

Development of models and algorithms for adaptive traffic routing with support for quality of service in a virtual data center network

Irina Bolodurina¹[0000-0003-0096-2587], Klaus Hänßgen²[0000-0002-1363-004X] and Denis Parfenov¹[0000-0001-2345-1143]

¹Orenburg State University, Orenburg, Russia

²Leipzig University of Applied Sciences, Leipzig, Germany

prmat@mail.osu.ru¹, klaus.haenszgen@htwk-leipzig.de²

Abstract—Nowadays virtual data center network is developing steadily and new approaches for work organization are still appearing. One of the problems of virtual data center network is the control of the traffic in cloud applications and services in the network environment of virtual data center. The advantage of modern infrastructure's virtualization is the possibility to use the software-defined networks and software-defined data storages. But the existing solutions algorithmic optimization does not take into account the peculiarities of routing the heterogeneous flows network traffic. The optimization task of traffic distribution in cloud applications and services is solved by using software-defined infrastructure and virtual data centers. We suggested the simulation model for the traffic in software-defined segments of data center networks, involved in user application and service requests within a network environment including heterogeneous cloud platform and software-defined data storages. Our model allows to implement the traffic management algorithm of cloud applications and to optimize the access to storage systems through the effective use of data transmission channels. In the course of experimental studies we found that the use of our algorithm leads to a decrease in response time of cloud applications and services, and, so increasing the productivity of user request processing and reducing the number of refusals.

Keywords—software-defined network, virtual data center, cloud computing, quality of service, adaptive traffic routing

1 Introduction

Over the past few years there has been a rapid growth in traffic in infocommunication networks. The main share of traffic is made up of services and applications connected with Big Data. The development of this trend can be explained by the need for companies to store and process of Big Data. But, work with Big Data means more than analyzing huge amounts of information. To date, Big Data technology also includes processing data that is regularly updated and comes from different sources [1]. At the same time, as noted in the IDC, the amount of

information will increase at a high pace: by 2020, the number of generated data will exceed 44 zettabytes. Despite the increasing share of Big Data traffic in converged networks, other types of traffic for which the bandwidth of the channel is not of paramount importance. For example, for business-critical applications and services that perform real-time data transfer, such as voice and video, round trip time, jitter, packet loss, and availability are more critical factors. In turn, for applications that handle files, the more critical factor is packet loss. Taking into account these features of modern multiservice networks, the problem of providing quality of service for data transmission becomes especially urgent.

The most critical situation is in the telecommunications networks of data centers. Modern data centers use different approaches to optimize both computing and network resources [3]. This fact simultaneously significantly complicates the architecture, imposes a number of limitations and makes demands on the functionality of the equipment used. The modern data centers using software-defined networks. The use of this technology allowed first of all organizing flexible routing of traffic inside the data center.

But software-defined networks cannot solve the problem entirely. Typically, on the basis of a traditional data center, several cloud platforms are deployed, which use different virtualization environments with different levels of abstraction. In this connection, the data streams within the data center pass through various virtual interfaces having their own delay, which does not allow the coordination of data flows. Therefore, for efficient routing of traffic within a virtual data center, it is necessary to develop a unified route planning strategy that does not depend on the virtualization environment and at the same time can provide a guaranteed quality of service.

Achieving this goal, as a rule, is based on the coordinated and complementary application of a variety of technological tools at virtually all levels of the reference model of open systems interaction (OSI). An important place among such tools is given to the OSI network layer tools, namely routing protocols, on the efficiency of which the numerical values of key end-to-end QoS indicators.

In this connection, the main requirements for forward-looking solutions in the field of routing are as follows:

- support for multipath routing [2] to ensure balanced network utilization and improve overall service quality;
- transition to flow based (flow based) models and routing methods, because modern network traffic has a predominantly flowing nature;
- use of composite metrics that maximally take into account the ratio of requirements relative to the numerical values of different QoS indicators;
- maximum consideration of packet processing features on network routers, including the specifics of the organization and processing of queues;

- ensuring high scalability of routing solutions, i.e., the ability to keep within its assigned limits its efficiency in the conditions of increasing the territorial distribution of the network, the number and types of user traffic being serviced.

Obviously, to improve the quality of service in a multiservice network, it is necessary to reduce the number of lost packets to the lowest possible level [4].

Currently, there are no routing methods adapted to the traffic characteristics of the multi-service data center network [4]. One way to solve this problem is to simulate routing methods under the self-similar load characteristic of a multiservice network. In work [5] it is shown that the use of the dynamic routing method is more effective than the static one due to faster network reconfiguration when changing the number of available channels. For automatic generation and modification of routing tables, internal routing protocols based on Distance Vector Algorithms (DVA) and Link State Algorithms (LSAs) are most often used [6].

2 Related work

In the proposed approach application quality of service (QoS) requirements, and monetary cost are jointly integrated into a cross-layer framework. This framework is used to effectively choose the optimal system parameters to adapt to the varying channel conditions to provide a communication-efficient, energy-aware system. The proposed cross-layer optimization problem is formulated as an optimization problem, where the design objective is to minimize the transmission energy consumption and the transmission monetary cost, while maximizing the QoS. This optimization problem is solved under the constraint that all successfully received packets must have a delay smaller than their corresponding delay deadline while maintaining the total distortion at a specific threshold dictated by the application. Simulation results show that the optimal decision based on weighted objective minimization can achieve the tradeoff between transmission energy and distortion, while maintaining application's end-to-end QoS requiremen

Monitoring of Quality of Service (QoS) in high-speed Internet infrastructures is a challenging task. However, precise assessments must take into account the fact that the requirements for the given quality level are service-dependent. The backbone QoS monitoring and analysis requires processing of large amounts of data and knowledge of which kinds of applications the traffic is generated by. To overcome the drawbacks of existing methods for traffic classification, we proposed and evaluated a centralized solution based on the C5.0 Machine Learning Algorithm (MLA) and decision rules. The first task was to collect and to provide to C5.0 high-quality training data divided into groups, which correspond to different types of applications. It was found that the currently existing means of collecting data (classification by ports, Deep Packet Inspection, statistical classification, public data sources) are not sufficient and they do not comply with the required standards. We developed a new system to collect training data, in which the major role is performed by volunteers. Client applications installed on volunteers' computers collect the detailed data about each flow passing

through the network interface, together with the application name taken from the description of system sockets. This paper proposes a new method for measuring the level of Quality of Service in broadband networks. It is based on our Volunteer-Based System to collect the training data, Machine Learning Algorithms to generate the classification rules and the application-specific rules for assessing the QoS level. We combine both passive and active monitoring technologies. The paper evaluates different possibilities of implementation, presents the current implementation of particular parts of the system, their initial runs and the obtained results, highlighting parts relevant from the QoS point of view.

Network traffic classification occupied a significant role in network management and network security areas because it introduces different services such as identifying the applications which are most consuming for network resources, it represents the core part of automated Intrusion Detection Systems (IDS), it helps to detect the malicious applications such as those produced by worms or Denial of services (DoS) attack. In addition, it helps to know the wide using applications for offering new products [1, 2]. Generally, Network traffic classification is a process of categorizing network traffic according to various parameters (such as port number, arrival time, type of protocol, packet length and etc) into a number of traffic classes. In the other hand, several challenges faced network engineers to classify network traffic, the most common challenge are increasing application types and the huge size of data traffics [3]. Due to the above mentioned challenges, several studies have been conducted to classify network traffic, such as using well-known port numbers which are obtained by IANA [4]. Payload-based classification is another approach used to classify traffic packets based on the field of payload [5, 6]. Signature-based approach is suggested to overcome the high cost in terms of time and complexity for payload-based through looking for a specific pattern (bytes) called signature [7]. Behaviour-based studies the different discriminate features to distinguish application. Different machine learning methods are introduced to automate network traffic classification such as nearest neighbors (NN) presented by Roughan et al.

3 Mathematical model

This section presents a mathematical model of a computer network of a virtual data center in which a dynamic routing algorithm and traffic flows are applied to the basic QoS metrics.

As part of this study, an approach is proposed that combines the routing of data streams and providing for them two QoS parameters—the minimum guaranteed throughput and the maximum guaranteed delay.

To describe the proposed approach to adaptive traffic routing in compliance with QoS guaranteed QoS, it is necessary to describe the virtual data center network. Within the framework of the task being solved the network can be represented as undirected weighted connected graph $G=(V,A,W)$, Here V – a set of graph vertices (communication nodes or routers), $|V| = N$, E – a set of graph edges representing

communication links, $|E| = M$, W – a set of edge weights (communication links metrics).

The set of control points of the virtual data center network in our approach is a set of virtual network functions. Virtual network functions are placed using virtualization based on Docker containers. Containers are hosted by traditional servers that act as compute nodes in the data center. Several virtual functions can be deployed at one compute node. Switching is done through a virtual interface.

To organize virtual connections, we take the following restriction imposed on the functional of virtual functions. As part of this study, virtual functions will be understood as virtual routers and virtual switches. Thus, the virtual function can be represented in the form of the following tuple $VNF = \{Type, Param\}$ - where Type - characterizes the type of the virtual function in a binary form Type = 0 - vRouter, Type = 1 vSwitch. In turn, Param parameter set characterizes the resource consumption of the virtual function and represents the tuple $Param = \{Ram, Hdd, Lan\}$.

Each channel $a_i \in A$ connecting the compute nodes in the virtual data center network is characterized by the following metrics $K = \{k_1, \dots, k_n\}$ which formalized form of the tuple.

To organize effective adaptive traffic routing, it is also necessary to describe the flows that circulate in the virtual data center network. To do this, we define traffic flows as a set of user requests $T_u = \{T_u^j\}$, where each T_u^j describes the j-th The request within which a traffic flow is generated. Each user request can be described by the following tuple of characteristics $T_{user} = \{T_{in}, T_{do}, \Lambda\} \in R^+$. Here $T_{in} = \{t_{in}^j\}$ set of moments times which characterize time of receipt the request in the VDC; $T_{do} = \{t_{do}^j\}$ set of moments times which characterize times of execute the request in the VDC; Λ - not time characteristics of the user request, which describe the QoS requirements for the flow.

Since the choice of the optimal path to the graph can be performed on the basis of the solution of the well-known shortest path problem [4, 5], which allows us to find the shortest path between two points on the graph on the basis of minimizing the sum of the edges weights making up the path, The work of shortest path algorithms is justified. It should be noted that the algorithms that solve the problem of finding the shortest path and carrying out a search in state space search are based on a group of mathematical methods that allow viewing possible configurations of the search area or states of system components for the purpose of searching optimal state. Each user request in the framework of this study is presented as a set of $u: E(G) \rightarrow R^+$ - capacity of arc in the network of VDC. Then flow of requests in the network of VDC is represent as $f: E(G) \rightarrow R^+$ -

All the multitude of flows can be divided according to the requirements for the service channels. To form the optimal route in a virtual data center network, it is

necessary to dynamically estimate the state of the channels in real time. In addition to providing QoS following restrictions must be satisfied.

The first restrictions is equation of traffic balance in the network of VDC:

$$ex_f(u, v) := \sum_{e \in \delta^-(U, V)} f(e) - \sum_{e \in \delta^+(U, V)} f(e), \forall e = (u, v) \in E(G) \quad (1)$$

where the condition of uninterrupted network operation $ex_f(u, v) \leq u(e)$ and $f(e) \leq u(e), \forall e \in E(G)$.

Then let's describe the distribution function of time request. In our model represent it as time-of-arrival function $\Psi : T_{in} \rightarrow R^+$. Also for time executions query we need set restrictions:

$$t_{do}^j = \Psi(t_{in}^j) \in T_{do} \subset \max \text{ where conditions for the satisfaction of request in VDC;}$$

$$T_{do} \subseteq T_{in} \text{ VDC can execute only part of the request;}$$

For execute the request we need determinate the main objects which using in VDC: $\{ex_k^j\} \in Ex$, set of executors (k executor of j request). The each executor can be divided by type:

$$Ex = \{VNFApp, NetServ, NetObj\}.$$

Then the execution time represent as next function which detailed description of time execution of user request:

$$T_{user}^j = \sum_{i=1}^n (t_{VNFApp}^{j,i} + t_{NetObj}^{j,i} + t_{NetServ}^{j,i}) \quad (2)$$

here $t_{VNFApp}^{j,i} = \Omega_{VA}^i(t_{in}^j)$ n – number of executor in each type; $t_{NetObj}^{j,i} = \Omega_{NO}^i(t_{in}^j)$ time execution of j request on i executor of type VNFApp; $t_{NetServ}^{j,i} = \Omega_{NS}^i(t_{in}^j)$ time execution of j request on i executor of type NetObj time execution of j request on i executor of type NetServ $\forall t_{in}^j \in T_{in}, \forall t_{do}^j = \Psi(t_{in}^j) \leq t_{do}^{j(max)}$.

4 Simulation model traffic in the virtual data center

As a rule, in the software-defined infrastructure of a virtual data center there are several heterogeneous applications and services. We can assume that in the network of a virtual data center here are at least three types of application traffic: web-applications, case-applications available on DaaS or SaaS models, and video services. To generate user requests in the simulation model we apply weight coefficients $k_1, k_2,$

k_3 for each traffic type. Each coefficient allows classifying requests into types and affects the following set of parameters: running time, routes, priority in the process queue, request intensity, and the distribution law for each type of traffic.

Presented as a multi-channel queuing system the simulation model of software-defined infrastructure of virtual data center includes a user request source (I), a queue (Qs) and a scheduler (S) who manages application hosting and launch (App), and computing cluster (Srv) and data storage system (Stg).

Queuing system model is stochastic. For its operation it is necessary to make a user request flow to cloud applications and services, following to the distribution laws and request intensities for each type of cloud applications and services.

To optimize application distribution in the cloud environment of virtual data center it is necessary to determine the traffic distribution laws for each application type and distribute the traffic into access objects (virtual servers, containers, and storage systems). For this purpose it is necessary to set a certain route and make the control law for it within the time interval $T=[t_1, t_2]$.

The dynamic of traffic in cloud applications and services of the software-defined infrastructure of virtual data center can be described by the following discrete system:

$$x_{i,j}(t + \Delta t) = x_{i,j}(t) - \sum_{k=1}^K \sum_{l=1}^N s_{i,j}(t) u_{i,l}^{j,k}(t) + \sum_{m=1}^N s_{m,i}(t) u_{m,l}^j(t) + y_{i,j}(t) \quad (3)$$

where N is the number of virtual nodes within the network; K – the number of application types within the network; $s_{i,j}(t)$ is the capacity of the channels between i -th computing node and j -th storage system ($i \neq j$); $y_{i,j}(t) = \lambda_{i,j}(t) \Delta t$ is the traffic volume (the number of user requests) at the moment t on the virtual node i and intended for transferring to the storage system j ; $\lambda_{i,j}(t)$ is the intensity of incoming load, which is defined as the total intensity of the user request flow connected to the virtual node i and used the storage system j ; $u_{i,l}^{j,k}(t)$ is the part of the channel transmission capacity in a certain segment of the software defined network (i, l) at the moment t for the user request flow to the application of type k , working with the data storage system j .

To exclude the possibility of overloading the objects of the virtual data center due to the limited queue buffers on compute nodes, as well as to use data transmission channel capacity efficiently a number of restrictions are introduced for network parameters for cloud applications in software-defined networks (SDN).

The restrictions are related to channel capacity limits can be written in the following form:

$$0 \leq u_{i,l}^j(t) \leq u_{i,l}^{j(\max)} \leq 1; \sum_{l=1}^N u_{i,l}^j(t) \leq \varepsilon_{i,l}^{j,k} \leq 1 \quad (4)$$

where $u_{i,l}^{j(\max)}$ is the limit of channel capacity available for the computing node i in SDN segment l for traffic transfer to storage j ; $\varepsilon_{i,l}^{j,k}$ is the part of the channel capacity for the compute node i in SDN segment l for the transmission of user requests to the application of the type k to storage system j .

The use of SDN within virtual data center allows managing the queues which introduces extra restrictions:

$$0 \leq x_{i,j}(t) \leq x_{i,j}^{(\max)}; \sum_{l=1}^N x_{i,j}(t) \leq x_i^{(\max)} \quad (5)$$

where $x_{i,j}^{(\max)}$ is a maximum allowed queue length on i -th compute node for processing of incoming traffic to storage system j ; $x_i^{(\max)}$ is a maximum allowed volume of the buffer on compute node i .

Let us consider the system performance as a criterion of optimality, gained through a fixed period $T=[t_1, t_2]$, which is formalized within the model as an objective function in the following form:

$$\sum_{t=0}^{t-1} \sum_{k=1}^K \sum_{l=1}^N \sum_{j=1}^N s_{i,j}(t) u_{i,l}^{j,k}(t) \rightarrow \max \quad (6)$$

For solving the optimization task we use an iterative method that allows us to explore the dynamics of the system at the interval $T=[t_1, t_2]$ and to control channel capacity for a certain type of applications in a software-defined network.

5 Algorithm of adaptive QoS routing

To assess the effectiveness of the developed algorithm for optimizing the adaptive routing of data flow balancing in the applications and services in the virtual data center, we have conducted a pilot study. We have chosen the Openstack cloud as the basic platform. For comparison, we have applied the algorithms used in the

On the basis of the constructed models, we have developed an optimization algorithm of adaptive routing and balancing of the application and services flows in a heterogeneous cloud platform, which is located in the data processing center. The algorithm aims to ensure the effective management of the application and services flows under dynamic changes in the load on the communication channels used to deploy data center software-defined networks by reducing the complexity of designing of optimal routes schemes.

Generalized algorithm is as follows:

Step 1. To split the SDN multiple channels in a subset of channels which are included in the tree of routes passing through the ST set segments, a subset of alternative channels passing through the SR set segments.

Step 2. To generate optimal routes in the SDN for the data stream of a particular class of applications in a hybrid cloud platform, on the basis of the weights of communication channels for each of the subsets.

Step 3. For each of the SDN channel determine the point of entry into the tree of optimal routes and in a variety of alternative channels.

Step 4. For each network object which is a leaf of the tree, search all the alternative routes with minimum cost, taking into account the channel weights in the previously constructed tree of optimal routes of SDN. To bind these lists to a network object, incident reporting channel and located below in the hierarchy.

Step 5. If a network object is not a leaf of the tree, then calculate alternative routes in the SDN for this object, taking into account the weight of the channel in the previously constructed tree of the optimum routes and select the best value of the alternative route. This procedure is performed to generate a list of alternative routes in the case of a dynamic load change of the communication channel.

Step 6. For each communication hub form the full list of alternative paths in SDN of data center.

Step 7. Analyzing the received protocol information, define if the load changes for some connection has happened or not. If so, move to Step 8, otherwise – to Step 7.

Step 8. Using the list of alternative routes, define if you need to change the route for the current data flow. If so, move to Step 9, otherwise – to Step 13.

Step 9. For a network object with a decreased potential and which alternative routes list include changed metrics connection, define the minimum length route and put the connection, which led to the network object potential decrease into the optimal route tree and the changed path from the optimal paths tree – into the set of alternative SDN routes. When required you should review calculation of channel's function weight.

Step 10. After the transfer to the alternative SDN route, you should define if the potential of other data center network objects, which placed higher in the hierarchy, has decreased. If so, move to Step 11, otherwise – to Step 12.

Step 11. You should define the new minimum length route for every network object which potential has been decreased. If the new minimal length route for every object of the network includes a route from the alternative route list, you need to put this it (route) into the SDN optimal routes tree and the route from the optimal routes tree into the set of alternative routes.

Step 12. Design the new optimal route tree in SDN of data center.

Step 13. Transfer the current application data flows and services at affordable data center routes, reconsider the tree entry points, and in a variety of alternative routes, reshape the list of alternative routes for each network entity changed. Go to step 7.

Application of the proposed optimization algorithm adaptive routing balancing data streams allowed to reduce the complexity of calculating the optimum route to the value $O(kN)$, wherein k - the number of completed transitions to alternative routes, N - number of objects in the SDN of data center. Thus, the algorithm is designed to speed up the search and selection of optimal routes for application and service data streams arranged in a heterogeneous cloud platform, under dynamic load changes on the communication channels.

6 Conclusion

The developed methods and algorithms allow to increase the level of research in the field of quality of service in multi-cloud platforms in the virtual data centers. The application of the proposed approaches based on the joint use of virtualization network functions and software-defined networks allows for more efficient planning of data flows and providing the required quality of service and a given level of security in the data center network.

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