Energy-Aware Slicing of Network Resources based on Elastic Demand through Daytime

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***Abstract*—Internet Service Providers (ISPs) provide services to support applications for users every day, enabling the creation of even more innovative tools for people communication, information exchange and content delivery. Nevertheless, they do not guarantee Quality of Service (QoS) to the users due to structural limitations. One emerging approach for ISPs is the slicing of network resources among clients, where a slicing algorithm defines the configuration of each slice, focusing on the improvements of QoS and resource utilization, such as bandwidth availability and energy consumption. Another crucial point is the elastic resource demand within periods of time through the day. Within this context, this paper proposes the Suitable Energy Efficiency (SEE) algorithm to allocate network slices according to both the daytime bandwidth requirement of the clients and the current energy consumption of the network infrastructure. The results indicate that the proposed algorithm defines suitable number of slices when compared to the existing approaches, while it improves the energy efficiency.**

***Index Terms*—Slicing, Elastic Demand, Energy Efficiency, Network Management, Planning.**

I. Introduction

Internet Service Providers (ISPs) are evolving their service delivery, supporting several clients simultaneously. Each client describes in the defined Service Level Agreement (SLA) distinct parameters to be met by the ISP [1]. In general, the ISPs need to deal with requirements such as low delay, Bandwidth (Bw) demand, resilience and expenditures, for example Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). These directly aspects influence the Quality of Service (QoS) and Quality of Experience (QoE), where final users become frustrated when they suffer problems of slowness, disconnections and high delays, among others.

An ISP wants to maximize profit, where the amount of active SLAs with clients and the network infrastructure energy consumption are directly related to it [2]. Regarding SLAs, the more clients, the higher the ISP's profit can be. ISPs increase the number of clients when they improve the bandwidth utilization in their network infrastructure. In the same way, energy consumption of the network infrastructure became an important point to be considered by the ISPs [3]. Energy issues can be evaluated from many perspectives, where Energy Efficiency (EE) can be defined as the amount of bandwidth allocated to clients per quantum of energy consumed by the network infrastructure.

Currently, a key point for ISPs is the elastic demand for network resources throughout the day, resulting from the mobility within cities, where ISPs need to dynamically expand or shrink the allocation network resources. Within this context, Network Virtualization (NV), Software Defined Network (SDN), and Network Function Virtualization (NFV) arose as emerging technologies to evolve ISPs and their service delivery, creating the idea of Future Internet Service Providers (FISPs) [1]. The combination of these technologies allows the splitting of network resources into slices, where each slice has a particular behavior, following the parameters defined in the SLA [4].

The first step to perform the network slicing task is the slice allocation, which is the definition of which network components (links and nodes) will be part of the each slice. Thus, the slice allocation is a crucial task to support the elastic services provision. The slicing process should be an strategic planning to allocate slices following the bandwidth demand. Nevertheless, the approach to be applied to perform this task is still an open issue.

In the same way, it is necessary to consider the changes in the slice structure to keep it suitable to meet the client's requirements through the day, since the network resource demand usually varies from a certain period of time to another. Consequently, the slice allocation algorithm used by the FISP to decide the best set of slices (where each one has a singular configuration per period of the day) to address the elastic resource demand will influence the performance of the FISP.

Within this context, this paper proposes a slice allocation algorithm, called *Suitable Energy Efficiency* (SEE), which allocates network slices considering the energy consumption and the bandwidth demanded by the clients throughout the day. The main objective of *SEE* is to allocate the most suitable slice configuration for each period of the day (specified in the SLA), while saving resources and supporting the service delivery. The performance of *SEE* was compared with an existing slicing approach. The results suggest that the *SEE* defines most suitable network slices for the FISPs context.

The remainder of this paper is organized as follows. Section II describes the proposed algorithm. Section III details the results of the experiments performed. Finally, Section IV concludes the paper and presents future work.

II. PROPOSAL

This section describes the SEE algorithm. It was designed to solve the problem of slicing network resources based on the elastic demand required in the SLAs. Moreover, several objective metrics are presented, that model the impact of the slice allocation in the physical network, considering bandwidth availability and energy consumption.

A. Suitable Energy Efficiency (SEE)

This section presents the *SEE* algorithm. It is used to allocate network slices focusing on the energy efficiency of the network infrastructure, while complying with the bandwidth demand required throughout the day. *SEE* is a greedy algorithm which searches for the most suitable network slices while using the previous allocated slice as baseline. Additionally, the objectives metrics that will be described in Section II-B are applied to define the cost/weight of the links (represented by the function $UpdateLink$). An overview of *SEE* is presented in Algorithm 1 and the notation used is described in Table I.

TABLE I
NOTATION

Symbol	Description
G	graph representing the network infrastructure
L	set of network infrastructure links
N	set of network infrastructure nodes
l	link between two nodes
$l_{w,t}$	cost / weight of link l in period t
C	set of FISP clients requests
$l_{Bw,t}$	bandwidth available on the link l in period t
l_{BwO}	original bandwidth available on the link l
T	set of periods (or *time slots*) defined in SLA
$Bw_{c,t}$	bandwidth required by the client c for the time slot t
f	network slice defined
F	set of network slices for all defined periods

Algorithm 1 Suitable Energy Efficiency (SEE)

Require: Requests of Clients (C) and Network Infrastructure (G)
Ensure: Set of Slices (F)
1: **for all** Client $c \in C$ **do**
2: **for all** Period $t \in T$ **do**
3: bool $PrevisousOk = true$, $CurrentOk = true$;
4: **for all** Link $j \in F_{c,t-1}$ **do**
5: **if** $j_{Bw,t-1} < B_{c,t}$ **then**
6: $PrevisousOk = false$; ▷ Previous slice can not be reused
7: **end if**
8: **end for**
9: **for all** Link $l \in L$ **do**
10: UpdateLink($l_{w,t}$,$B_{c,t}$);
11: **end for**
12: Slice $F_{c,t}$ = SearchProcess(G,c); ▷ Algorithm 2
13: **if** $F_{c,t}$ == $Fail$ **then**
14: $CurrentOk = false$; ▷ Current search could not found a slice
15: **end if**
16: **if** $PrevisousOk$ and $CurrentOk$ **then**
17: **if** $Energy(F_{c,t}, t) \geq Energy(F_{c,t-1}, t)$ **then**
18: $F_{c,t}$ = $F_{c,t-1}$;
19: **end if**
20: **else**
21: **if** $PrevisousOk == true$ **then**
22: $F_{c,t}$ = $F_{c,t-1}$; ▷ Previous slice $(t-1)$ will be reused in t
23: **end if**
24: **end if**
25: **end for**
26: **end for**
27: **return** F ▷ Set of Slices

From line 2 to line 8, *SEE* assigns the cost of the links for the current analysis. If it is not the first run of the algorithm (i.e., a previously allocated slice exists), then SEE checks if the previous slice ($F_{c,t-1}$) can be used in the current period of time t, having the bandwidth requested ($B_{c,t}$). This strategy aims to minimize changes in the network elements allocated to the slices, avoiding the necessity of adaptation (which has a computational cost [4]). Next, between lines 9 to 15, an independent search process is performed to define another possible slice to be allocated in period t. This search process will be described in Section II-C, where Algorithm 2 is detailed.

Line 16 verifies if the previous allocated slice ($F_{c,t-1}$) and the one defined in the search process ($F_{c,t}$) meet the client's request ($B_{c,t}$). When both slices are able to be used, the one that results in less energy consumption by the network infrastructure is chosen (line 17).

The energy consumption of a slice is calculated following Equation 1, where $l_{Bw,t}$ is the bandwidth available on the link l in period t and $E_C(x)$ is the energy consumption of the link when x Mbps are allocated to it, following Equation 4 described previously in Section II-B. If only one of them is suitable, it is allocated as the slice for the period ($F_{c,t}$). In case none of the slices can meet the requirements, a fail status is returned representing that the FISP can not meet the client's request.

$$Energy(Slice\ f,\ Period\ t) = \sum_{Link\ l\ \in\ f} E_C(l_{Bw,t}) \quad (1)$$

The goal of CSS is to identify, between previous slice and the slice defined in the search process, which one minimizes the energy consumption of the network infrastructure.

B. Objective Metrics

During the search process for the most suitable slice for each client, it is possible to use many criteria for the objective metric, for example available bandwidth in the links, power consumption of the network infrastructure, estimated reliability of the slice, among others. The objective metric defines the cost/weight of the links during the allocation process. For each period of time t, a link l will have a cost/weight $l_{w,t}$.

In reference [5], an objective metric based on bandwidth was proposed, as shown in Equation 2. The metric models the impact of a slice allocation on the available bandwidth of the links individually, focusing on the maximization of the number of active SLAs.

$$l_{w,t} = exp\left(\frac{l_{Bw,t}}{Bw_{c,t}}\right),\ if\ Bw_{c,t} \leq l_{Bw,t}; \tag{2}$$

In Equation 2, $l_{Bw,t}$ is the available bandwidth on the link l in the period t and $Bw_{c,t}$ is the bandwidth requested by the client c for the time period t. The links with $l_{Bw,t} < Bw_{c,t}$ are removed by the algorithm (i.e., disregarded in the searching process). *Exp* represents the exponential function, which is used to generate a sharper drop in the link cost.

However, the Equation 2 does not consider all the possible criteria to improve the resource usage, such as energy consumption. Thus, we propose two objective metrics to consider energy issues during the slice allocation process: (1) a metric based on the current energy consumption of the links in the network infrastructure, as presented in Equation 3; and, (2) a combined approach to merge the focus of the proposed energy-aware metric and the bandwidth-aware metric proposed in reference [5], as defined in Equation 5.

$$l_{w,t} = \frac{E_C(l_{Bw,t})}{E_C(l_{Bw,t} + Bw_{c,t})} \tag{3}$$

where

$$E_C(x) = \begin{cases} 0.48,\ if\ 0Mbps\ < x\ \leq\ 100Mbps; \\ 0.9,\ if\ 100Mbps\ < x\ \leq\ 600Mbps; \\ 1.7\ if\ 600Mbps\ < x\ \leq\ 1Gbps; \\ 0,\ otherwise; \end{cases} \tag{4}$$

In Equation 3, $l_{Bw,t}$ is the available bandwidth of the link l, $Bw_{c,t}$ is the bandwidth requested by the client, and $E_C(x)$ is the energy consumption of the link when x Mbps are allocated to it, following Equation 4. These values about the relation between energy consumption and bandwidth are presented in reference [6].

$$l_{w,t} = exp\left(\frac{l_{Bw,t}}{Bw_{c,t}}\right) + \frac{E_C(l_{Bw,t})}{E_C(l_{Bw,t} + Bw_{c,t})} \tag{5}$$

The first term of Equation (5) identifies the impact of the bandwidth request ($Bw_{c,t}$) under the available bandwidth of the link ($l_{Bw,t}$). On the other hand, the second term of Equation 5 measures the increment in the energy consumption of the link if the bandwidth requested is allocated.

C. Search Process

The base of *SEE* algorithm is the search process (line 12 of Algorithm 1), which is described in Algorithm 2. Initially, the set of nodes to be analyzed is defined, where the initial node is not considered, since it is the client's edge point to the FISP infrastructure. Later, between lines 2 and 8, the cost of the links are assigned according to the objective metric applied (as shown in Section II-B). Variable W represents the cost to reach each node in the network infrastructure. The direct neighbor nodes of client c receive the cost $l_{w,t}$ (obtained by the function $getLinkInfo(Node,\ Node)$), while to the remaining nodes it is assigned ∞ (infinity). Lines 9 to 22 search for the set of links that best fits the requirements for the network slice.

Algorithm 2 Searching Process

Require: Network Infrastructure G and Client Request c
Ensure: Slice f or $Fail$

1: $S = N - \{c\}$;
2: **for all** Node $j \in S$ **do**
3: $W_j = \infty$;
4: $l = getLinkInfo(c, j)$;
5: **if** (($l_{w,t} < \infty$) and ($l_{Bw,t} \geq Bw_{c,t}$)) **then**
6: $W_j = l_{w,t}$;
7: **end if**
8: **end for**
9: **while** S not empty **do**
10: Node $Min = lower(\ W\ )$;
11: $l = getLinkInfo(c, Min)$;
12: **if** ($l_{Bw,t} < Bw_{c,t}$) **then**
13: **return** $Fail$ ▷ Can not meet the requirements;
14: **end if**
15: $S' = S' - \{Min\}$;
16: **for all** Node $j \in S'$ **do**
17: $l = getLinkInfo(Min, j)$;
18: **if** (($l_{w,t} < \infty$) and ($W_j > W_{Min} + l_w, t$) and ($l_{Bw,t} > Bw_{c,t}$)) **then**
19: $W_j = W_{Min} + l_{w,t}$;
20: **end if**
21: **end for**
22: **end while**
23: Slice $f = sliceBuilding(W)$
24: **return** f ▷ Containing the configuration of the slice

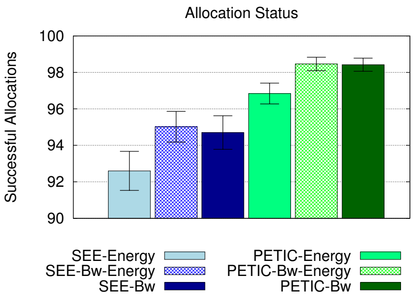
Between lines 15 and 21 the algorithm travels over set S' (the unprocessed nodes) checking if the node with the current best cost Min (obtained by the $lower$ function) can be used to reach other nodes with lower cost. If *Min* has a cost that does not meet the requested bandwidth for the period ($Bw_{c,t}$), the algorithm identifies that it can not meet the client requirements, then the search process is interrupted (line 13). When the most suitable node is identified, the algorithm iterates through every node verifying if the *Min* node can reach the other nodes with a lower cost ($W_j > W_{Min} + l_w, t$).

Finally, in line 23 the output slice f is configured (function $sliceBuilding$) based on the information of most suitable links in W (fulfilled in the previous steps). In line 24 the slice f is returned as the output of the search process.

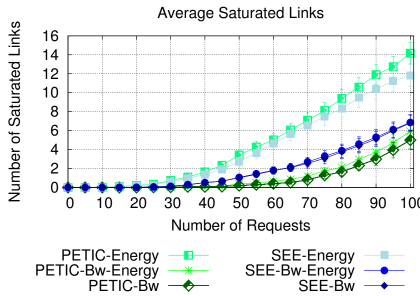
III. Results

This section presents the performed experiments to evaluate the *SEE* algorithm regarding the definition of network slices. In order to carry out the experiments, a simulator[1] was developed to allocate the network slices.

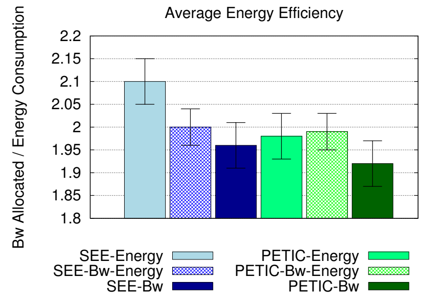
[1] bitbucket.org/rafaellgom/slicing-timeslot/



(a) Successful allocation in the ATT Scenario.



(b) Saturated Links in the ATT Scenario.



(c) Energy Efficiency in the ATT Scenario.

Fig. 1. Results

The experiments use ATT topology (24 nodes and 60 links) to evaluate the algorithms, becoming feasible option to be used in the performance evaluation [7]. Each link in the network infrastructure was configured with 1Gpbs of initial available bandwidth.

The experiments aim to evaluate the ability of the proposal in allocating a set of network slices with two parameters: (a) a set of nodes to be connected (uniformly chosen) and, (b) 24 bandwidth values (average of 50 Mbps), assigned to the periods of the day. One hundred sets of requests were randomly generated, where each set was composed of one hundred clients requesting 24 network slices, representing the schedules of the day (i.e., the set size T is 24).

The performance of *SEE* algorithm was compared with an existing approach of *PETIC* [5], using the objective metrics presented in Section II-B: bandwidth suitability (called Bw), energy-aware metric (illustrated as $Energy$) and the combined approach (represented as $Bw - Energy$). Four metrics are evaluated: Successful allocations (Figure 1(a)), the number of slices the algorithm was able to allocate with the requested bandwidth; Saturated links (Figure 1(b)), the number of links that have available less than 10% of the original bandwidth; and Energy Efficiency (Figure 1(c)). the ratio between bandwidth allocated to the network slices and the amount of energy spent by the network infrastructure.

Figure 1(a) illustrates the number of requests that the network slice complies with the defined SLA. The PETIC solved, in average, more requests than SEE. This better performance occurs because PETIC performs the search for the most suitable slice individually, i.e., it does not consider the previous slices as base. The SEE algorithm reached a close performance (around 3% lower). It is possible to note that the objective metrics based on bandwidth suitability (Bw and $Bw - Energy$) increase the number of slices allocation, regardless the slicing algorithm applied.

According to Figure 1(b), the utilization of the objective metric based only on energy tends to saturate the bandwidth of the links more quickly, reaching around the double of the number of saturated links when compared to the bandwidth-aware metrics. Thus, the number of saturated links and successful slices allocation are closely related.

Figure 1(c) shows the energy efficiency of the network during the slice allocation process. It can be seen that the *SEE* algorithm achieves its objective, i.e., it can improve the energy efficiency of the network by about 7%, outperforming the existing *PETIC* algorithms. The main reason of this better performance is an allocation which focuses on links that are already in use, saving energy while performing allocation of slices. As expected, it is possible to note that objective metrics considering energy issues improve the energy efficiency of the FISP, in both analyzed slicing algorithms.

The results indicate that the *SEE* strategy is able to improve the energy efficiency, reaching a performance 7% higher for the price of 3% lower number of successful requests. Additionally, based on the results, it is possible to note the role of the objective metric in the performance of the algorithms. When the combined metric is applied, the algorithms tend to decrease the number of saturated links, as well as to increase the number of successful allocations and the energy efficiency. Thus, the mixed approach of energy and bandwidth benefits the FISP regarding the main issues of resource management.

IV. Conclusion

Emerging technologies have been used in the Internet Service Providers to to improve services delivered. With these technologies, it is possible to provide services through network slices. However, the definition of which network components should be part of each slice is an open issue. Therefore, the Suitable Energy Efficiency (SEE) algorithm is proposed, which focuses on allocating network slices according to the bandwidth demand needed by clients throughout the day while increasing the energy efficiency of the FISP. The *SEE* algorithm overcame an existing approach, reaching a higher energy efficiency (around 7%).

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