

# Optimizing Virtual Network Functions Placement in Virtual Data Center Infrastructure Using Machine Learning

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**Abstract.** We have elaborated a neural network model of virtual network flow identification based on the statistical properties of flows circulating in the network of the data center and characteristics that describe the content of packets transmitted through network objects. This enabled us to establish the optimal set of attributes to identify virtual network functions. We have established an algorithm for optimizing the placement of virtual data functions using the data obtained in our research. Our approach uses a hybrid method of visualization using virtual machines and containers, which enables to reduce the infrastructure load and the response time in the network of the virtual data center. The algorithmic solution is based on neural networks, which enables to scale it at any number of the network function copies.

## 1. Introduction

Today, considerable volumes of data circulate in modern telecommunication networks. The modern paradigm is need new solutions effective control of traffic in networks and, at the same time, do not demand cardinal changes of the existing infrastructure of a data center. Traditional data centers use the concept of resources virtualization for various infrastructure facilities (network, computing nodes, systems of storage etc.) to achieve the goal. The application of a complex approach to virtualization is reflected in the architecture of virtual data centers (VDC). This architecture was used for the placement of multi cloud platforms. Multi cloud platforms use hybrid methods of virtualization based on software-defined components. It enables to increase the efficiency of computing resources use and, thus, to reduce the economic cost of maintaining the infrastructure of traditional data centers. However, the conception of resources virtualization is not quite effective. It allows abstracting the processed and transmitted data flows from physical devices [1]. But, nowadays, the problem of the effective placement of key components of the virtual network environment in a multi cloud platform is not solved [2].

One of the approaches applied in virtual data centers apart from the virtualization of traditional objects of network infrastructure, is the use of software realization instead of traditional hardware solutions, such as firewall, load balancer, NAT, routers and others. In practice, such solutions are based on the technology of network function virtualization (NFV) [3]. The NFV technology provides more flexible deployment and enables to control the virtual objects of a multi cloud platform, which perform the roles of hardware network devices, more effectively [4]. As a rule, the NFV technology is applied together with the software-defined network (SDN) and enables to exercise adaptive traffic control. However, the technology of network function virtualization has a number of disadvantages. The main problem is the lack of effective methods of planning for placing virtual objects in physical



computing nodes. The review of research shows that existing solutions for placing the NFV in the infrastructure of data center use the approaches based on virtual machines or containers. The existing solutions do not deal with resource intensity of each virtual network function and its functional purpose for multi cloud infrastructure of the VDC. We have developed the approach that allows us to cluster the existing virtual and physical objects of infrastructure and, then, to place virtual network functions. The main idea of our solution is to estimate the consumption of resources by each element of the network. Besides, we will use the hybrid method of virtualization based on the simultaneous use of virtual machines and containers to create a flexible solution. It will enable to optimize the placement of the technology of network function virtualization in the infrastructure of a VDC.

Our approach is relevant, since it represents the combination of two modern innovative technologies in the field of the organization of network functioning and virtualization of its components for resource and data flow control in the SDNs based on the technology of network function virtualization. The goal of our investigation is to improve the quality of service (QoS) for applications and services of the multi cloud platforms placed in a VDC. Besides, we use the methods of intellectual data analysis to process information about the state and load of key objects as well as the flows between network devices received from the systems of computing nodes monitoring in the software-defined infrastructure of the multi cloud platform. It enables to receive the consolidated assessment of the QoS and to predict uninterrupted operation and operability of the software-defined infrastructure of a multi cloud platform and the entire virtual data center.

Further, we will describe our approaches to the optimization of the placement of virtual network functions in the multi cloud environment of VDC. Section 2 gives information about modern research and the existing approaches to working with network functions. In Section 3, we describe the methods and approaches applied within a framework of our solution. Besides, we describe the main stages of its implementation. The neural network work model, which is a basis for the formation of cards of placement of network functions in the multi cloud environment of virtual data center, is presented in section 4. Section 5 and 6 we gives the algorithmic solution and experimental investigation in network environment of VDC.

## **2. Related work**

The variety of physical network devices of various vendors increases both capital expenditure and operational costs for the maintenance of data centers. The technology of network function virtualization allows solving this problem by the realization of network functions as software. The application of the NFV implies the use of the technology of network objects virtualization, which functions as software and particular computing processes, or as complex infrastructures of cloud computing instead of hardware solutions.

The group of scientists headed by Min Chen [5] analyzes the architecture and mechanisms of the interaction between the technology of NFV and the SDNs. As noted in the research, if the number of the users who launch applications in the multi cloud network environment increases, there is a competition for resources. Each user request is described by the requirements to network environment from the viewpoint of productivity, safety, and the effective control of objects in virtual infrastructure.

Scientists from Arizona State University [6] have studied a multi cloud system. They offer an approach to the creation of network architecture based on the NFV technology as alternatives for traditional hardware network devices. However, this research does not solve the main problem concerning the methods of NFV placement on computing nodes.

The NFV technology also has other a number of disadvantages. One of them is associated with the organization of the coordinated control of the entire network infrastructure of the VDC. To solve this problem, scientists from University of Wisconsin-Madison have proposed an approach, which is a framework of the OpenNF [7]. This approach provides the effective coordinated control of both the internal state of network functions and the state of data transmission network. But, this decision does not solve another important issue associated with the overall performance and load on the controller of network functions.

The scientists from Nation Chung Cheng University have investigated the reduction of load on the controller to ensure the work of the NFV technology [8]. As a rule, in case of the SDN use, the controller classifies the traffic received from the ports on network nodes to define a path to network objects, which play a role of the virtual network functions. This process generates large volumes of traffic in the plane of control. The authors offer the expansion for the architecture based on the SDN to reduce the load created by network traffic on the controller due to the use of the NFV technology. The solution represents two-layer classification of traffic based on the OpenFlow protocol. Network events are analyzed in the plane of data instead of the plane of control.

The group of scientists headed by Hassan Jameel Asghar has developed a scalable system to work with the technology of network function virtualization in the multi cloud environment [9]. The authors have offered an abstract model of the standard network function distributed between several cloud platforms. The system enables to increase the speed of package processing considerably in comparison with similar hardware solutions. An essential disadvantage of the concept is the resource intensity of this system. The overhead costs of the deployment and work of the Splitbox network functions demand the same quantity of computing resources as in case of hardware network devices.

Thus, it is established that the technology of NFV and the existing cloud solutions based on the software-defined infrastructure of the VDC has a number of advantages, which enable to improve the quality of service in data transmission networks. However, today, there are adequate and effective solutions, that would enable to control the placement of the NFV on physical and virtual computing nodes in the data center.

### 3. Methods and approaches

Nowadays, neural networks are the most effective and high-speed method for forecasting, parameter identification, clustering and classifications in various fields of knowledge. Today, we see many successful examples of the application of a neural network approach for the creation of intellectual information systems [10]. Besides, the advantage of the neural networks use is the possibility of adaptive self-training with the use of additional methods of approaches. We have used an iterative approach based on a group of methods associated with the optimization of placement of VFN on the objects of the software-defined infrastructure of the VDC.

First of all we will present all network objects of the multi cloud platform placed in the VDC as a communication graph. The graph is based on the topology of the physical network switching. Each network object is the graph vertex. It can be described by a basic set of parameters, which characterize each element of the network and influence productivity. We have chosen the following characteristics as parameters: volume of memory, volume of disk space, the frequency and quantity of kernels, etc. Further, we will use these characteristics as the input parameters acting as the training set for a neural network during the study of data.

A multi cloud platform supports the placement of various applications and services. Therefore, to identify the flows of traffic passing through infrastructure facilities of the VDC is an important task for the placement of virtual network functions. In this research, we have used the method based on the analysis of the known network ports for popular applications to obtain this information. This method enables to make an integrated classification of traffic flows; however, since there are non-standard network solutions applied in service-oriented applications, the obtained data will not be enough for the effective control of traffic flows. For a deeper analysis of traffic flows as a data source, we offer to use the method of decoding the protocols of communication based on the analysis of contents of the transferred packages. However, since this approach has rather high resource intensity, it will be used only at a low level of the analysis, for more exact identification of traffic flows of similar applications. The third method uses the sample approach based on the specific signatures located in protocol heading for the identification of the application. The fourth method is based on machine training. This method uses the accumulated data obtained by the above-mentioned methods and applies to them the algorithms of machine training to identify the applications based on characteristic packages and the

saved-up statistics of data flows. The advantage of this approach is that algorithms can be trained in real time that will allow reconfiguring software-defined infrastructure of the VDC on the fly.

The proposed solution is based on an integrated approach to the collection of data on the traffic flows circulating in a multi cloud platform. It will allow optimizing the placement of network functions on computing nodes of the VDC. To achieve the goals of the research, we have created a neural network system to predict the placement of network function virtualization in the multi cloud environment of the virtual data center.

#### 4. Model of the clustering of infrastructure facilities of the virtual data centers for the placement of network functions

We have chosen Kokhonen's network as a neural structure for modeling, since it is the most efficient in the clustering and classification of objects. Another important factor is the visualization of results; it enables to improve the understanding of the structure and character of data at early stages and to specify a neural network model further. Due to the peculiarities of network function virtualization, the support of classification in Kokhonen's network can be used to identify the uniform elements in network for further optimization of their placement. Kokhonen's network is trained by a method of consecutive approximations. Starting from the initial placement of objects selected randomly, the algorithm gradually improves it to supply the data clustering. Another advantage of Kokhonen's network is the opportunity to identify new clusters. The trained network detects clusters in the training data and refers all the data to certain clusters. If the network meets a set of data, which differ from any known samples, it will independently reveal a new cluster of elements then. This feature is very relevant, since it allows entering new network functions into the architecture of virtual data center without the actual change of algorithms of their distribution on physical and virtual computing nodes.

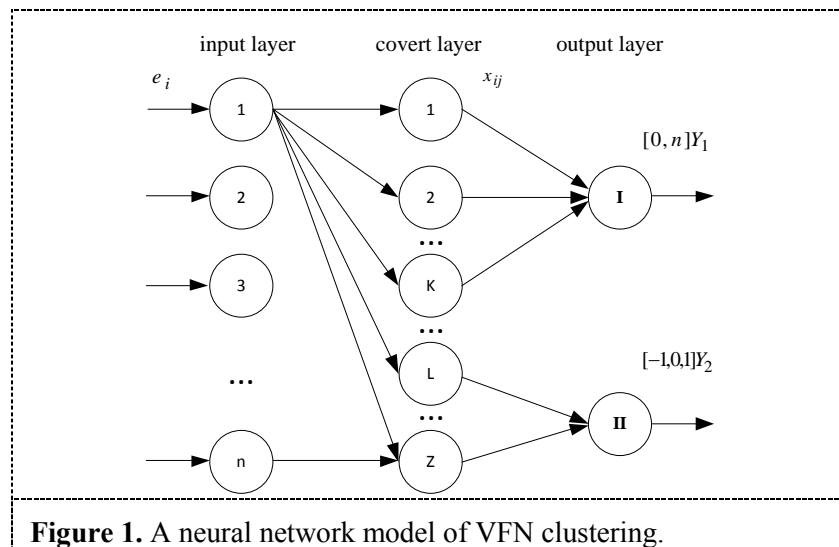
The principle of creating a neural network system to optimize the placement of network function virtualization in the multi cloud environment of the virtual data center is as follows. We have selected a number of criteria using the data obtained from the systems of virtual data center monitoring. This enables to both identify the virtual network function and assess its load on computing nodes. Criteria are formulated so that the answer could be always represented in the binary form. i.e. 1 is "Yes" or 0 is "No". The obtained data enable to form the vector of signals  $E = \{e_1, e_2, \dots, e_n\}$ , which is placed at the entrance of a neural network. The vector of output values is similar, it has binary components.

The neural network is a two-dimensional matrix of neurons of dimension  $n$  (the number of inputs of each neuron) per  $m$  (the number of neurons). The number of inputs of each neuron is determined with respect to the number of criteria established earlier. The amount of neurons  $m$  coincides with the required number of classes and corresponds to the number of the unique network functions used in work of a multi cloud platform. The importance of each of the entrances to neuron is characterized by the numerical size called by weight. It is set in the form of matrix:

$$X = \begin{pmatrix} x^{11} & x^{12} & \dots & x^{1j} \\ x^{21} & x^{22} & \dots & x^{2j} \\ \dots & \dots & \dots & \dots \\ x^{i1} & x^{i2} & \dots & x^{ij} \end{pmatrix} \quad (1)$$

With the vectors of weight coefficients of connections  $x^{ij} = \{x_1^{ij}, x_2^{ij}, \dots, x_n^{ij}\}$  as its elements.

Kokhonen's network consists of three layers of neurons. The basis of the network is a covert Kokhonen's layer. However, in this research, we have offered a changed scheme of output neurons of Kokhonen's network to obtain the results to identify destination and, simultaneously, to find critical loading on a calculating node (Fig. 1).



**Figure 1.** A neural network model of VFN clustering.

We offered to divide the covert layer of Kohonen's neural network into two sets. The first set of neurons  $[1...K]$  is responsible for the identification of a network function placed in the VDC. The work of neural network changes input scales at the exit layer activates the linear function  $Y_1$ , which takes the value  $[0...n]$ , where 0 means that the network object under study has no signs of the VFN, and values from 1 to  $n$  correspond to a particular network function identified by a neural network model. The second set of neurons  $[L...Z]$  analyzes the loading of the network object under study and initiates the function  $Y_2$  at the exit, which take the values  $[-1, 0, 1]$ , where 0 is a normal state, -1 means that the network function is idle or does not perform its functions, and 1 means that the network function is overloaded.

The basic criteria used as input data to detect virtual network functions are network records and events, data of the time of packages going through a network object, time of packet input and output, memory loading, the use of CPU, the intensity of dataflow, TTL and others. The data collected in the network are placed at the entrance of a neural network and create a full neural network. That being the case, we should simplify and verbalize a neural network by excluding some elements without the significant reduction of the detection quality.

To train a neural network, we have used the data obtained from the system of monitoring of virtual data center of the Orenburg State University. We have chosen the most popular virtual network functions for the experimental study such as vRouter, vNAT, vFirewall, vProxy, vSwitch, vDPI.

The application of the developed neural network system enables to identify virtual network functions correctly in 93-98% of cases, while the resource intensity is insignificant. This increases the efficiency of optimization for placing them in the infrastructure of a multi cloud platform.

## 5. The algorithm for optimizing the placement of virtual network functions in the data center infrastructure

Our model of identification of virtual network functions allows optimizing their placement in the virtual data center. We will optimize the placement of the network functions found in the virtual data center by using Kohonen's network by the following criteria: the current load created on computing nodes; resource intensity of a network function; the number of flows going through computing nodes. The main objective of virtual network functions placement is to choose the optimum number of the nodes to implement required functionality as a software solution. Thus, there is a problem of resource planning. Planning is of particular relevance in the organization of dynamic topology in the virtual data center, since the load on computing nodes can change over a wide range at rather short intervals of time and depends on the chosen type of specific network functions placement. To solve the task of optimization, we have developed the algorithm for monitoring the infrastructure of the virtual data center as well as for the placement and launch of network functions. In comparison with the available



analogs, the algorithm uses the heuristic analysis of traffic flows and their classification depending on the type of a network function.

The general algorithm has the following sequence of steps.

Step 1. To identify the arrangement of virtual network functions taking into account the topology of the network infrastructure of the virtual data center.

Step 2. To estimate the number of the launched copies of each virtual network function and to range them according to the popularity of the network infrastructure. The popularity is estimated towards traffic flows, which run through the launched copies of a virtual network function.

Step 3. To define the load on physical and virtual computing nodes created by each copy of function.

Step 4. To compare data and to define virtual network functions, which demand scaling or folding, using the data obtained in steps 1 and 2.

Step 5. To reconfigure the topology on the controller of the software-defined network, stop and release the occupied resources of virtual data centers for network functions, which require folding.

Step 6. To evaluate a method of placement for virtual network functions, which require scaling and creation of the maximum load on infrastructure. To distribute the most loaded network function using a hybrid way of placement (the containers developed in the virtual machine). To transfer network functions, which are less loaded but require scaling, to the operating mode of the virtual machine.

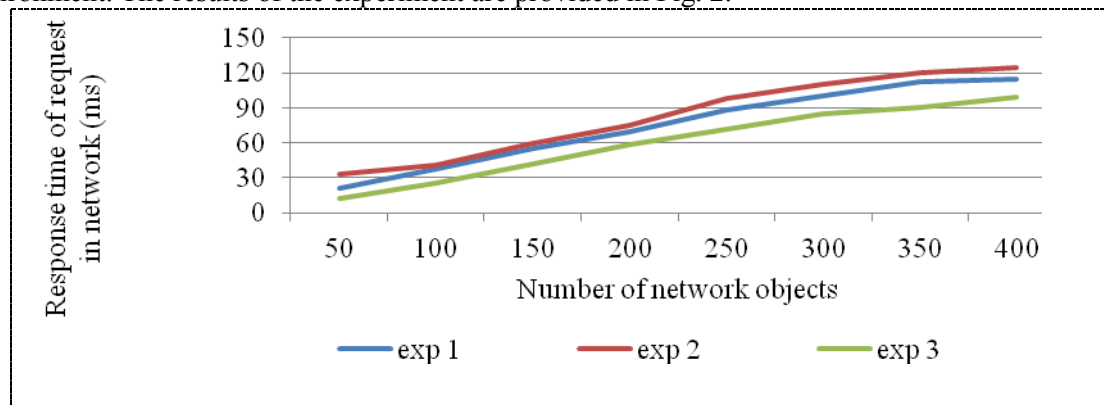
Step 7. To provide the migration of the virtual machines with network functions on the least loaded computing nodes.

The approach in this algorithm for controlling the placement of virtual network functions enables to take into account a method of placement and to organize the work of the virtual data center with account for circulating traffic flows and regulate the number of the launched copies of each function.

The purpose of experimental investigation is to define the efficiency of using the developed algorithm for placing the virtual network functions in infrastructure of the virtual data center.

We have created the templates of container placement and the images of virtual machine for the deployment in the software-defined infrastructure of data centers for each virtual network functions.

We have created the flows based on statistical information using the generator of requests to imitate the work of network environment in the data centers. To estimate the productivity of virtual network functions, we have used the flows with varying intensity: in the first case, the flows created minimum permissible load. This enabled to estimate the time of a response and delays brought by the infrastructure of the virtual data center (exp. 1). In the second case, we have created the working load on the virtual network functions in the infrastructure of the virtual data centers. This enabled to estimate the time of response for applications in network environment (exp. 2). In the third case, an experimental study evaluated the operation of a virtual network environment of a multi cloud platform, using the developed algorithm for optimizing the location of virtual network functions (exp. 3). In this case, we have established the consumption of resources for each of the launched copies of virtual network function. This enabled us to predict the required resources in network environment. The results of the experiment are provided in Fig. 2.



**Figure 2.** Diagram of dependence of response time in the multi cloud platform

The research has shown that the static placement of containers on physical nodes is inefficient, since it does not enable to redistribute loading quickly. Besides, the transfer of a container to another computing node leads to the loss of the current connections. The placement of virtual network functions on the basis of virtual machines was more efficient due to flexible load balancing. However, the load on computing nodes has considerably increased due to additional overheads for the use of virtual machines. In our research, the most efficient placement was the placement with the use of containers in virtual machines. It has enabled to increase the density of the placement of applications and services in virtual data centers. Besides, it has enabled to place the containers and applications of services and data in direct network proximity from each other and to reduce the time of response to user requests from applications and, thus, to increase the overall performance of a system.

## 6. Conclusion

Our research enabled to create a neural network model of virtual network function identification. The proposed model of classification based on the statistical properties of the flow defined a systematic approach to the selection of the optimal set of attributes of the traffic flow. The developed algorithmic solutions, which are based on hybrid methods of virtualization and use the data of a neural network model, enabled to optimize the placement of network functions in software-defined segments of the data center network. The results show that the optimization of the number of NVF enables to improve the quality of service by 20-25% by reducing the response time and load on physical network devices. It became possible due to the identification of applications at the initial stage by using the data of the NVF placement in the network of the virtual data center. Further, we are going to assess our approach with a larger number of NVF, since it will allow us to assess the accuracy of our solution.

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