# Network Traffic Characterization in the Control Network of OpenStack based on Virtual Machines State Changes

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Abstract: The adoption of private clouds is an option for optimizing the use and organization of computing resources. Although the cloud benefits are been known for some time, there are still questions on how to plan the cloud infrastructure in order to avoid basic network performance issues. OpenStack is one of the most widely used open source solutions for building private Infrastructure as a Service (IaaS) clouds. OpenStack distributes network traffic across multiple interfaces and virtualized networks, which connect hosts to its cloud services, divided into the domains: control, public, or guest. The present work aims to characterize network traffic in the OpenStack control domain produced by changing the state of virtual machines (VMs). There are few works related to the network infrastructure scenario on private clouds, research in this area is generally focused on public domain or guest domain operations. In this sense, we performed a characterization in the OpenStack administrative network. In order to perform OpenStack network characterization, experimentation methods were used to identify operating services as well as to measure network traffic in the OpenStack control domain during a set of common operations in VMs.

## 1 INTRODUCTION

Private cloud computing operates on its own infrastructure, maintained by the organization which owns it. Thus, all cloud maintenance as well as the security / performance aspects are responsibility of this organization. In addition, private clouds aims to meet the necessities of the owner organization, and are accessible only by authorized users, ensuring the organization control over its resources (Jadeja and Modi, 2012). In this context, network traffic analysis / characterization is relevant to discover information regarding to cloud security and performance.

OpenStack in an open source software which allows to create and manage private or public IaaS clouds. IaaS private clouds using OpenStack typically have VMs as their base unit, but it also available container and bare metal capabilities. Inside the cloud provider's infrastructure, multiple network interfaces and virtualized networks are employed to ensure network traffic isolation. However, this isolation is also necessary to avoid some cloud administrative operation affect the network performance from the users of these cloud services and/or other cloud provider administrative operations. For example, the process of creating a new instance of a VM typically involves copying the VM image from one computer to another and this could mean a network traffic volume of over 10Gb. OpenStack provides methods for cloud administrators to manage the cloud performance (OpenStack, 2019c).

There are few studies related to the analysis of the cloud providers administrative network traffic. Mainly, the works in this area focused on the user perspective (Chaudhary et al., 2018, Alenezi et al., 2019), relinquishing the internal operations, and behavior of the cloud provider. Thus, this paper aims to study the provider's infrastructure, specially its networking layer related to how the most common user operations over an VM instance (*e.g.*, create, stop, etc.) impacts on the administrative network of the provider using OpenStack. An accurate traffic analysis and characterization enables an efficient management of the network resources (*e.g.*, accurate bandwidth allocation).

This article is organized as follows. Section 2 presents a cloud computing overview and introduces OpenStack aspects. Section 3 explains the problem motivation, and related work. Section 4 discusses the characterization approach adopted and scenario. Sec-

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tion 5 shows our experiments and results. Finally, Section 6 presents our analysis and characterization.

## 2 CLOUD COMPUTING & OpenStack

Cloud computing allows an optimized and on demand way of offering and consuming computational resources such as processing, storage and networking. Cloud solutions comprise the orchestration and management of several well established technologies, *e.g.*, virtualization, Network File System (NFS), Software Defined Networking (SDN), *etc.* Moreover, virtualization is one of the most relevant techniques for the cloud computing paradigm. Virtualization provides the capability of better exploiting physical hardware, which is one of core concepts in cloud computing.

In this context, there are several open source cloud solution software, *e.g.*, OpenStack, CloudStack, and Open Nebula. In fact, OpenStack adoption has evolved in multiple industries (OpenStack, 2018a) making it a very popular cloud solution.

OpenStack is an operating system for clouds allowing to control a large pool of resources throughout a data center (OpenStack, 2019c). Currently, OpenStack has twenty releases and a new release is launched every six months. OpenStack is a modular solution providing a wide range of services, and several optional modules. Among the most fundamental OpenStack modules are:

- **Horizon:** provides a dashboard service used for cloud overview and management.
- **Nova:** Responsible for the distribution and management of instances, *e.g.*, initialization, scheduling, and deallocation of VMs;
- **Neutron:** provides network connectivity for OpenStack services and user instances;
- **Glance:** manages the storage and retrieval images of VMs and containers;
- **Swift:** responsible for the storage and retrieval of unstructured objects;
- **Cinder:** provides persistent block storage for running instances; and
- **Keystone:** provides authentication and authorization services.

OpenStack services can be distributed all the way through the data center hosts, but they still interact with each other in order to provide cloud services (*e.g.*, VM access and configuration, Figure 1). Thus, the services distribution must be planned in order to meet the consumer performance requirements.

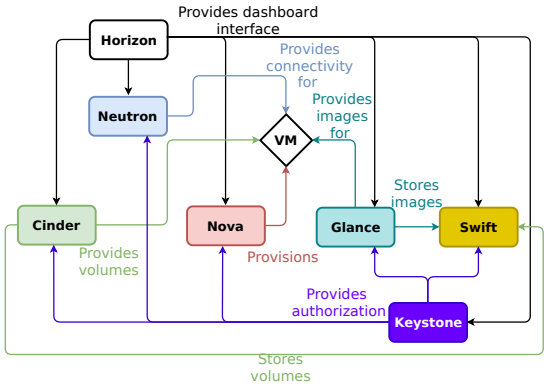



Figure 1: Services interaction related do VM operation.

Figure 2 shows the OpenStack network connectivity organization (OpenStack, 2019b). OpenStack deployment may be more or less complex due to the scenario and consumer requirements.

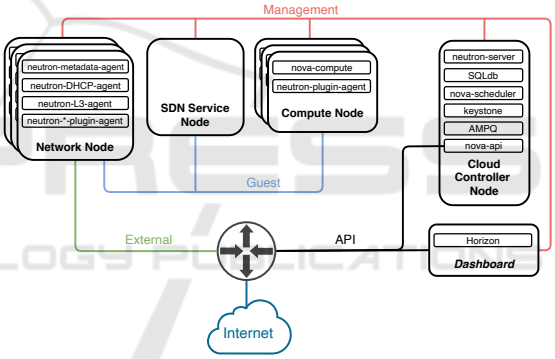



Figure 2: OpenStack networking setup (OpenStack, 2019a).

A short explanation about the networking setup presented on Figure 2 (OpenStack, 2019a):

- **Management Network:** most internal network, it should be reachable only within the data center. OpenStack components communicate over the Management network and it is considered the Management Security Domain. All communications and calls between services are performed through this network. VM images and miscellaneous requests are transmitted through this domain, as well as the access to data stored on volumes (*i.e.,* Cinder, Glance, and Swift) access and status checks.
- **Guest Network:** used for VM communication within the cloud deployment. This network is considered the Guest Security Domain. User network traffic is typically isolated using VLANs.
- **External Network:** the addresses on this network

may be reachable by the Internet. Depending on the deployment configurations, the External network is used to provide VMs with Internet access. This network is in of the Public Security Domain.

- **API Network:** this network is used in order to expose all OpenStack Application Programming Interfaces (APIs) to tenants, thus it's reachable by the internet as well. The API network may be the same network as the External network and it's considered the Public Security Domain.

OpenStack cloud solution is very flexible and allows several ways of deployment. It's important to keep in mind that inter-services communications occur no matter which topology is chosen. Thus, messaging between services is an essential process for correct operation of the cloud environment. The minimal setup requires two kinds of nodes, one of them is the Cloud Controller node and the other one is the Cloud Compute node (Figure 3).

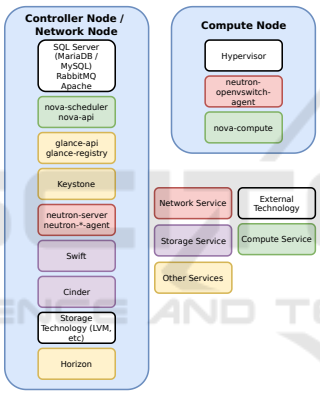



Figure 3: Minimal topology for OpenStack deployment.

OpenStack services can be distributed across various types of nodes (Figure 4) and these can be replicated to increase the horizontal scalability of the cloud. The Compute Node replication is the most common approach.

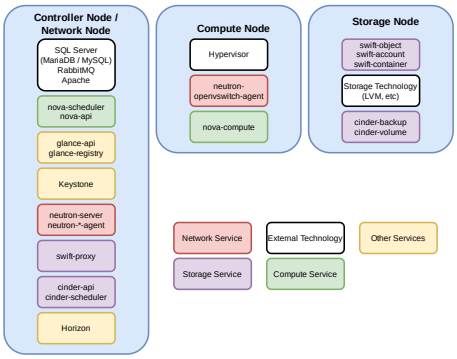



Figure 4: Basic topology for OpenStack deployment.

Figure 4 shows an example of a topology in which the block storage service (Cinder) and object storage were moved to a Storage Node. The planning complexity of the network topology increases when dealing with more than two types of nodes.

## 3 MOTIVATION & RELATED WORK

The cloud provider infrastructure is essential to guarantee a satisfactory operation, high performance, and scalability. Cloud provider infrastructure comprises several computer, switches, routers, and storage which can be organized / connected using several different approaches. Although the organization of the provider's infrastructure is not a popular research subject, there is no doubts there are many questions about which criteria should be used to guide a cloud infrastructure design. Moreover, most research in this area focus on analyzing the cloud infrastructure from the user perspective (Aishwarya. K and Sankar, 2015,Shete and Dongre, 2017,Chaudhary et al., 2018, Alenezi et al., 2019), relinquishing the internal operations and behavior of the cloud provider. Thus, there is a lack of information regarding how tasks submitted by the consumers (*e.g.*, VM launch) may impact the behavior of the management network.

OpenStack has several services which can be related to perform a consumer request over a VM instance (Figure 1). These services (listed in Figures 3 and 4) can be specifically developed for OpenStack (*e.g.*, Nova, Cinder, Horizon, *etc.*) or External Services (*e.g.*, Apache, Xen, KVM, MariaDB, RabbitMQ, *etc.*) used by OpenStack services to accomplish its tasks. Although it is simple for the consumer to request a VM instance to launch by simple command (API or Horizon, Figure 2), on the provider infrastructure this means the smooth execution of various tasks between OpenStack Services and External Services using several interfaces (network and software). However, if any service is allocated to a specific node (*e.g.*, Cinder - Figure 4) communication will continue to exist but will be between nodes.

Cloud performance depend on analyzing its behavior while the cloud is being used (Bruneo, 2014). There is the need for identifying relevant cloud operations. Several cloud operations comprises some tasks in the networking layer, and demand analysis of what is being transmitted through the network and its finality. Thus, the problem here being discussed lays upon the lack of information about operations occurring within the cloud providers networking layer (specially the internal network traffic). Network traffic

Table 1: Related work comparison.

| Criteria | (Sankari et al., 2015) | (Flittner and Bauer, 2017) | (Gustamas and Shidik, 2017) | (Venzano and Michiardi, 2013) | (Sciammarella et al., 2016) |
|---|---|---|---|---|---|
| CR1-Collect traffic on the OpenStack cloud management network | Partially. The document focus on analyzing the SDN traffic of data centers | No | Yes | No | Yes |
| CR2-Classify the network traffic regarding the state changes in the virtual machine | No | No | No | No | Partially. Only VM creation and termination |
| CR3-Analyze the collected traffic in order to identify which service the packets are related | No | No | No | No | No |
| CR4-Store the characterized traffic into a database | Not informed by the author | Not informed by the authors | No | Not informed by the authors | Not informed by the authors |
| CR5-Identify the timing in which packet was collected (timestamp) | Yes | Not informed by the authors | No | Not informed by the authors | Yes |

characterization helps on this understanding by using techniques and methods which enable a systematized network traffic measurement and identification.

In this sense, this paper proposes an analysis and characterization of the network traffic in the provider infrastructure, specifically in the management network, related to VM operations triggered by the consumers (*i.e.*, end users) on an OpenStack cloud.

Regarding the related work, we defined five criteria which are used to compare our analysis and characterization to other works (Table 1). The work of (Sciammarella et al., 2016) is the most related one to our proposal. However, the authors (Sciammarella et al., 2016) focus only on the network traffic amount generated by creating and destroying multiple VM instances in geo-distributed collaborative clouds. The authors do not separate traffic between services, nor do they try to identify the time to perform operations and the amount of calls for each OpenStack service.

# 4 CHARACTERIZATION & PROPOSAL

Traffic classification and characterization is not a new research topic. In this context, traffic characterization has been a task of considerable importance in the area of network management and security. Thus, through the use of traffic classification / characterization techniques, benefits such as increased accuracy for network resource allocation can be achieved. Therefore, traffic characterization is also a task used to understand and solve performance issues in computer networks (Dainotti et al., 2006).

In general, the study of network traffic is separated into two steps (Dainotti et al., 2006): (i) measurement: the collection of data traveling on the network; and (ii) traffic analysis is performed to identify/classify characteristics relevant to the problem. The traffic measurement can employ several tools to capture the data traveling across the network (*e.g.*, TCPdump, and Wireshark). Depending on how measurement is realized, it can be classified as (Williamson, 2001): Active (network traffic creation by the monitoring system, inducing specific situations) and Passive (capture only existing network traffic). The most significant techniques used in Internet traffic classification are (Dainotti et al., 2012, Finsterbusch et al., 2014):

- Port-based. Most common method for traffic classification. Consists on parsing the communication ports of the TCP / UDP header in order to create an association with the applications/services.
- Statistical. Uses of packet load independent parameters such as size, time between arrivals and packet flow duration. This method has broader application than other methods which require access to the payload of the packet, since in certain scenarios access to the payload is restricted.
- Pattern matching. Based on Deep Packet Inspection (DPI), which is recurrent in both traffic classification and implementation of NIDS. In this sense, it is possible to compare the contents of packages with a pre-assembled rule set.
- Protocol Decoding. Based on session state reconstruction and application information obtained from package contents. Protocol identification is based on protocol header characteristics and packet sequences.

In the context of OpenStack management network it's possible to deploy a port-based approach, since the OpenStack environment allows it. It comprises all administrative traffic and may separate traffic from some services into VLANs or network interfaces. By default, on minimal installation, all this traffic is on a single VLAN or NIC. Since management network is a core network in OpenStack infrastructure, we're working on a very specific scenario in which the services must be related to OpenStack operation, so there are no worries about protocols using cryptography and services have well defined ports.

We adopted an Active measurement of the consumer operations on a VM instance. Since we found no information to serve as a baseline for operations on VM instances, we chose the Active approach and defined the sequence of operations. This sequence of operations performed by a consumer in the state of the

VM is called: induced VM lifecycle. OpenStack has a total of 12 possible states in which a VM instance can assume (OpenStack, 2018b). However, by analyzing the operations of our user on our private OpenStack cloud, we find out the vast majority of our users typically have their VMs in only 6 states (Figure 5).

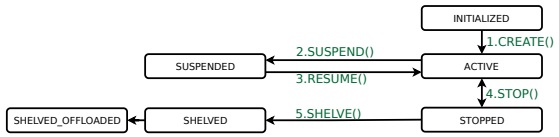



Figure 5: Induced VM lifecycle.

For each state change we collect traffic to identify the amount of data transmitted, the elapsed operation time, and the number of API calls. This data is collected by OpenStack Services, and the External Services. This data is used to perform our traffic characterization.

## 5 TESTBED, EXPERIMENTS & RESULTS

We used CloudLab (http://cloudlab.us) testbed for deploying OpenStack release Queens. CloudLab allows servers to be allocated to one of their top three clusters, Utah, Clemsom, or Wisconsin. On average, each server has 256GB of memory and two 2.4Ghz processors each, totaling 16 cores. We use the flavor m1.small - 1vCPU, 2 GB RAM and 20GB disk storage. It is also possible to choose network between 1Gb/s and 10Gb/s, we use 1Gb/s.

The two nodes topology (Figure 6) was adopted since it was enough to configure the networks as well identify the communication between nodes. We collected a traffic measurement from controller server by collecting traffic from management network interface (VLAN1, Figure 6) and loopback interface, since there are services running in the Controller Node.

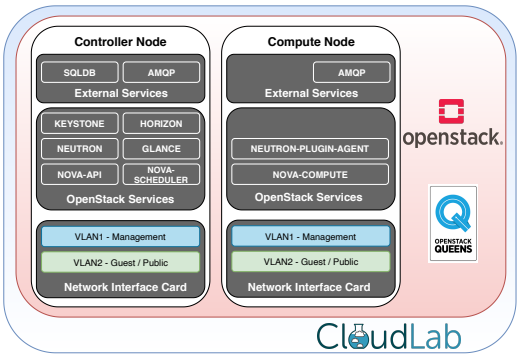


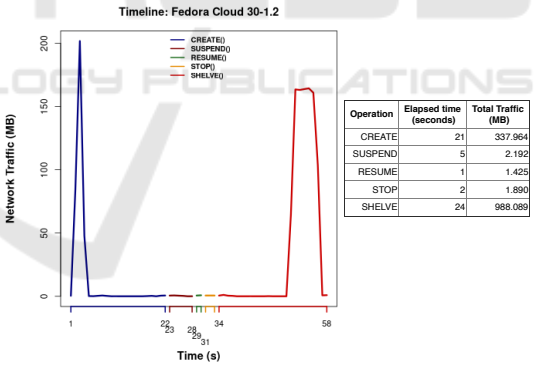

Figure 6: CloudLab testbed setup.

We developed a tool for the automation of experiments. Packet capture was implemented with a tool developed in Python which uses of OpenStack APIs (especially the *novaclient*). This tool is used to capture packets using TCPdump, perform state change operations on VM instance, and measure the elapsed time for each operation. In order to avoid use of cached information, after a experiment the entire cloud is terminated and a new one is created for the next experiment (Clean-slate approach). Each experiment was run 10 times, deviation was below 2%. ETC category in tables represents External Services and most of this is composed of RabbitMQ traffic.

We performed experiments using eight different operating system (OS) images for instances of VMs, but due to paper limit of pages we are showing the results only for the most usual images:

1. **GNU/Linux Fedora Cloud:** version 30-1.2, 319 MB, and QCOW2 image file format;
2. **GNU/Linux Ubuntu Server:** version 18.04 LTS, 329 MB, and QCOW2 image file format; and
3. **MS-Windows Server:** version 2012 R2, 6150 MB, and QCOW2.GZ image file format.

Figure 7 shows the experiment timeline for GNU/Linux Fedora Cloud 30-1.2 OS image.




| Operation | Elapsed time (seconds) | Total Traffic (MB) |
|---|---|---|
| CREATE | 21 | 337.964 |
| SUSPEND | 5 | 2.192 |
| RESUME | 1 | 1.425 |
| STOP | 2 | 1.890 |
| SHELVE | 24 | 988.089 |

Figure 7: GNU/Linux Fedora Cloud 30-1.2 OS image.

Tables 2 and 3 show measured traffic classified by service and API calls respectively. It is possible to infer from Figure 7: measured traffic increases between seconds 2 and 4, during CREATE operation. The total traffic between seconds 2 and 4 sums up to around to 334 MB. Table 2 shows Glance is responsible for 333 MB during CREATE operation. Thus, this peak represents the OS image transfer. Same behavior happens to SHELVE operation. It's possible to infer a peak between seconds 51 and 56, totaling 919 MB of networking traffic. According to Table 2, Glance is responsible for 983 MB. Thus, this peak means the snapshot transfer through the network.

Table 2: Measured traffic in management and loopback interface for GNU/Linux Fedora Cloud 30-1.2 (MB).

| | Glance | Nova | Keystone | Neutron | ETC | Total |
|---|---|---|---|---|---|---|
| **CREATE** | 333.0054 | 0.00552 | 0.059566 | 0.03646 | 4.857366 | 337.9643 |
| **SUSPEND** | 0.000208 | 0.001823 | 0.001036 | 0.000208 | 2.188956 | 2.192231 |
| **RESUME** | 0 | 0.001169 | 0 | 0.007437 | 1.416463 | 1.425069 |
| **STOP** | 0 | 0.00117 | 0.011781 | 0 | 1.877207 | 1.890158 |
| **SHELVE** | 983.0146 | 0.00207 | 0.035559 | 0.011514 | 5.025322 | 988.0891 |

Table 3: API calls by service - GNU/Linux Fedora Cloud 30-1.2 .

| | Glance | Nova | Keystone | Neutron | Total |
|---|---|---|---|---|---|
| **CREATE** | 1 | 3 | 5 | 15 | 24 |
| **SUSPEND** | 0 | 0 | 0 | 0 | 0 |
| **RESUME** | 0 | 0 | 0 | 2 | 2 |
| **STOP** | 0 | 0 | 0 | 0 | 0 |
| **SHELVE** | 12 | 0 | 3 | 10 | 25 |

Figure 8 shows the experiment timeline for GNU/Linux Ubuntu Server 18.04 LTS OS image.

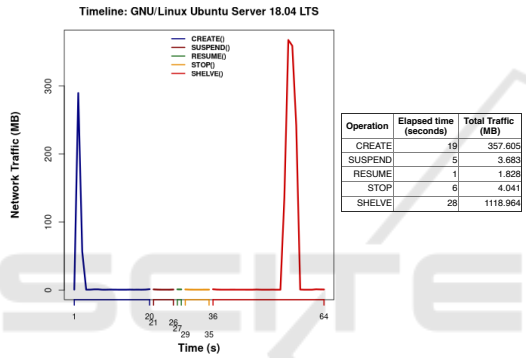



Figure 8: GNU/Linux Ubuntu Server 18.04 LTS.

Tables 4 and 5 show measured traffic classified by service and API calls respectively. CREATE operation registered a peak at second 2. Measured traffic at second 2 is around to 290 MB. On second 3 measured traffic is 57 MB. In the other hand, during SHELVE operation measured traffic from second 54 to 57 is higher than the rest in the operation. Measured traffic from second 54 to 57 is around to 1105 MB. Both peaks, from CREATE and SHELVE operations, are due to the image and snapshot transfer, respectively. Since Table 4 shows that Glance is responsible for most networking traffic during these operations.

Table 4: Network traffic (MB): management and loopback interface - GNU/Linux Ubuntu Server 18.04 LTS (MB).

| | Glance | Nova | Keystone | Neutron | ETC | Total |
|---|---|---|---|---|---|---|
| **CREATE** | 344.1754 | 0.003027 | 0.057792 | 0.035739 | 13.33273 | 357.6047 |
| **SUSPEND** | 0.000208 | 0.00117 | 0.011826 | 0.000104 | 3.669552 | 3.68286 |
| **RESUME** | 0 | 0.001169 | 0 | 0.005117 | 1.821232 | 1.827518 |
| **STOP** | 0 | 0.00117 | 0.011937 | 0.000104 | 4.028234 | 4.041445 |
| **SHELVE** | 1102.15 | 0.001377 | 0.011982 | 0.014614 | 16.78581 | 1118.964 |

Table 5: API calls by service - GNU/Linux Fedora Cloud 30-1.2.

| | Glance | Nova | Keystone | Neutron | Total |
|---|---|---|---|---|---|
| **CREATE** | 1 | 2 | 3 | 15 | 21 |
| **SUSPEND** | 0 | 0 | 0 | 0 | 0 |
| **RESUME** | 0 | 0 | 0 | 0 | 0 |
| **STOP** | 0 | 0 | 0 | 0 | 0 |
| **SHELVE** | 8 | 1 | 1 | 10 | 20 |

Figure 9 shows the experiment timeline for MS-Windows Server 2012 R2 OS image.

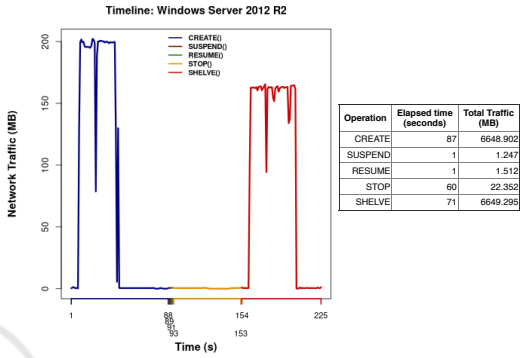



Figure 9: Results using MS-Windows Server 2012 R2.

Tables 6 and 7 show measured traffic classified by service and API calls respectively. Similarly the other experiments, CREATE and SHELVE operations take longer to execute and they produce more traffic than the others. CREATE operation produces around to 6600 MB of which 6500 MB are measured between second 8 and 43. SHELVE operation produces around to 6600 MB as well and the period between 162 and 202 seconds is responsible for 6400 MB. Table 6 shows Glance is once again responsible for most of the measured traffic in CREATE and SHELVE.

Table 6: Measured traffic in management and loopback interface for MS-Windows Server 2012 R2 (MB).

| | Glance | Nova | Keystone | Neutron | ETC | Total |
|---|---|---|---|---|---|---|
| **CREATE** | 6615.86 | 0.004698 | 0.035729 | 0.030551 | 32.97104 | 6648.902 |
| **SUSPEND** | 0 | 0.000507 | 0 | 0 | 1.246532 | 1.247039 |
| **RESUME** | 0.000104 | 0 | 0 | 0.007438 | 1.504655 | 1.512197 |
| **STOP** | 0.00052 | 0.002282 | 0.013943 | 0.007958 | 22.32741 | 22.35211 |
| **SHELVE** | 6619.848 | 0.003573 | 0.035414 | 0.0155 | 29.39219 | 6649.295 |

Table 7: API calls by service - MS-Windows Server 2012.

| | Glance | Nova | Keystone | Neutron | Total |
|---|---|---|---|---|---|
| **CREATE** | 1 | 3 | 3 | 13 | 20 |
| **SUSPEND** | 0 | 0 | 0 | 0 | 0 |
| **RESUME** | 0 | 0 | 0 | 0 | 0 |
| **STOP** | 0 | 1 | 1 | 5 | 7 |
| **SHELVE** | 8 | 2 | 2 | 10 | 22 |

Regarding to the API calls, all the experiments show Neutron and Glance have the highest numbers of calls (Tables 3, 5 and 7). Most times there are not so many API calls during SUSPEND and RE-

Table 8: Management traffic per operation.

| Operating System | Image size (MB) | SUSPEND (MB) | RESUME (MB) | STOP (MB) | CREATE *minus* Image size (MB) | SHELVE *minus* Image size (MB) |
|---|---|---|---|---|---|---|
| GNU/Linux Fedora Cloud 30-1.2 | 319 | 2.192231 | 1.425069 | 1.890158 | 18.96427 | 669.08910 |
| GNU/Linux Ubuntu Server 18.04 | 329 | 3.68286 | 1.827518 | 4.041445 | 28.60469 | 789.96375 |
| MS-Windows Server 2012 R2 | 6150 | 1.247039 | 1.512197 | 22.35211 | 148.9015 | 149.2949 |

Table 9: Elapsed time for each operation (seconds).

| | Elapsed time (seconds) | | | | |
|---|---|---|---|---|---|
| Operating System | CREATE | SUSPEND | RESUME | STOP | SHELVE |
| Fedora Cloud 30-1.2 | 21 | 5 | 1 | 2 | 24 |
| GNU/Linux Ubuntu Server 18.04 | 19 | 5 | 1 | 6 | 28 |
| MS-Windows Server 2012 R2 | 87 | 1 | 1 | 60 | 71 |

SUME operations. In fact, SUSPEND and RESUME operations are similar to suspending and reactivating a physical machine. Thus, there's no need for many API calls, since it can be done straight by the hypervisor in the Compute Node. The same can be applied to STOP operation, which means the machine will be turned off.

# 6 ANALYSIS

SUSPEND, RESUME, and STOP operations produce linear networking traffic (Table 8). The two columns on the left show how much network traffic was used when subtracted the size of the image you use. We have identified an increase when we were actually expecting a constant value because the image should only be left with API call traffic. We define it as future work to analyze whether part of this surplus could be due to TCP acknowledgments or related to the amount of API calls (Table 9).

We find out the number of instances being created or shelved at one time can easily clog up the OpenStack management network using a minimal setup (Figure 3). If there are OpenStack projects launching or shelving more than 10 VM instances of Ubuntu Server at a same time on a 1Gb/s network (which is not a significant number) this may cause performance degradation in all OpenStack administrative services (including user access to other storage services such as Swift and Cinder). Thus, the topology of Figure 4 should be adopted keeping in mind it will not solve the slow problem but at least will not affect the execution of other OpenStack services. The problem will only can be solved alocating right network bandwidth to support the amount of desired VM launching or shelving.

SUSPEND, RESUME, and STOP operations do not depend on the OS image, so the networking traffic is highly related to how long the operation took to execute (Table 9).

# 7 CONSIDERATIONS & FUTURE WORK

The experiments suggest a common behavior for all operations. SUSPEND, RESUME, and STOP operations show a constant management network traffic while CREATE and SHELVE network traffic depend on the OS image size.

OpenStack is a distributed system, so its operation is complex, and there are several asynchronous requests among its services/modules. In fact, in OpenStack setups RabbitMQ is the most important tool for dealing with those asynchronous requests. RabbitMQ message broker implements Advanced Message Queuing Protocol (AMQP) for managing queues of Remote Procedure Calls (RPCs). The ETC category showed in each networking traffic table (Tables 2, 4, and 6) contains RabbitMQ traffic which should be analyzed using a flow based approach (since there are no source and destination ports to be evaluated).

Our future work are focused on creating a baseline traffic which considers management traffic only per operation (it excludes the image transfer network traffic). Moreover, we intend to verify a linear regression model application so it would be possible to predict the networking traffic amount generated per operation and could be useful for networking resource management (*e.g.*, bandwidth allocation).

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