Mechanisms for management of SLA for Virtual Software Defined Networks based on QoS Classes

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***Abstract*—This paper presents the contributions of the phd thesis "Mechanisms for management of SLA for Virtual Software Defined Networks based on QoS Classes". Over the years the Internet has become the primary means of communication, where the users expect to access the Internet anytime, anywhere, and with a certain quality level. As a consequence, in the past few years the traffic demand to Internet access has increased. However, since the current Internet does not guarantee Quality of Service (QoS) and Quality of Experience (QoE), the companies apply a Service Level Agreements (SLA) with Internet Service Providers (ISPs). In this way, the Internet service providers aim to improve utilization of network resources and service delivery to the users through the deployment of Virtual Networks (VNs) over Software Defined Networks (SDNs), called virtual software defined networks (VSDNs). However, the management of this type of environment still presents open issues. In this context, a set of mechanisms to manage VSDN was developed. The objectives of the developed mechanisms are to negotiate, to deploy and to adapt the VSDNs according to the current state of the network infrastructure and the SLA definition.**

Keywords*—*Virtual Network, Software Defined Networks, Network Management, Quality of Service, Quality of Experience.

I. Introduction

Currently, the human society wants to be connected to the Internet all the time to share content or to be aware of events anywhere in the world with at least a minimal quality level support. This trend has enormously amplified resource demands in edge and access networks. To pursue Quality of Service (QoS) and Quality of Experience (QoE) between clients (e.g., companies) and Internet Service Providers (ISPs), a Service Level Agreement (SLA) is negotiated to define network parameters to be fulfilled by the ISPs [1].

ISPs focus on improving the Bw utilization in their networks, since a good resource management scheme allows the ISPs to increase the number of SLAs with clients, also increasing profit. Currently, energy consumption becomes an important aspect to be considered by the ISP [2]. Besides maximizing their profit, ISPs aim to fulfill the SLA parameters, since they impact the user's experience during possible failure events in the ISP. Within this context, resilience is a key requirement to ensure QoS to the users [3].

Within this context, ISPs tend to apply Network Virtualization (NV) and Software Defined Network (SDN) principles to address this scenario, allocating Virtual Network Resources (VNRs) with flexibility and to make the network service adaptable/customizable [4], as well as make improve resource usage of the ISPs. When coupled with the SLA, this new scheme creates a modus operandi in which the user agrees on a basic SLA contract, but also specifies SLA adjustments to be made according to client defined policies. SDN and NV controls can be integrated in a Network Hypervisor (such as Flowvisor [5] or OpenVirtex [6]), which allows the slicing of the network in layers. Each layer has a particular set of resources and protocols, corresponding to a customized VN. We call this VN over a SDN infrastructure a *Virtual Software Defined Network* (VSDN).

Thus, the current Internet access scenario based on VN and SDN claims for solutions to ensure that the network resources are properly allocated to maximize the QoS/QoE, while reducing cost for the providers [7]. Therefore, the PhD thesis[1] [8] proposes a set of mechanisms to deal with the life cycle of a VSDN. It encompasses some key tasks that are needed to provide a good Internet access, as well as retain and attract customers by performing the following: (i) negotiating the parameters of the VSDN; (ii) allocating the VSDNs according to the infrastructure status and the SLA; and (iii) adjusting the VSDN if it is not suitable in relation to the user requirements and traffic demand.

The proposed mechanisms aim to: (a) provide the capacity to define SLA parameters (measurable and unmeasurable) and to identify the most suitable parameters to the VSDN; (b) guarantee that the ISP attends the parameters of the SLA and QoS/QoE for the users; and (c) improve the usage of network resources and energy efficiency of the ISP.

This paper is organized as follows. Section II describes the context of the thesis. Section III presents the proposed architecture to integrate the mechanisms for negotiation and management of VSDNs. Sections IV, V and VI describe the set of proposed mechanisms. Section VII shows the scientific production resulting of the proposed mechanisms, while Section VIII summarizes the contributions and results of the PhD thesis.

II. Context

The VSDN enables service providers to use virtualization and build dedicated, elastic virtual network, tailored to reach their customers [4]. VSDN decouples the strict ownership relationship between network operators and their access networks. Through the development of virtual networks, adaptive functions can be requested on-demand to support the delivery of more flexible services. Figure 1 illustrates the VSDN scenario addressed in the thesis [8].

Based on Figure 1, an example of usage can be described: if the client deploys a VSDN with an ISP, it can

[1] http://www.lrc.ic.unicamp.br/ rafaellgom/files/phd.pdf

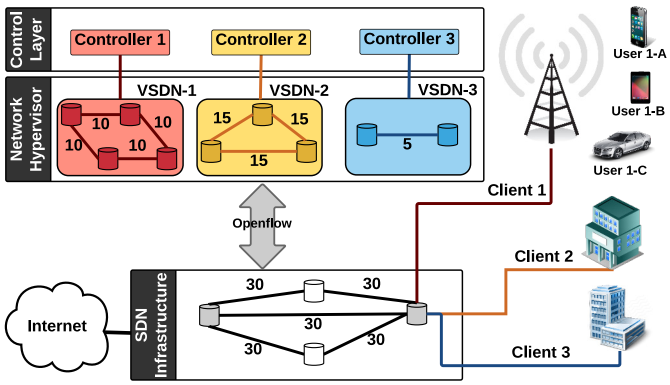

Fig. 1. Scenario representing the context of VSDN.

deploy the VSDN-1 with 10 Mpbs, which has $Controller1$. Independently, the ISP could deploy the VSDN-2 with 15 Mpbs and VSDN-3 with 5 Mbps, that have $Controller2$ and $Controller3$, respectively. The service delivered to each client is different (since, the resource and the behavior of the VSDN could be distinct) and they are isolated among them.

III. Architecture to Manage ISPs

An architecture to integrate the mechanisms for negotiation and management of VSDNs was developed [9]. The proposed architecture was designed to complement and extend the interaction between Controller and switches, i.e., it attaches management capacity to the existing approaches of virtualization under SDN infrastructures.

Figure 2 illustrates the proposed architecture and relationships between its modules. Each environment that exists in the VSDN context is represented by green boxes and the modules of the proposed architecture are depicted by gray boxes. The whole environment has the following components: (a) Infrastructure Layer; (b) Network Hypervisor; (c) Control Layer; and (d) ISP-Manager.

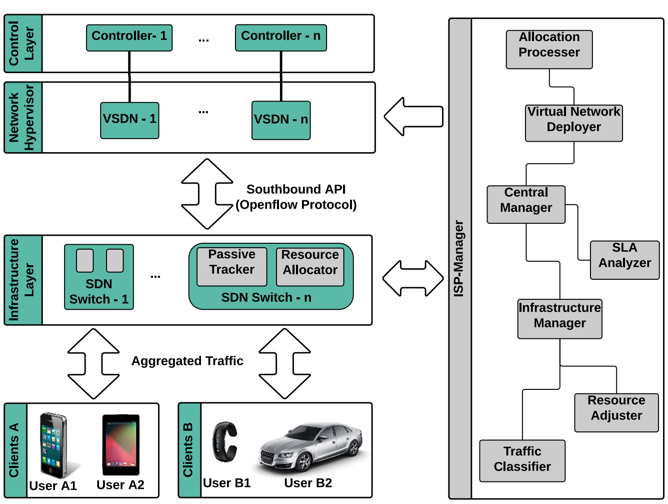

Fig. 2. Overview of the architecture.

The *ISP-Manager* environment represents the central part of the proposed architecture, aiming to enable the tasks of negotiation, deployment and adaptation of VSDNs. The *ISP-Manager* exchanges information between the *Infrastructure Layer*, the *Network Hypervisor* and the *VSDN Controllers*.

The *Infrastructure Layer* represents the set of SDN switches that compose the network infrastructure. Each SDN switch has an agent that encompasses the modules *Passive Tracker* and *Resource Allocator*. The proposed architecture uses the infrastructure information to manage the ISP, where the *Passive Monitoring* collects information from each the infrastructure. After, the *ISP-Manager* evaluates the infrastructure condition and decides to adjust a VSDN, where *Resource Allocator* module performs the resource allocation for the VSDN on-the-fly. The *Control Layer* represents the existing SDN controllers that are deployed to control a VSDN. The *Clients* environments encompass the devices that use the deployed VSDNs, for example cellphones, tablets, smart watches, among other. All of them are entities that already exist to perform a VSDN deployment.

Regarding the *ISP-Manager*, it controls the interaction among the other modules, i.e., the behavior of the architecture as a whole. To manage the VSDNs, it is necessary to take into account the current SLAs. This task is performed by the *SLA Analysis* module, which determines if it is feasible to deploy the VSDN and the best parameter for the client based on the SLA definition. Thus, this module checks the information about the resources available in the *Infrastructure Manager* (which acts as the ISP interface to resource management) and requests the resource allocation for the deployment of the new VSDN. In the same way, the *SLA Analysis* informs the *Virtual Network Deployment* module about the set of protocols defined in the SLA and instantiated in the VSDN.

The focus of *Virtual Network Deployment* module is: (i) to generate the topology of the VSDN and configure it into the network hypervisor and (ii) to instantiate the set of protocols defined in the SLA under the SDN controller tied to the VSDN being deployed. The topology is generated by the *Allocation Processer*, which applies an allocation algorithm in the system (will be described in Section V).

The goal of *Resource Adjuster* is to identify when the SLA and the current VNR do not address the current network state, as well as when the allocated resources are idle (two developed mechanisms will be described in Section VI). A most suitable adjustment of VSDNs is performed when the QoS classes of the flows are considered. Thus, the module *Traffic Classifier* executes this classification (based on the traffic classifier proposed in reference [10]).

IV. SLA Negotiation

A. Negotiation Protocol

A SLA is an agreement between parties, for example a provider and its client. The SLA must have some elements in its description: the parties, agreement parameters, description of the services (usually measurable parameters), obligations, and the cost of the services. Beyond these traditional SLA elements related to the VNs, this work defines as additional elements (as proposed in reference [11]): the description of the classes and features to be applied in the desired class. We consider as *resources* the parameters that are measurable, such as bandwidth. On the other hand, we consider as *features* the parameters that describe characteristics or behaviors of the VN, for example, the routing protocol.

With the developed protocol the client can define SLAs using some classes, each class with its particular parameters (resources, features, contract duration, price and others). Then, the SLA is used for automatic negotiation, where the decision model of the negotiation party implies to: define attribute constraints; identify the desired objectives; and prioritize these objectives.

B. Support Mechanism

A client negotiates a VSDN through a SLA with the ISPs to choose which provider has the best proposal (who best fits the requirements) [12]. Regarding to VSDNs negotiation aspects, usually the client is not concerned about which protocol is being used by the ISP. Actually, the client wants some properties to be deployed in the network, which define the behavior of the network as a whole. It is a new paradigm provided by the VSDN and the flexibility offered by that.

Therefore, the thesis [8] aims to fulfill the existing gap regarding to the protocols evaluation originated by this new paradigm, and to support the deployment of the VSDNs. We modeled a similarity metric [13] that focuses in VSDN negotiation aspects and a Fuzzy Decision Making Model (FDMM) to support the negotiation of SLAs of VSDNs [14].

1) Similarity Metric: The proposed metric [13] measures the similarity between the protocol (set of properties) requested by the client and the protocol offered by each ISP. It evaluates the offered protocols according to the requested properties they can fulfill, independently of the network technology of the ISP. So, the proposed metric enables the free competition among providers, since ISPs with distinct infrastructure technologies can offer equivalent service to the client.

2) A Fuzzy Approach for Decision Making: The FDMM chooses which offered protocol is most suitable to the set of properties requested by the client, using the following criteria: (i) the similarity between the properties requested and the ones offered by the ISP being analyzed at the moment; and (ii) the price assigned to the offered protocol. The decision model considers these two aspects because we assume the client expects to get the protocol that best fulfills the requested properties as well as it has the lowest price as possible. Thus, the proposed FDMM aims to bring to the client the cheapest offered protocol that best fits the required set of properties.

V. VSDN Deployment

The flexibility and management control provided by VSDNs does not come for granted. To deploy VSDNs, ISPs must develop allocation algorithms that decide which components (links and nodes) will take part on the VSDN to comply with client requests. The thesis [8] proposed several algorithms to perform two tasks: (1) the deployment of alternative paths to achieve reliability inside the VSDN, while obeying the SLA parameters; and, (2) the definition of paths to interconnect the desired nodes, considering some criteria, such as available bandwidth, impact on energy consumption, risk mitigation and/or network reliability. Thus, the algorithms aim to minimize the total bandwidth committed, to improve the Energy Efficiency (EE) and to attend the desired reliability (calculated according to the method presented in reference [15]), to solve the requests.

A. Relative Disjoint Paths

This section presents the *Relative Disjoint Paths (RDP)* algorithm to generate the redundancy inside the VSDN according to a desired factor. It is the basis for disjoint paths generation using a *Path Definition* algorithm (detailed in next section), which finds a tree that connects a source node to a set of destination nodes. The notation presented in Table I is applied to model the VSDN allocation problem. The steps performed by *RDP* are presented in Algorithm 1.

TABLE I. NOTATION

Symbol	Description
G	Weighted directed graph representing the ISP topology
D	Set of destination nodes
l	An edge of the network
w_l	Weight/cost for the edge l
G'	Updated ISP topology
R	Reliability of the current virtual topology
R_r	Reliability requested in SLA
p	Redundancy level ($0 \leqslant p \leqslant 1$)
$\wp$	Quantity close to infinity
G_f	Merged virtual topology

Initially, Algorithm 1 defines a loop to iterate over the possible redundancy factors (p). Inside the loop, we find the tree T_1 with node s as root by running a Path Definition algorithm ($PathDefinition(Graph, Node)$ function), which finds the best path between nodes based on a defined objective function.

Therefore, T_1 contains the links belonging to the paths from s to nodes D. Line 4 assigns to e the number of links to be updated to generate the redundancy in the topology, as a percentage from the number of links in T_1 according to the desired redundancy ($0 \leqslant p \leqslant 1$).

Algorithm 1 Relative Disjoint Paths (RDP)

1: $p = 0$; ▷ No Redundancy Case
2: **while** $p \leq 1$ **do** ▷ Redundancy ≠ Full
3: Tree $T_1 = PathDefinition(G,\ s,\ D)$;
4: $e = p * |T_1|$;
5: **for all** Link $j \in T_1$ **do** ▷ Update the links of T_1
6: **for all** Link $i \in G$ **do**
7: **if** ($i == j$) **then**
8: **if** ($e > 0$) **then**
9: $j'_w = \wp$;
10: $e = e - 1$;
11: **else**
12: $j'_w = 0$;
13: **end if**
14: **end if**
15: **end for**
16: **end for**
17: Tree $T_2 = PathDefinition(G',\ s,\ D)$;
18: Graph $G_f = MergePaths(T_1,\ T_2)$;
19: **if** ($Bw_{Impact}(G_f) + En_{Impact}(G_f) < best$) **then**
20: $R = Reliability(G_f)$;
21: **if** ($R > R_r$) **then**
22: $best = Bw_{Impact}(G_f)\ +\ En_{Impact}(G_f)$;
23: **end if**
24: **end if**
25: $Increase(p)$;
26: **end while**

After the *Path Definition* algorithm is run, Algorithm 1 updates the cost of each link in the graph, creating a new graph G'. Therefore, the algorithm replaces the cost w_l of the links according to the desired redundancy, i.e., it replaces the cost w_l of the first e links of P_1. The update of these links aims to avoid the allocation of an already used link in the alternative path search. While the number of links is not reached, the link cost is replaced by $\wp$ to avoid its use, and after it is reached, the link cost is replaced by 0 to encourage its allocation.

In the next step, the algorithm finds the tree T_2 in the graph G' with the updated cost of the links by running the same *Path Definition* algorithm applied before. After that, the algorithm merges the trees of T_1 and T_2 (line 18) to create a graph with links and nodes that exist in both trees. The resulting graph is the final topology G_f that contains relative disjoint paths between the node s and the nodes of D.

After creating G_f, the algorithm verifies the best option, i.e., it measures the impact of G_f under the energy consumption (Equation $En_{Impact}(G_f)$) and Bw availability (Equation $Bw_{Impact}(G_f)$), a detailed description of both can be found in reference [16]. $best$ is a variable to identify the topology that has less impact on the available Bw and energy efficiency of the network infrastructure. If the "best" option is found it checks if the current G_f reaches the reliability Rr defined in the SLA. The reliability R of G_f is calculated according to the method presented in reference [15].

Upon finishing the while loop, the desired redundancy is increased to allow more already allocated links (in the primary path) to be avoided in the alternative path search. The amount of increment is configured by the network administrator, for example: 0.1, 0.25, or 0.5 per iteration. In the thesis [8], an increment of 0.25 is applied during the experiments.

B. Objective Functions

There exists several ways to define the weight (w_l) of a network link (l). Thus, in the thesis [8] some objective functions were proposed to assign these link weights. Next, the proposed approaches are described:

- *Weighted-Path* [17]: aims to find paths with the lowest number of hops that satisfy the desired bandwidth, regardless the current state of the network infrastructure.
- *Feasible-Bw* [18]: considers the available bandwidth of the links in front of the requested bandwidth, focusing on the maximization of VSDNs allocated.
- *Bw-Risk-Ratio* [19]: evaluates the available bandwidth and the risk of the link, analyzing the region where the link is located. Thus, it depends of risk analyzes provided, such as [20].
- *Energy-Aware* [21]: measures the impact of the allocation of a link in the VSDN from the energy consumption perspective.
- *Bandwidth and Energy Efficiency Focus (BEE-Focus)* [16]: finds paths with higher bandwidth availability, as well as lowest impact in the energy efficiency.
- *Dynamic stAte of Bandwidth and Energy Efficiency (DA-BEE)* [22]: analyzes the current state of the network infrastructure to apply priorities to the impact in the available bandwidth and the energy consumption.

C. Experiments

To evaluate the impact and benefits of the proposed solutions, we used a VSDN allocation simulator[2] to analyze the main issues about the VSDN allocation.

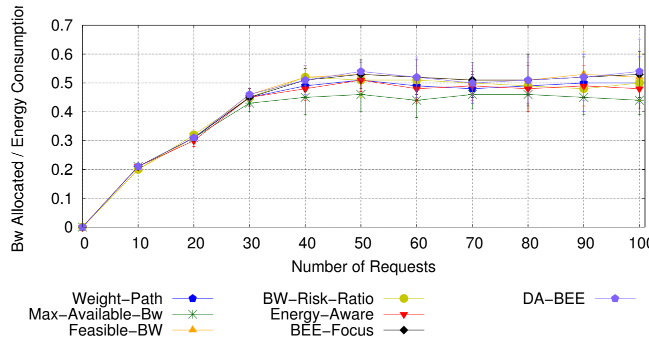

Fig. 3. Energy Efficiency of the ISP.

Figure 3 illustrates the energy efficiency of the network. Based on Figure 3, it can be seen that the algorithms based on energy (*DA-BEE*, *BEE-Focus* and *Energy-Aware*) improve the energy efficiency of the network, where it outperforms the algorithms based only on bandwidth (*Feasible-Bw*, *Weighted-Path* and *Max-Available-Bw*).

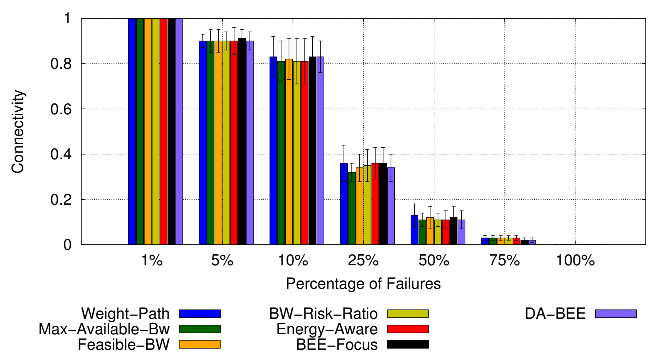

Fig. 4. Post-Failure Connectivity Status.

To evaluate the algorithms from a post-failure perspective, Figure 4 shows the percentage of allocated VSDNs that are operational (still connects the desired nodes) after failures. The "x" axis of Figure 4 represents the percentage of network components that randomly fail. Based on Figure 4, it can be seen that the *RDP* algorithm is suitable to define resilient VSDNs. The level of connectivity is directly related to the number of network components allocated by the algorithm to the VSDN, since the higher the number of components in the VSDN the higher is the probability of break in the connectivity when a failure occurs.

VI. VSDN Adjustment

Real network measurements reveal that traffic demands fluctuate over the time [23]. In access network scenarios, these changes in traffic demands can decrease the quality experienced by the user, due to the congestions that occur when demands exceed the allocated resources. Thus, a flexible and on-demand SDN-VN resource allocation scheme can improve the resource utilization in dynamic Future Internet

[2] bitbucket.org/rafaellgom/vn-allocation/

environments. This enhances the profits for the ISPs, while reducing the cost for clients and keeping the services with at least a minimal quality level.

Within this context, the thesis [8] proposes two adjustment mechanisms to increase or decrease the VNR: Resource Adjustment According to Network Demand (RAAND) [24] and *Multimedia-Aware virtual REsource Management (MAREM)* [25] (based on the utility function Bitrate-Aware Resources Suitability - BARS) [26]).

A. RAAND Mechanism

RAAND aims to define if it is necessary to request a resource adjustment for the provider based on the traffic demand measurement. Despite the traffic demand information, RAAND works with the concept of acting limits. These limits are the maximum and the minimum values that RAAND can request to the ISP. The minimum is the set of initial resources defined in the SLA, representing the minimum feasible resource allocation. It is not of interest to the ISP to decrease the allocation below this level, because it will reduce its profit. On the other hand, the maximum is the upperbound of resource allocation allowed by the client. It represents the highest price that the client is willing to pay, since the resource allocation and the price are directly related.

B. BARS Utility Function

QoE can be measured by the Structural SIMilarity (SSIM) [27] metric, which has been used as a basis for several prior QoE studies [28]. In the thesis [8], we focus on the suitability of VNR against the multimedia traffic volume and its impact on the perception of quality by users.

We performed a study to express the percentage necessary to keep videos with a good quality level (SSIM is higher than 0.7 [29]) according to the given bitrate x. Several videos were transmitted with distinct available Bw, and from the data collected a regression approach was applied [30] to relate the resulting video quality (SSIM) and the percentage of available Bw (VNR). As result, two utility functions are defined and presented in Equation (1).

$$Pow(x) = (0.79{*}x^{0.074}) \quad Log(x) = 0.58{*}(ln^{(x)}{+}0.80) \quad (1)$$

C. MAREM Mechanism

MAREM analyzes a flow and identifies if it is part of a video class or not (based on the classification agent present in reference [10]) to establish if it is necessary to adjust the VN Resources. Additionally, it uses information about the flows and user's demand (traffic volume), the traffic of video flows, and the current VNR.

In general, *MAREM* measures the VNR needed by each flow present in the set of video flows according to the *BARS* utility function and the bitrate of the flow. Thus, it defines the adjustment necessary to keep the quality of the videos, or to avoid waste of resources.

D. Experiments

The experiments aim to evaluate the developed adjustment mechanisms and their ability to avoid low QoE for video transmissions. The experiments consist of a set of data and video flows injected into the VN that interconnects source and destinations. The MAREM, using both utility functions described before, and the RAAND mechanism were compared with the static VNR allocation approach. Three cases of static allocation schemes were tested: 5Mbps, 10Mbps, and 15Mbps. Regarding the evaluation, the average SSIM value of the sent videos was used.

Figure 5 shows the average SSIM values. The adjustment mechanism of MAREM and *RAAND* keep the quality of the videos above the acceptable threshold ($SSIM \geq 0.7$) [27]. Despite the *15-Fixed* scheme, the other fixed value approaches suffer with the traffic variation, resulting in a poorer quality for the transmitted videos. When the MAREM differentiates flows, it can consider the adjustment when the video flows need it, since the multimedia traffic has higher requirements.

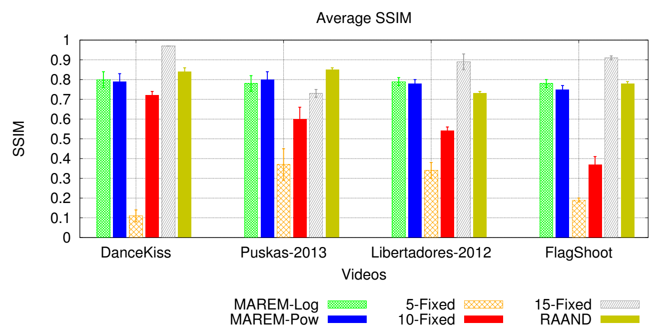

Fig. 5. SSIM results.

VII. Publications

As result of the contribution of the thesis [8], the following papers were published: 5 papers in international journals [9], [10], [16], [19], [25] and 10 papers in international conferences/symposium [11]–[14], [17], [18], [21], [22], [24], [26]. The points addressed by these published papers were cited through this manuscript, enhancing the distinct goals.

Most of these papers were published in high visibility journals and conferences like Elsevier Computer Networks, Elsevier Journal of Network and Computer Applications (JNCA), IEEE Transactions on Network and Service Management (TNSM), Springer Multimedia Systems Journal (MMSJ), IEEE GLOBECOM, ACM SAC, IEEE ICC, IEEE AINA and IEEE IM. Additionally, two registries of patents were deposited in the National Institute of Properties (INPI) of Brazil [31], [32].

VIII. Conclusions

In this paper, the contributions of the thesis [8] were presented: (i) an architecture to join mechanisms of negotiation and management of VSDNs; (ii) a traffic classifier; (iii) a full SLA negotiation protocol for VSDNs; (iv) a mechanism to support SLA negotiation; (v) algorithms to allocate VSDNs; and, (vi) the definition of two adjustment mechanisms to adapt VSDNs. The experiments performed show the advantages of the proposed mechanisms, which achieve their goals, improving the usage of network resources of the ISP and guaranteeing a better QoS/QoE to the users.

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