology is able to support off-peak bandwidth demand on all virtual links.

The problem can also be defined with Integer Linear Programming (ILP), precisely. The physical network is modeled as a graph $G_s = (V_s, E_s)$, where V_s is the set of vertices, and E_s is the set of edges in G_s. So, $N_s = |V_s|$ represent total number of physical nodes, and $L_s = |E_s|$ shows total number of links in the physical topology.

The virtual network topology is a *strict subset* of the actual physical network topology. Each of the virtual networks is modeled as a graph $G_v = (V_v, E_v)$, where V_v is the set of virtual nodes, and E_v is the set of virtual links. Each virtual link, between node i and j ($L_{i,j}$), in the n_{th} virtual network (VN_n) is associated with fixed bandwidth allocated for that VN at any time. This allocated bandwidth capacity is represented here with $C_n^{i,j}$, which can be regarded as the constraint for the bandwidth usage during both peak time and off-peak time In addition, $P_n^{i,j}$ is set of links over a path between node i and j, in n_{th} virtual network. Besides, VN_T is set of all involved virtual networks.

Over the off-peak hours, networks are less utilized due to lower customer traffic demand, and this provides the opportunity to reconfigure a set of physical links to sleep without violating the bandwidth constraint for VNs. Off-peak traffic demand on each virtual link for the n_{th} virtual network is represented by OTD_n. In this regard, $\gamma_n^{i,j}$ represents (off-peak) traffic demand between node *i* and *j* in the n_{th} virtual network. Over off-peak period, available bandwidth capacity on virtual link between *i* and *j*, in n_{th} virtual network, is presented by $ac_n^{i,j}$.

We use $\delta_{i,j}$ to show the link status between node *i* and *j*. It is "1" in case the link is active, or it is "0" when the link is in sleep mode or off. Besides, $pl_{i,j}$ represents power consumed by the physical link between node *i* and *j*.

Considering the above definitions, the optimization problem can be formulated as follows:

$$Maximize \left\{ |E_s| - \sum_{i=1}^{N_S} \sum_{j=1}^{N_S} \delta_{i,j} \right\} \tag{1}$$

Subject-to:

$$\forall\, \gamma_n^{i,j} \in OTD_n\,,\ \exists\, P_n^{i,j} \qquad \forall n \in VN_T \tag{2}$$

$$C_n^L \geq \gamma_n^L + \sum_{for\ all\ diverted\ demands} \gamma_n \qquad \forall L \in P_n^{i,j} \tag{3}$$

Eq. (1) states the objective of maximizing the total number of links in the physical topology that can be put to sleep during off-peak hours. Eq. (2) makes sure of full connectivity between virtual nodes in the reduced topology. Eq. (3) indicates off-peak bandwidth constraint as described previously.

IV. PROPOSED ALGORITHM

The proposed heuristic algorithm considers all the links status as initially active, and then considers the identification of maximum number of links to be removed from the physical topology subject to the constraints.

The proposed algorithm is shown in Listing 1. The initial parameters are calculated in first step in order to be used in next steps for sorting and decision-making matters. Firstly, Stress Rate (SR_k) is needed to be calculated for all substrate network links. SR_k presents intensity of involved virtual networks over link *k*, and it is calculated by Eq. (4). This helps link sorting in the second step. Secondly, in order to ensure full connectivity after link removal as one of the constraints, we need to make sure none of the direct connected nodes to the link are isolated. In this regard, it is necessary to check both direct connected nodes to have at least one other connection for all virtual networks involved in the link. Therefore, a parameter named $Flag_k$ will be calculated for each physical link *k* checks its isolation. This speeds up the algorithm in terms of reducing the process in finding a replaced path. The parameter will be calculated with Eq. (5).

Step1: Calculate Stress Rate (SR_k) and $Flag_k$, using Eq. 4, and Eq. 5, for all the links over the ISP.

Step2: Calculate the off-peak available capacity ($ac_n^{i,j}$) over the links based on off-peak traffic demand, and Eq. (6).

Step3: Sort the links in ascending order, based on SR. For links with equal SR, sort it based on link utilization. So, the top link in the list, has the fewest number of VNs involved, and is the least utilized link over the network.

Step4: For the top unchecked link in the list, if the Flag is 1, remove the link *k*, and go to next step; otherwise go to Step 7.

Step5: Find a replaced path by network default routing algorithm for two previously direct connected nodes (a, b) of link *k*, for all the involved VNs. Considering off-peak traffic demand, update the available capacity of the links for each VN over the path, with the following calculations and conditions:

$ac_n^{i,j} = ac_n^{i,j} - \gamma_n^{a,b} \rightarrow$

- **If** for all the links over the replaced path: $ac_n^{a,b} \geq 0$, **then** go to the next step.
- **If** there is one or more links over the replaced path that $ac_n^{a,b} < 0$, **then** put back the link to the topology and undo the updates, then go to Step 7.
- **If** no replaced path is founded between node "a" and "b", **then** put back the link to the topology, and go to Step 7.

Step6: Check the capability of link removal for all VNs involved in the link, then:

- **If** for all the VNs the link is removable **then** go to the next step.
- Otherwise, put back the link into the topology and undo the updates, then go to the next step.

Step7: Repeat Step 4 for the next link, unless all the links are checked; otherwise stop.

Listing 1. Heuristic Algorithm

$$SR_k = \frac{number\ of\ VNs\ involved\ in\ link_k}{total\ number\ of\ VNs\ over\ ISP\ (VN_T)} \tag{4}$$

$$Flag_k = \begin{cases} 1 & \text{Both connected nodes have at least one other connection to all VNs involved in } link_k.\ (link_k \text{ is not isolated}) \\ 0 & \text{Otherwise } (link_k \text{ is isolated}) \end{cases} \tag{5}$$

In the second step the algorithm will calculate available bandwidth capacity for each virtual link over off-peak hours. This is driven using off-peak traffic demand, which is given to the algorithm as an input, and with Eq. (6).

$$ac_n^{i,j} = C_n^{i,j} - \gamma_n^{i,j} \quad (6)$$

Since the links with higher number of involved VNs are more essential for connectivity and bandwidth demands, the algorithm starts link sleeping from a link which has the fewest number of VNs involved. In addition, the second priority is link utilization. This is considered in third step in which the algorithm sort the links in ascending order based on SR. For links with equal SR, the algorithm sort the links based on their link utilizations.

Afterwards, the algorithm tries to check the possibility of setting a link into sleep mode by finding a alternative path, for all involved VNs in the link, which has sufficient bandwidth capacity for re-routed traffic. Specifically, if a physical link is to be removed, for all the affected VNs, an alternative path consisting of remaining active virtual links with sufficient bandwidth needs to be identified. This happens in step 4, 5 and 6. At first, it checks the $Flag_k$to make sure link is not isolated and prevent unnecessary calculations. In case link is not isolated, the algorithm tries to remove the link from the topology and then check the existence of any alternative path between two previously connected nodes, considering off-peak traffic demand, based on the operator's deployed routing protocol such as shortest path routing. If the algorithm is able to identify a path which supports the required off-peak demand for the link, then it confirms the link as a candidate for sleeping during off-peak time. Besides, the algorithm needs to update available bandwidth for all the links involved in the alternative path in the VN under consideration.

In some cases, over a physical link, one or some of the virtual links are not removable, since there is no replaced path or enough capacity on others to redirect the traffic, while the others are. Step 6 of the algorithm deals with this issue. It makes sure that the algorithm set a physical link into sleep mode, unless there is an un-removable virtual link over it.

V. PERFORMANCE EVALUATION

In order to evaluate our heuristic algorithm, we have simulated several random network virtualization scenarios. Here, the objective is to evaluate the efficiency of the algorithm in setting the links into sleep mode, regarding off-peak bandwidth demands. The off-peak topology has to support full connectivity and off-peak bandwidth demands. Therefore, we have simulated several virtual network scenarios over GÉANT topology.

We considered GÉANT as our physical network topology, since it is a universal real network topology and its real link bandwidths are published. The GÉANT network has 22 nodes and 36 links. The physical capacity for each link is used as announced by GÉANT project [8]. The links are assumed with residual bandwidth. Four setups for virtual network scenarios are simulated over the physical network topology. In each setup 10 scenarios are generated randomly and the effectiveness of our algorithm has been assessed. For the first setup, each scenario contains 2 randomly generated virtual networks over GÉANT network. In the second, third and fourth setup each scenario has 4, 6, and 8 respectively, randomly generated virtual networks. For simplicity the bandwidth demand from each VN is the same for all the cases.

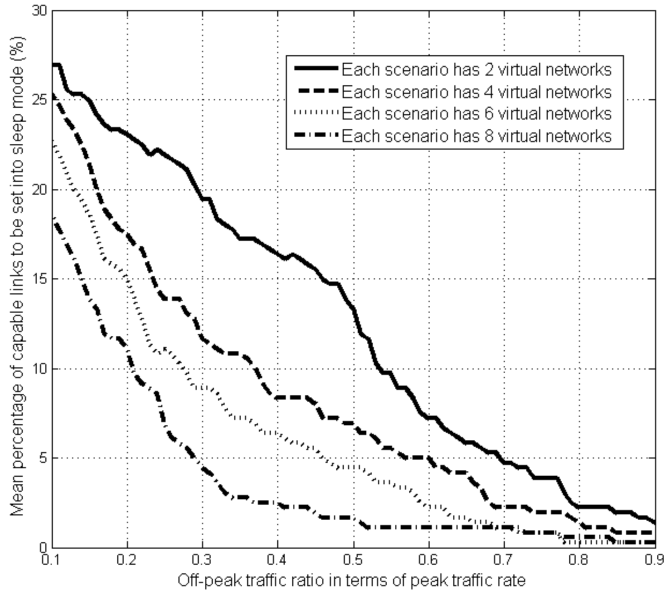

Figure 2. Percentage of possible sleep links based on off-peak traffic demand.

Our heuristic algorithm has been evaluated under different fraction rates of off-peak bandwidth demands as compared to the allocated bandwidth. The average results are shown in Figure. 2. The results show in a condition, for the first setup, when the off-peak traffic rate is 0.1 of the allocated bandwidth, our proposed algorithm is able to push 26.9% of physical links into sleep mode, while still full connectivity and off-peak bandwidth demands are satisfied for all involved virtual networks. Besides, as it shown in Figure 2, by increasing the off-peak traffic demand ratio, for both cases, the number of capable links to be set into sleep mode, are decreasing. This is expected due to bandwidth constraints and virtual link availability over the network. Moreover, the increase of the number of active virtual networks (while keeping the off-peak bandwidth demand fixed), the number of capable links to be set into sleep mode, will be decreased. This is happening because our algorithm to guarantee the full connectivity and off-peak bandwidth demands needs to bring a replaced path which has enough bandwidth for redirected traffic for each single virtual network. Hence, by increasing the number of virtual networks the requirements that needed to be satisfied in order to push a link into sleep mode will be increased. In addition, in order to evaluate the error rate of our results, we calculated the Standard Error of the Mean (SME) of ten different scenarios. The maximum error for the first setup is 1.6% and for all other setups it is 2.1%. By decreasing the off-peak traffic rate the algorithm has higher degree of freedom since it is easier to find a feasible alternative path, which supports the redirected traffic during off-peak time. On the other hand, for the high off-peak traffic rates, freedom degree of algorithm is lower. Hence, we expect the algorithm experience higher standard deviation values over the lower off-peak bandwidth demands. The SME

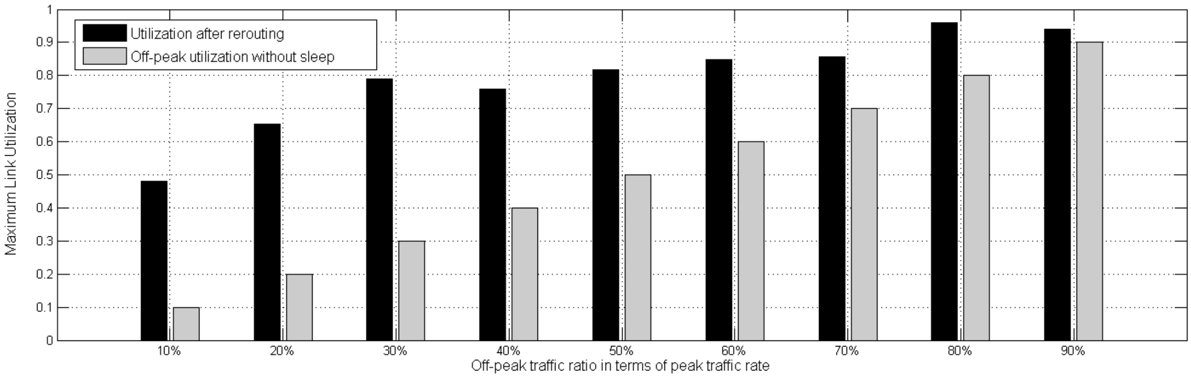

Figure 3. Link Utilization

results confirm our expectation.

Besides, we have plotted the link utilization after and before using our proposed algorithm. The results of this measurement, for different off-peak traffic ratios, are shown in Figure 3. Link utilization is tested over the same substrate topology with 5 virtual networks, for 10 random scenarios, while we considered the off-peak bandwidth demand as different fractions of the peak time bandwidth for all the links. In this case, the allocated bandwidth for each VN is based on the peak time demand, making sure that the bandwidth share is able to support the "worst-case" traffic demand. As such, the figure indicates the link utilization during off-peak time without removing any link for sleeping. As can be seen, the link utilization during the off-peak time is noticeably low. When link sleeping operation is applied, the utilization of remaining active links becomes higher, but still within the controlled bound. It is worth mentioning that, the link utilization shown in Figure 3 for this scenario is the maximum point of all test scenarios. Since different sets of sleeping links are identified for each test scenario, there is no such a link that is put to sleep for all cases.

Therefore, the heuristic algorithm over the defined scenarios based on GÉANT topology is able to save energy by setting notable number of links into sleep mode over off-peak hours. This happens while the algorithm still guarantee the full connectivity and off-peak bandwidth demands over network virtualization environment. Besides, the link utilization is more proportional to the power consumption, and not more than defined maximum threshold.

VI. CONCULUSION

Information and Communication Technology consumes 10% of total energy consumed in industrial countries. This triggers the necessity of energy saving in this area. One of the important technologies in ICT is virtual networking that enables network resource sharing between CPs. Therefore, We have proposed a novel algorithm which tries to maximize the number of capable links to be set into sleep mode over the network off-peak hours. Hence, the algorithm saves energy over off-peak hours of virtual networks. In order to evaluate the suggested algorithm we have simulated several virtual network scenarios over GÉANT substrate network topology. The results confirmed the effectiveness of the algorithm in regards of saving energy over off-peak hours. Simulation showed the algorithm is able to set considerable number of the links into sleep mode in order to save the energy, and keep the link utilization in controlled area.

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