

# Interactive Visualizations for Planning and Strategic Business Decisions in NFV-Enabled Networks

Muriel Figueredo Franco, Ricardo Luis dos Santos, Ricardo Cava, Eder John Scheid, Ricardo José Pfitscher, Carla Dal Sasso Freitas, Lisandro Zambenedetti Granville  
 Institute of Informatics – Federal University of Rio Grande do Sul - Porto Alegre, Brazil  
 {mffranco, rsantos, racava, ejscheid, rjpfitscher, carla, granville}@inf.ufrgs.br

**Abstract**—Network Functions Virtualization (NFV) is driving a paradigm shift in telecommunications networks, fostering new business models and creating innovation opportunities. In NFV-enabled networks, Service Providers (SPs) have the opportunity to build a business model where tenants can purchase Virtual Network Functions (VNFs) that provide distinct network services and functions. However, the chance to negotiate VNFs requires a change in traditional network planning strategies to accommodate tenants demands. In this context, the planning tasks perform a critical role in the introducing of business strategies that encompass both profit and health of services, which requires operators to have a broad understanding of the environment. In this paper, we propose the usage of two interactive visualization techniques to help NFV network operators in planning and strategic decisions. We advocate that our visualizations can aid in NFV planning tasks, such as infrastructure investment, resources allocation, and service pricing. We present three case studies to provide evidence of the feasibility and effectiveness of our visualizations.

**Keywords** – Network Functions Virtualization; Network Management; Network Planning; Information Visualization.

## I. INTRODUCTION

Network Functions Virtualization (NFV) decouples packet processing from dedicated hardware middleboxes to Virtual Network Functions (VNFs) running on commercial off-the-shelf servers [1]. NFV itself and the fact that it changes service provisioning have attracted many interests from industry and academia [2]. The NFV benefits include the potential to speed up service delivery, simplified network operations, and reduced costs. Today, NFV concept is driving a paradigm shift in telecommunications networks, fostering new business models and creating innovation opportunities. By adopting this concept, network operators can readily deploy and configure network services to offer solutions for distinct customers profiles, supporting multiple tenants demands.

Service Providers (SPs) have the opportunity to migrate their legacy networks to networks based on NFV and Software-Defined Networking (SDN). In NFV, SPs have the opportunity to build a business model where tenants can purchase VNFs that provide distinct network services and functions [3]. That model benefits tenants (*e.g.*, by reducing capital/operational expenditures and easing the contract of new services) while increasing SP's revenue. However, the ability to negotiate VNFs requires a change in traditional network planning strategies to accommodate tenants demands, such as changing the strategy to offer VNFs with high performance and trustful operation according to tenant's interests. Thus, planning strategies for such networks not only are based on cost minimization but also

require the maximization of flexibility to support the market's competitive landscape.

Planning tasks in NFV-enabled networks require operators to have a broad understanding of the environment to propose business strategies that encompass both profit and health of services. In summary, the operator must consider three key aspects of NFV planning: (*i*) service infrastructure requirements, which represent the virtual and physical available resources; (*ii*) tenants consumption profiles, which allows the understanding and prediction of the network usage; and (*iii*) characteristics inherent to VNFs, such as resources contracted by tenants and packets processed. This information leads SPs to drive the direction of the business, providing adequate information for the network operator to create a strategy to increase the business competitiveness. Also, planning helps operators to improve the capacity of the business (*i.e.*, number of tenants allowed and VNFs available), the service performance, and consequently, the SPs revenue.

Relevant information and relationships between VNFs and tenants are complex to understand by using traditional planning tools because they cannot deal with all key aspects of NFV planning, such as providing information for the network operator to have insights about the necessity of changing VNFs configurations and investments priorities. To tackle this issue, information visualization can be a viable tool for network operators to investigate tenant demands and improve business strategies. The benefits of information visualization for NFV planning include the easy understanding of the tenant consumption profile, fast identification of VNFs that generate more revenue, and simplified analysis of resources usage. Visualization techniques are likely to help the operator in making decisions that avoid service degradation as well as adapting services according to market trends. However, despite these potential applications and benefits, visualization solutions are still scarce in the context of NFV [4]. The lack of mature work in the area reduces the capacity of network operators of making appropriate decisions, which may event inhibit the adoption of new technologies such as NFV and SDN [5].

In this paper, we present a solution to aid network operators and vendors in the planning on NFV business models. We extend the VISION platform [6] to provide an interactive visualization based on Hierarchical Edge Bundling technique [7] that helps operators understand the behavior of the environment where VNFs run, such as easily identifying the most common tenant's requests and how the available VNFs supply it. This visualization provides insights for a better planning of infrastructure investment, resources allocation policies, and

service prices. We also present a visualization using the Sankey diagram technique [8] to correlate resources allocation, VNF usage, and profits. Thus, the operator can identify behaviors that are incompatible with the business strategy (*e.g.*, overprovision of resources for not profitable VNFs) to have insights about how to improve the business. Finally, we conducted three case studies in different scenarios to show the application and feasibility of our visualizations.

The remaining of this paper is organized as follows. In Section II, we review related work. In Section III, we introduce our visualizations and give details about them. In Section IV, we present three case studies to demonstrate the feasibility of our visualization solution. Finally, in Section V, we conclude the paper and comment on future work.

## II. RELATED WORK

Designing a computer network to support all business requirements is a hard task and involves several decisions that impact on service levels, profits, and competitive advantage. Such decisions are even more challenging when network technologies in place tend to be more disruptive than traditional wired networks, such as SDN, NFV, and wireless communications. These new technologies require specific planning tools and strategies to both guarantee high-quality services for customers and assure SP's profits. The current literature on network planning include works that address topics as diverse as optimizing energy efficiency in data centers [9], analyzing data of mobile applications [10], and improving security in future networks [11]. In this Section, we review some relevant studies on network planning, mainly those related to new technologies and challenges in networking.

EI-Beaino et al. [12] investigate wireless network planning for the upcoming 5G networks. The planning process is focused on the deployment of wireless networks with requirements with regard to coverage, capacity, and quality of service (QoS). The authors were able to minimize the number and optimize the location of base stations in a selected geographical area using a heuristic algorithm. In another study, Plets et al. [13] perform an evaluation of two wireless network planning approaches for a very large industrial hall. The inconclusive results indicate that more studies for network planning in large environments are required for filling the gap in the area. Moreover, the authors highlighted that no wireless network planners available so far could deal with intra-network interference.

Pavon-Marino and Izquierdo-Zaragoza [14] propose the Net2Plan, a visual solution devoted to planning, optimization, and evaluation of communication networks. Net2Plan can also support the development of distinct planning tools. Izquierdo-Zaragoza et al. [15] discuss the opportunities and challenges of interactions between SDN controllers and current network planning tools. The authors propose a Net2Plan tool and investigate the capacity to orchestrate an OpenFlow-based network on top of the OpenDaylight controller. However, although the Net2Plan solution can be adapted for planning networks of any technology, it is limited to the tasks of network design, traffic evaluation, and generation of reports. Moreover, the original features of Net2Plan do not provide visualizations to support planning decisions in a business model based on NFV-enabled networks.

Velasco et al. [16] propose a novel network planning framework, which allows the network operator to plan and reconfigure the network dynamically according to traffic changes. The authors report two case studies regarding transport networks, showing that resource overprovisioning can be minimized and that overall network costs can be reduced. However, as was not their focus, such framework does not provide ways for the network operator to have insights about business strategies or customers profile.

At the industry side, the Real Status company [17] maintains the HyperGlance platform to aggregate resources data and relationships into a unified and interactive visualization. HyperGlance integrates data from various sources (*e.g.*, OpenStack, OpenDaylight, and Nagios) to generate useful visualizations, hence improving the network operators capacity for planning and managing complex networks. Nonetheless, HyperGlance neither supports NFV technology nor covers particular issues concerning NFV planning.

Although network planning has received significant attention from researchers and companies, none of the existing solutions exploits planning of NFV-enabled networks. As a consequence, there is a lack of tools that deal with NFV features and its business opportunities. We also emphasize that information visualization techniques be generally underused as a resource to assist network operators in NFV planning tasks. To address this situation, in the next sections, we introduce our visualization techniques designed to support NFV planning.

## III. VISUALIZATION SOLUTION FOR NFV PLANNING

In this section, we present a set of visualizations to assist network operator in NFV planning tasks (*e.g.*, capital investment and resources allocation). Our solution is composed by visualizations that consider static and dynamic information from NFV environment to allow operators to understand the business strategy and tenant's demands in a clear way. Hence, the operator can have insights to make strategic decisions about the NFV business, such as determining how to invest correctly in infrastructure and performing actions that avoid future problems in service performance. In essence, our visualizations are based on two main visualization techniques: (*i*) Hierarchical Edge Bundling technique [7] to visualize the relationships and the edges adjacency in complex graphs; and (*ii*) Sankey Diagram [8] that implements a technique to explore complex flows scenarios. These techniques were found as valuable for this study and have been adapted to meet the specific needs of NFV-enabled networks planning.

We have implemented the proposed visualizations as templates on VISION platform, which was developed in a previous work [6] aiming at simplifying the management of NFV-enabled networks and assisting in problem identification process. VISION obtains and manipulates data from an NFV environment and presents it using visualization techniques, thus helping human operators understand and avoid recurrent VNF problems. One of the richest features of VISION is the capacity to integrate new visualization solutions; it allows the reuse of modules of the platform in the implementation of new visualizations. For example, an operator can implement visualizations on the web-based interface and use the data layer module to obtain and access information. Therefore, VISION

is responsible for collecting and processing the data from the NFV environment, hence allowing us to focus in proposing novel visualizations techniques for NFV planning.

Although VISION collects several data from the NFV environment, it does not consider the information from the VNF Descriptor (VNFD) and Network Service Descriptor (NSD). The European Telecommunications Standards Institute (ETSI) specifies the VNFD file as a template which describes a VNF in terms of deployment and operational behavior requirements [18]. Also, the NSD file is defined to present the network service in an XML notation, including the virtual hardware requirements, dependencies, and conflicts. These descriptors files define important details about how the VNFs will run, such as the amount of required resources for each VNF, distinct flavors available (*i.e.*, contractable plans that define how much resources will be allocated for each VNF), and capacity of the network. Thus, descriptors are valuable for planning decisions. To obtain this data, we extend the Data Collector module to be able to collect and store data from VNFDs and NSDs available in the NFV environment. Also, we implement a new module that is responsible for providing visualizations templates for the Visualization Builder module.

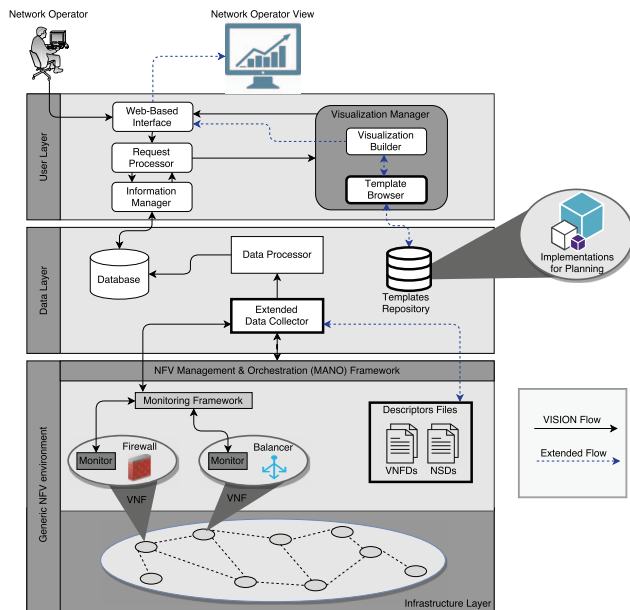


Fig. 1: Extended Conceptual Architecture of VISION

In Figure 1, we introduce the extended VISION conceptual architecture, in which the flow to collect information and create visualizations are depicted with solid lines. Moreover, the dashed lines show the extended flow with new connections that we implemented to build our visualizations. The new modules and components are highlighted with bold borderline. VISION architecture (Fig. 1) is organized in three distinct layers to isolate the modules in relation to their function: *i)* User Layer contains modules that implement the user interface, processes requests, and creates visualizations; *ii)* Data Layer contemplates the modules in charge of collecting, processing, and organizing the data from NFV environment and monitors; and *iii)* Generic NFV environment layer represent the infrastructure

and the NFV correspondent elements.

As suggests the architecture flow, we can follow three main steps to build the proposed visualizations. First, the Data Collector communicates with the MANO (Management and Orchestration) framework, VNF monitors, and Descriptors files (extended feature) to populate the database with relevant information. Next, the Data Processor prepares this information to be available for the Information Manager requests. Finally, the Visualization Manager selects the templates and creates the visualizations according to the operator requests.

The Data Collector module obtains data (*e.g.*, VNFs events and textual forwarding graph representation) from MANO framework. For this, the Data Collector can send GETs messages via API REST (Representational State Transfer) to MANO. This module can also access the NFV descriptors files directly to extract information. Besides, this module may collect data from customized monitors placed into the VNFs. The network operator must only configure, in VISION platform, the monitor's parameters (*e.g.*, correspondent VNF, hardware, and IP address from the monitor) to allow the data collection. We define the initial polling time for data collecting as five minutes, but it can be changed in the platform settings, by the operator.

Although the proposed work uses an existing architecture, it is not limited to it. In the rest of this section, we will introduce two visualizations techniques to tackle the challenges of planning and strategy changes in NFV business models. A prototype with main features of our visualizations is available online<sup>1</sup>. This prototype was implemented using the d3js library, which is a javascript library for manipulating documents that allows creating interactive visualizations.

#### A. Visualization of Relationships and Business Demands

In NFV-enabled networks, we have some VNFs from service provider's application and several tenants of the service. The operator needs to have extensive knowledge of the information about relationships and demands related to the business actors (*i.e.*, tenants and VNFs) to efficiently plan the NFV business. In fact, understanding this information is a challenging task itself because of the amount of data involved. In order to simplify the planning tasks, we propose a visualization of relationships and business demands. Our visualization is an adaption of the ClusterVis technique [19], which is an interactive visualization to represent relationships between entities along with multiple attributes. ClusterVis borrows ideas from the Hierarchical Edge Bundling technique [7]. With this visualization (Fig. 2) we present information about the NFV environment in a useful way to ease the planning tasks. The network operator, for instance, can analyze and compare statistics (*e.g.*, how much resources are allocated for each VNF or tenant) to have insights about how to improve or maintain the service health.

The visualization consists of a central circle that contains nodes representing the business actors. The blue and yellow nodes are, respectively, the tenants and VNFs that compound the business. The blue lines inside the main circle show the relationship among the nodes. For instance, a tenant node

<sup>1</sup><http://inf.ufrgs.br/~mffranco/VisPlanning/>

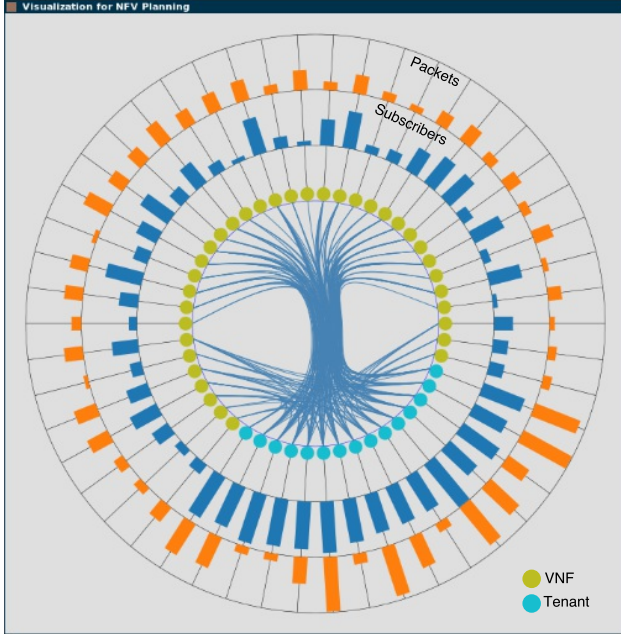


Fig. 2: Visualization of Relationships and Business Demands

is represented with connections (blue lines) to contracted VNFs nodes. Also, the rings around the inner circle contain bar charts, each bar with size proportional to the value the corresponding node attribute the ring represents. The first ring presents the number of subscribers for each node while the outer ring indicates the amount of packets per second associated with each node. A settings menu (see Section IV) allows customizing all the rings for representing any information collected by the Data Collector module, such as calls per second, CPUs cores, and allocated memory. Moreover, the network operator can select a ring to sort the visualization. For example, the operator can sort the nodes by packets per second and the nodes will be presented in increasing order (see Section IV). Thus, the nodes with more packets associated will be displayed first, followed by nodes with fewer packets, hence facilitating the human interpretation.

In summary, our visualization is based on representing three main subsets of data about the NFV environment: (i) tenants and VNFs that compound the business; (ii) resources allocated to operate the business (e.g., resources assigned for each VNF and flavors contracted by tenants); and (iii) relationships among business actors (i.e., tenants and VNFs). In addition, other relevant information (e.g., amount of packets being processed and latency time) can be collected by custom monitors put inside the VNFs [20]. By using our visualization, the network operator can detect planning issues, such as identify when a virtual firewall that is processing a huge amount of packets is with less memory and CPU cores allocated than other VNFs that are idle (see Section IV-A).

Other features that we propose allow network operators to interact and customize the visualization according to their needs. Such features include, for example: (i) information about nodes and rings are displayed by hovering the mouse;

(ii) new rings can be removed or added either to simplify the visualization or obtain details about a node; and (iii) color attributes can be defined to nodes according to categories (e.g., red colors to firewalls and green to load balancers). In Section IV, we discuss two examples of these features through case studies.

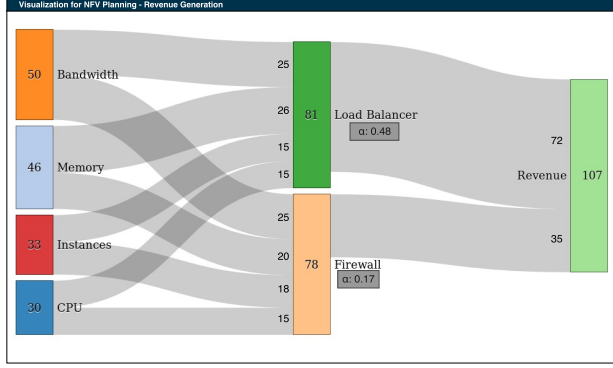
### B. Visualization of Allocated Resources and Revenue Generation

Resources Planning (e.g., resources allocation policies and infrastructure investment) is a fundamental task to estimate the amount of resources needed to offer a computing service [21]. This task requires a continuous planning to run in a flexible environment with high dynamic demands. Furthermore, incorrect planning of resources allocation can reduce the potential to obtain profits in NFV-enabled business. For instance, the provisioning of resources to run services that generate little revenue requires attention to avoid implications in the business health. To aid the network operator, we propose a flow-based visualization that shows the amount of resources allocated to run VNFs of a determined group as well the total revenue obtained by all groups of VNFs. Hence, this visualization helps the operator in having insights about the profit potential of each service, which is relevant to make decisions that improve the business strategy.

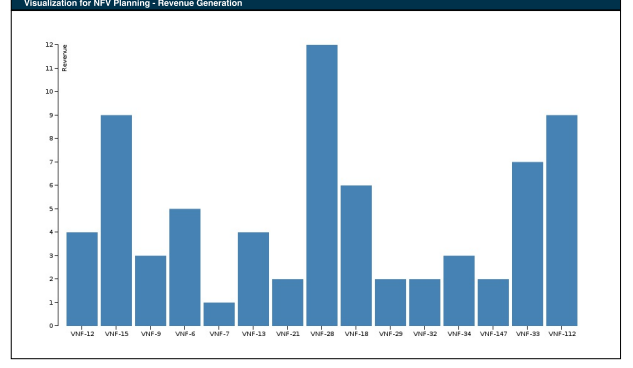
Our visualization of allocated resources and revenue generation is based on a Sankey Diagram [8]. It presents a flow view to support the interpretation of how many resources are being spent to generate the business revenue. Figure 3a shows this visualization and its main features. The beginning of the flow (left-to-right) represents the resources available inside the rectangles. The connection lines highlight the amount of resources provisioned to a group of VNFs (i.e., services). Next, in the middle of the flow, a representation of the total amount of allocated resources is provided, that means the sum of all allocated resources to run the services. Finally, we present the total revenue obtained by each group. For example, in this case, we observe a group with 15 load balancers, which are consuming 25 units of bandwidth, 26 units of memory, and 15 units of CPU. The total of resources allocated to this group is 81 units of resources, and this generates a revenue of 72 units.

To facilitate the interpretation of our visualization, we define general values as a reference for resources and revenue units: (i) one unit of memory is equal to 1GB, (ii) each unit of bandwidth corresponds to 10Mbps, (iii) one unit of CPU Core is equal to one instance of CPU; and (iv) each unit of revenue represents the amount of \$100. Thus, for example, the group of load balancers has allocated 26GB of memory, 250Mbps of bandwidth and 15 CPU cores, thus resulting in a revenue of \$7200 (72 units). Moreover, the network operator can set any value to define one unit of each resource. For instance, 2GB of memory can represent one unit of memory, and \$50 can be the reference value of one unit of revenue.

Figure 3a also shows a revenue coefficient ( $\alpha$ ). This value is related to each group of VNFs, and it represents a trade-off between the cost of running the VNFs and the revenue that they provide. The objective of showing this coefficient is to help network operators identify groups of VNFs that are lucrative to the business. Thus, the service with higher  $\alpha$  is



(a) Visualization based on Sankey Diagram



(b) Complementary visualization with a revenue overview of each load balancer instance

Fig. 3: Visualization of Allocated Resources and Revenue Generation

the most profitable for the business. The revenue coefficient is obtained individually for each category of VNF. For example, in Figure 3a we have two values of potential revenue: one for firewalls and other for load balancers. We compute the average cost  $C$  to run a VNF of a given type (*e.g.*, cost of one firewall) according to Equation 1. The rationale behind it is: for each resource  $i$  allocated to a VNF  $j$  of a group, we add a specific weight ( $W_i$ ). The weighted sum of resources allocated to each VNF, divided by the number of VNFs in the group ( $n$ ), results in the average cost to run one VNF in the group. We assume that the network operator is responsible for determining the resource weights (*i.e.*, resources hard to obtain will have a higher  $W$  than others in abundance). Next (Equation 2), we calculate the average revenue of one VNF ( $R$ ), which is the result of a division between the total revenue ( $Rt$ ) and the number of running VNFs ( $n$ ). Finally (Equation 3), we obtain the revenue coefficient ( $\alpha$ ) by dividing the average cost ( $C$ ) per the average revenue ( $R$ ).

$$C = \frac{\sum_{j=1}^n [\sum_{i=1}^r A_i * W_i]}{n} \quad (1)$$

$$R = \frac{Rt}{n} \quad (2)$$

$$\alpha = \frac{C}{R} \quad (3)$$

In addition, our visualization allows the network operator to set elements that will be visible in the flow, such as which resources and what group of VNFs will be used as the basis for the visualization. Besides, the operator can access a complementary visualization that represents an overview of the revenue of the VNFs being analyzed. Figure 3b shows this complementary visualization and presents the revenue associated to each VNF in the load balancers group. The two visualizations (Figs. 3a and 3b) can be combined to provide powerful resources to help network operators in performing different tasks for NFV planning, hence improving the capacity of operators to understand the business. For instance, the operator can identify abnormal behaviors that lead to a wrong conclusion about the group revenue, such as a unique VNF

with high revenue can incorrectly suggest that an entire group is attractive to the business.

#### IV. CASE STUDIES

We analyze different scenarios to provide evidence of the effectiveness and technical feasibility of our proposed visualizations. In this section, we present three case studies focusing on distinct planning issues in NFV-enabled business. First, we explore the visualization of relationships and tenants demands to provide a way for identifying fails in the resources allocation policies and flavors available in the business. Secondly, we present a visualization to understand where to invest in the business to maintain its health and to increase its competitiveness. Finally, we use the flow diagram visualization to investigate the correlation between allocated resources and revenue generation to determine how much profit a category of VNFs is providing.

##### A. Case Study #1

Let us suppose the following scenario: the network operator perceives a substantial increase in complaints about service performance by tenants. In an initial analysis, monitoring tools inside the NFV environment report an overload of packets being processed in a determined period of the day, which is impacting the latency of some VNFs and, consequently, the service performance. Based on this information, the operator wants to identify the situation and then, conducts a deeper investigation to make decisions to avoid further problems.

Initially, there is no obvious issue that indicates a problem in the NFV-enabled business. In order to investigate the business, the operator accesses our visualization of relationships and business demands. In Figure 4, we present the operator customization: VNFs and tenants as yellow and blue nodes, respectively, and located in the first ring; the amount of packets processed are shown in the second ring; the allocated bandwidth in the third ring; the number of CPU cores in the fourth ring; and the available memory in the fifth ring. Also, in this visualization, the network operator chose the option to sort the visualization by the number of packets processed. Thus, the visualization shows first the nodes that process the

larger amount of packets followed by nodes that are processing a smaller amount of packets (*i.e.*, increasing order).

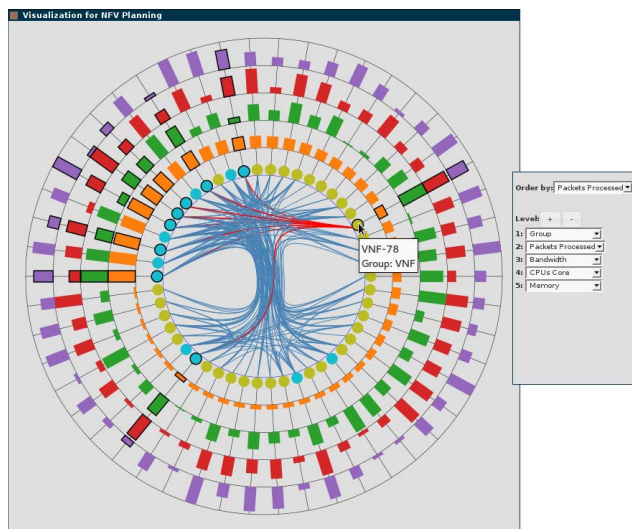


Fig. 4: Investigation about fails in planning of the resources allocation policies and flavors available

By using our visualization, the operator has an insight: there are some VNFs with few allocated resources that are handling many packets per second, while other ones are with idle resources. This problem is highlighted when we analyze the rings of allocated resources and observe that there are several resources allocated to VNFs that are processing few packets. The operator has this insight, for example, by noticing that VNF-78 (see Fig. 4) has a small second level bar graph (*i.e.*, the orange bar that represents the amount of packets being processed) while having a full bar for bandwidth (green bar) and CPU cores (purple bar). Besides, we note that other VNFs share the same behavior. Such problem can occur because the network operator did not consider the business demands when defined the initial business structure, thus resulting in bad policies for resources allocation and incompatible VNFs flavors.

To tackle this problem, the network operator must plan a new strategy for resource allocation, thus changing the allocation policies to consider dynamic demands of the business. As another solution, the operator can decide to perform changes in the way of how the tenants are charged to use one VNF. Thus, tenants that consume more packets will pay more to use flavors that provide high availability of resources. Also, the network operator can structure the business to support flexible flavors in which tenants will pay according to their demands.

### B. Case Study #2

In traditional business scenarios, the competition between companies leads to a continuous increase in the quality and variety of products available for customers. It is not different in NFV-enabled business, where the services providers need to implement a better service performance and cost according to tenants longings and markets landscape. Therefore, the SPs need to have a broad knowledge of the tenants' profiles and

their demands to realize strategic investments and changes to improve the business competitiveness.

In this case study, we create a scenario where a service provider has a substantial amount of capital to invest in business infrastructure. The network operator needs to understand the business demands to plan how to evolve the business in a right way. For instance, if the tenants are contracting a lot of VNFs that are firewalls with flavors that provide a greater capacity to process packets, then this can suggest that an investment in firewalls with sufficient resources available is a good planning decision. Hence, the operator can use our visualization to plan the next directions of the business expansion.

Figure 5 presents a visualization that provides resources for identifying which category of VNFs (*e.g.*, load balancer and firewall) are the most contracted and what resources are more requested by the tenants. In this visualization, the operator sets an option to display the category of each node in the inner ring. Hence, the colors are defined according to the services that each node represents. For example, the gray and yellow nodes are, respectively, firewalls and DPIs. The purple nodes represent the tenants of the business. The second ring presents how many tenants are contracting each VNF or - when analyzing only tenants nodes - the amount of VNFs contracted by tenants. The last three rings represent information about resources allocated to each node (*e.g.*, memory, bandwidth and CPU cores). Moreover, the operator defines the visualization to be sorted according to the number of subscribers. Thus, the nodes with the largest number of subscribers are presented first, followed by the other nodes.

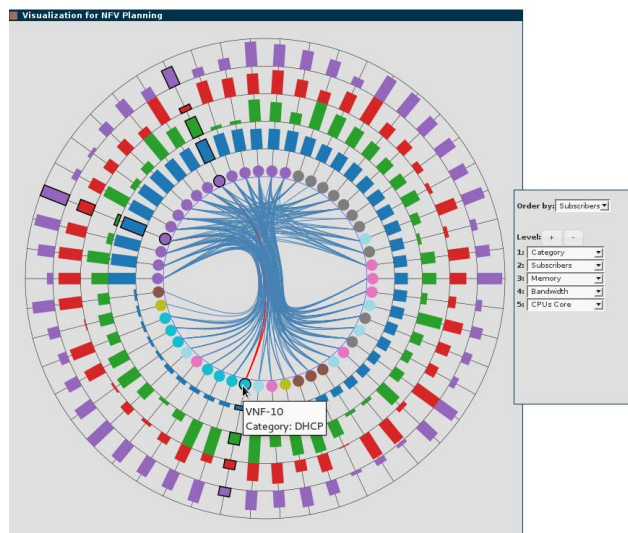


Fig. 5: Visualization for planning of business investment

In a first analysis, the operator observes that VNFs with more subscribers are firewalls (gray nodes). Besides, one can notice that the tenants have a preference for firewalls with more memory allocated, and by observing, one can conclude that the VNFs with more subscribers (largest blue bar) are firewalls that have more memory allocated (largest green bar) than others. Moreover, the operator can have another insight: there are

many DHCP (blue nodes) with few or none subscribers (*e.g.*, VNF-10). This suggests an incorrect investment in a service that does not comply with the tenants' interest.

The network operator needs to make decisions to mitigate these behaviors, thus adapting the business to the market tendency and tenants demands. To achieve this, the operator could invest capital to run firewalls with flavors that provide a large amount of memory. Furthermore, some DHCPs could be removed from the business, hence releasing resources for other services. The tenants that need an individual DHCP, for example, must pay to contract a special flavor. Thus, based on these decisions, the operator obtains a profitable business model, which provides both high-performance VNFs according to tenants demands (*e.g.*, firewalls and other interesting services) and VNFs that supply the necessities of individual requirements (*e.g.*, DHCPs with low demand but attractive to some tenants).

### C. Case Study #3

This case study is based on a situation where the network operator identified, in a previous investigation, three categories of VNFs which may be interesting for improving the business. The operator has the following relevant information: (i) firewalls and load balancers are the VNFs with more subscribers in the business; and (ii) some video caches have few subscribers but high demand (*i.e.*, many packets being processed and calls-per-second). Even though load balancers have more subscribers than video caches, this is not an obvious indicative about which of them are more profitable. Based on this information, the network operator needs to understand how profitable to the business is each service.

The operator accesses our visualization of allocated resources and revenue generation to have insights that help in planning new business strategies and investment. Figure 6 presents the amount of resources allocated and subscribers for each group of VNFs being analyzed. The visualization contains, in the flow start (left), the amount of allocated resources (*e.g.*, CPU cores, memory and bandwidth) to run a group of VNFs and the number of tenants contracting it). The middle of the flow represents the sum of all allocated resources. Finally, we present the revenue of each group of VNFs. Besides, the revenue coefficient ( $\alpha$ ) highlights the services that are being the most profitable to the business.

For this case study, we define the following values as reference to allocated resources and revenue: (i) one unit of memory is equal to 1GB, (ii) each unit of bandwidth represent 10Mbps, (iii) one CPU unit is equal to one CPU core; and (iv) each unit of revenue is equal to \$500 (five hundred American dollars). Thus, the operator needs to use these references when converting the visualization values to real outgoing and incomes.

By analyzing the flow visualization (Fig. 6a), the operator identifies that even though there are only a few subscribers to the video caches, this service is very profitable for the business. Such insight occurs by comparing the amount of revenue (\$75000) and the  $\alpha$  of video caches with others. Thus, this service needs to be maintained in future planning. Moreover, the firewalls demonstrate that are also attractive to the business. Many tenants are subscribing firewalls (79 subscribers), and

there is a significant revenue (\$67500) and  $\alpha$  value. On the other hand, the load balancers, which have a good number of subscribers and allocated resources, provide a revenue below of the expected. Therefore, the network operator must plan an strategy to make available VNFs that correspond to the business goals, such as new load balancer pricing and flavors to supply tenants demands and, also, ensure a profitable service.

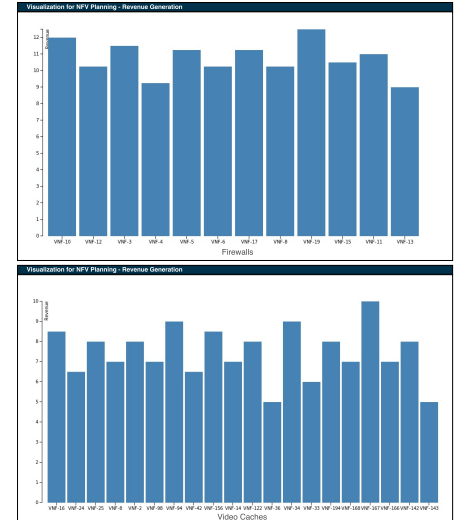
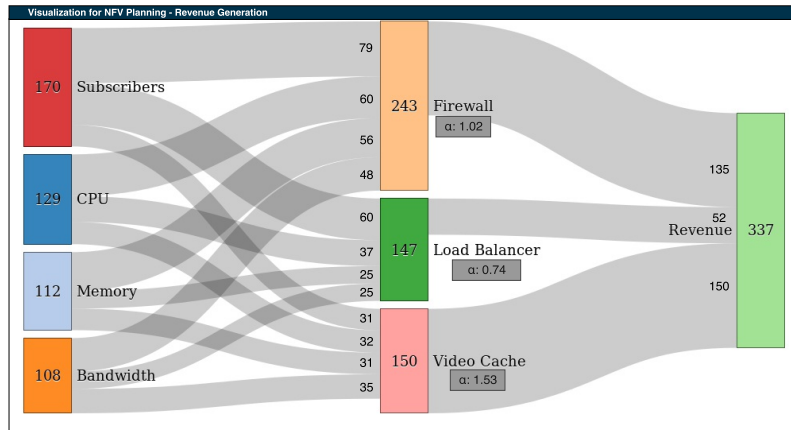
Moreover, the complementary visualization (Fig. 6b) provides information to conclude that there are more video caches (20 VNFs) than firewalls (12 VNFs); it also suggests that, in the mean, one firewall generates more revenue than one video cache. However, the video caches obtain a better result for  $\alpha$  because one instance of video cache is less expensive for implement than others services. Based on this analysis, we can note that another attractive approach to the business can be based on defining a new strategy that reduces the cost to run a firewall, thus increasing the profit potential of this service.

## V. CONCLUSIONS AND FUTURE WORK

In this paper, we have introduced two interactive visualizations that help network operators make planning and strategic decisions in NFV-enabled business. Such visualizations provide insights for a better planning of infrastructure investment, resource allocation policies, and services pricing. By using our visualizations, operators can identify mistakes in the business strategy and highlight priorities that require attention, thus improving the operator ability to maintain the business health and competitiveness. Furthermore, we proposed an extension of the VISION platform to integrate new visualizations, hence enabling the platform to collect and process relevant data for supporting our visualizations.

Case studies provided evidence of the effectiveness and feasibility of proposed visualizations. In the case study #1, we detailed a scenario where the network operator needs to identify fails in resource allocation policies and flavors available in the business. The operator uses the visualization of relationships and business demands to detect that there are VNFs with few resources allocated, which are handling many packets per second, while some VNFs have idle resources. In case study #2, the service provider has a substantial amount of capital to invest in infrastructure and needs to know the better way to improve the business. Thus, the operator accesses our visualization to identify which VNFs and services are most interesting for tenants. Finally, in case study #3, we provided a deep investigation of business profits. The operator uses our visualization of resources allocated and revenue generation to determine which is the most profitable group of VNFs, hence understanding which service is more lucrative for the business.

As future work, we will extend our visualizations to provide addition features for NFV planning, such as profit estimation, simulation of planning changes, and an integrated editor for contactable flavors. Also, we intend to investigate artificial intelligence techniques to provide a prognostic about market tendency and business problems. Besides, we plan to provide a collaborative solution for network operators to share information that helps others operators in NFV-enabled business planning tasks.



(a) Flow visualization to understand amount of resources spent for each service to generate the business revenue and profits

(b) Complementary visualization with a revenue overview of each video cache and firewall available

Fig. 6: Determining most profitable group of VNFs and business priorities

## REFERENCES

- [1] ETSI NFV ISG, "Network Functions Virtualisation," Jun 2012, White Paper.
- [2] R. Mijumbi, J. Serrat, J. L. Gorricho, N. Bouten, F. D. Turck, and R. Boutaba, "Network Function Virtualization: State-of-the-Art and Research Challenges," *IEEE Communications Surveys Tutorials*, vol. 18, no. 1, pp. 236–262, Firstquarter 2016.
- [3] G. Xilouris, M. A. Kourtis, M. J. McGrath, V. Riccobene, G. Petralia, E. Markakis, E. Palis, A. Georgios, G. Gardikis, J. F. Riera, A. Ramos, and J. Bonnet, "T-NOVA: Network functions as-a-service over virtualised infrastructures," in *Network Function Virtualization and Software Defined Network (NFV-SDN), 2015 IEEE Conference on*, Nov 2015, pp. 13–14.
- [4] V. T. Guimares, C. M. D. S. Freitas, R. Sadre, L. M. R. Tarouco, and L. Z. Granville, "A Survey on Information Visualization for Network and Service Management," *IEEE Communications Surveys Tutorials*, vol. 18, no. 1, pp. 285–323, Firstquarter 2016.
- [5] R. Mijumbi, J. Serrat, J. I. Gorricho, S. Latre, M. Charalambides, and D. Lopez, "Management and orchestration challenges in network functions virtualization," *IEEE Communications Magazine*, vol. 54, no. 1, pp. 98–105, January 2016.
- [6] M. F. Franco, R. L. d. Santos, A. Schaeffer-Filho, and L. Z. Granville, "VISION – Interactive and Selective Visualization for Management of NFV-Enabled Networks," in *2016 IEEE 30th International Conference on Advanced Information Networking and Applications (AINA)*, March 2016, pp. 274–281.
- [7] D. Holten, "Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data," *IEEE Transactions on Visualization and Computer Graphics*, vol. 12, no. 5, pp. 741–748, Sept 2006.
- [8] P. Riehmman, M. Hanfler, and B. Froehlich, "Interactive Sankey diagrams," in *IEEE Symposium on Information Visualization, 2005. INFOVIS 2005.*, Oct 2005, pp. 233–240.
- [9] T. Yang, Y. Lee, and A. Zomaya, "Collective Energy-Efficiency Approach to Data Center Networks Planning," *IEEE Transactions on Cloud Computing*, vol. PP, no. 99, pp. 1–1, 2016.
- [10] A. Lahmadi, F. Beck, E. Finickel, and O. Festor, "A platform for the analysis and visualization of network flow data of android environments," in *2015 IFIP/IEEE International Symposium on Integrated Network Management (IM)*, May 2015, pp. 1129–1130.
- [11] M. H. Khyavi and M. Rahimi, "Conceptual Model for Security in Next Generation Network," in *2016 30th International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, March 2016, pp. 591–595.
- [12] W. El-Beaino, A. M. El-Hajj, and Z. Dawy, "On Radio network planning for next generation 5G networks: A case study," in *Communications, Signal Processing, and their Applications (ICCSPA), 2015 International Conference on*, Feb 2015, pp. 1–6.
- [13] D. Plets, E. Tanghe, A. Paepens, L. Martens, and W. Joseph, "WiFi network planning and intra-network interference issues in large industrial warehouses," in *2016 10th European Conference on Antennas and Propagation (EuCAP)*, April 2016, pp. 1–5.
- [14] P. Pavon-Marino and J. L. Izquierdo-Zaragoza, "Net2plan: an open source network planning tool for bridging the gap between academia and industry," *IEEE Network*, vol. 29, no. 5, pp. 90–96, September 2015.
- [15] J. L. Izquierdo-Zaragoza, A. Fernandez-Gambin, J. J. Pedreno-Manresa, and P. Pavon-Marino, "Leveraging Net2Plan planning tool for network orchestration in OpenDaylight," in *Smart Communications in Network Technologies (SaCoNeT), 2014 International Conference on*, June 2014, pp. 1–6.
- [16] L. Velasco, A. Castro, D. King, O. Gerstel, R. Casellas, and V. Lopez, "In-operation network planning," *IEEE Communications Magazine*, vol. 52, no. 1, pp. 52–60, January 2014.
- [17] Real Status, "Hyperglance - A visibly diffent approach to cross-domain, hybrid IT management," <http://www.real-status.com/>, 2015.
- [18] ETSI GS NFV-MAN, "Network Functions Virtualisation (NFV); Management and Orchestration," Dez 2014, White Paper.
- [19] R. Cava, M. Winckler, and C. M. D. S. Freitas, "ClusterVis: Visualizing Nodes Attributes in Multivariate Graphs," in preprint.
- [20] R. J. Pfitscher, E. J. Scheid, R. L. dos Santos, R. R. Obelheiro, M. A. Pillon, A. E. Schaeffer-Filho, and L. Z. Granville, "DReAM - a distributed result-aware monitor for Network Functions Virtualization," in *2016 IEEE Symposium on Computers and Communication (ISCC)*, June 2016, pp. 663–668.
- [21] D. Candeia, R. A. Santos, and R. Lopes, "Business-Driven Long-Term Capacity Planning for SaaS Applications," *IEEE Transactions on Cloud Computing*, vol. 3, no. 3, pp. 290–303, July 2015.