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Performance investigation and comparison between virtual networks and physical networks based on an advanced testbed network

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***Abstract*—Virtualization is one of the key technologies in the evolution of computer networks. Recently, many research institutes, universities and companies are building Cloud computing platforms or networked testbed environment based on virtualization technologies. The reliability of virtual networks has become a hot topic, which has been attracting significant attentions in the network research community. In this paper, we evaluate, and in particular compare, the performance of virtual networks and existing physical networks based on our advanced networked testbed, called Sea-Cloud Innovation Environment (SCIE). The performance investigation is carried out under both intra-domain (i.e., national networks) and inter-domain (international networks) environment, in terms of several key performance metrics including round trip time, throughput, packet loss, and jitter. The results obtained from this evaluation can provide useful reference to optimize the performance of the virtualized network platform.**

Keywords—Virtualization; Network experimental environment; Performance evaluation; Testbed

I. Introduction

The existing Internet infrastructure has been exposing many serious problems due to ever-increasing development of new application environments, emerging user requirements, and innovative network infrastructure. Tremendous research initiatives have been devoted to the investigation of future network architectures, resulting in a variety of innovative solutions. However, due to the ossification problems of the existing Internet and the sealed commercial devices and systems, it is hard, and even impossible to deploy and measure the performance of new network architecture and innovative solutions having been proposed. It is urgently calling for a real network experimental environment to be established to support the performance investigation for future Internet.

Virtualization is able to simulate a physical host into multiple virtual logic hosts, allowing multiple users to coexist by sharing the same physical resources. As an effective way for promoting the development of innovative network research ideas, virtualization technology has recently been attracting increasing attentions by many research institutes, universities, and companies. For example, Amazon EC2 platform [1], Google App Engine [2], and Microsoft Azure [3] are all based on the virtualization technology. Many countries have also initiated several large projects to advance virtualization technologies, such as Global Environment for Network Innovations (GENI) [4], Future Internet Research and Experimentation (FIRE) [5], and CloudLab[6]. GENI is supported by National Science Foundation (NSF), aiming to provide an open, virtual, large-scale, and innovative experimental environment; FIRE is designed to support several large-scale scientific experiments, established by European Union (EU) in 2007; and CloudLab allows researchers to build their own Cloud and facilitates the evaluation of correlated experiments on future networks.

The network experimental environment based on virtualization technology can facilitate the performance investigation of future network architecture. The experimental environment can be built making the best use of limited and idle resources, and can be easily managed and controlled based on virtualization technology. Most existing projects on network testbed rely on virtualization technology to test and evaluate the innovative solutions about future networks. In the long-term considerations, virtualization would evolve into the foundation of supporting the development of future Internet. Despite the network testbed projects have made significant progress and have also been running to provide resource services, there still exist several key issues to be solved, such as whether virtual experimental environment has authenticity comparing to the real physical experimental environment, deciding the faithfulness and promotion of the virtual experiment environment.

Virtualization is a resource management technology, abstracting the CPU, disk, memory, and network resources from physical entities. Open vSwitch (OVS) [7] led by Nicira Networks, is a multilayer virtual switch running on virtual platform, such as Kernel-based Virtual Machine (KVM), Xen, etc. Not only can OVS provide dynamic Virtual Machines (VMs) with accessing to network and switching through the second layer, but also can well control the access strategy, network-isolated, and traffic monitoring in virtual networks. OVS supports the existing standard management interfaces and protocols, such as NetFlow, sFlow, SPAN, RSPAN, CLI, LACP, 802.1ag, etc., facilitating the network administrators to manage the virtual networks. KVM [8] is an open source system virtualization module, and has been considered as one of mainstream VMs in academia. The hardware can be fully

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virtualized based on KVM, allowing the host of multiple VMs on one physical machine, to reduce the hardware expenditure and help reducing the cost on infrastructures. Besides, each VM has its own virtualized hardware, including network cards, disk, etc.

This paper aims to evaluate and compare the performance of virtual networks and existing physical networks in our advanced testbed, called Sea-Cloud Innovation Environment (SCIE), to provide the answer for outstanding question: whether virtual experimental environment has authenticity comparing to the real physical experimental environment. The performance investigation is carried out under both intra-domain (i.e., national network) and inter-domain (international network) environment, in terms of several key performance metrics including round trip time, throughput, packet loss, and jitter. The results obtained from this evaluation can provide useful reference to optimize the performance of the virtualized network platform.

The rest of the paper is organized as follows. Section II reviews the related virtualization technologies. Section III presents the experimental scenarios and designs. The simulation experiments and analysis are carried out in Section IV. Finally, Section V concludes this study.

II. Related Work

Very recently, Ryan Shea *et al.* [9] performed thorough measurement and evaluation of network performance between different VMs in Cloud computing environment, and revealed that the scheduling policies of CPU in VMs had great effects on TCP and UDP traffic between VMs.

The authors evaluated the performance of the existing network and the testbed network in statistic dimension and time dimension [10]. They found a quite high fitness degree between the actual network and the testbed simulation, and, therefore concluded that the miniaturized testbed environment can also be used to simulate the outfield test, in comparison with the actual network.

In [11], Sheng *et al.* presented a virtual network mapping framework, called ORSTA, based on opportunistic resource sharing and topology-aware node ranking. The experiment results indicated that physical resource can be utilized more efficiently and achieved more virtual network requests over time with ORSTA.

A study of VMs from the perspective of power consumption while processing network transaction is discussed in [12]. The authors showed KVM and Xen had more energy consuming when running network transaction, and found that it could reduce the overhead using adaptive packet buffering potentially.

The existing literature reveals that the mainstream network experimental environments integrate multi-source and heterogeneous resources based on virtualization technologies, to provide network users with experimental resources. Hence, the authenticity of virtual experimental environment is crucial and significant. Since authentic evaluation has not been largely explored, in particular under both intra-domain (i.e., national network) and inter-domain environment (i.e., international network), this paper compares the virtual network with the existing physical network through measuring the network performance, and prepares a series of evaluation to build a solid foundation for perfecting the performance and reliability of innovation experimental environment.

III. The Experimental Design

A. The Sea-Cloud Innovation Environment (SCIE)

The main aim of this paper is to measure the performance of the virtual network based on the SCIE, and to evaluate the authenticity of virtual networks through comparing with the existing physical network under identical scenarios and configuration.

The SCIE is an advanced nationwide testbed with the extension to international-scale at the moment, supported by the "Strategic Priority Research Program - New Information and Communication Technology" of the Chinese Academy of Sciences [13]. The aim of the SCIE is to build an open, general-purpose, federated, and large-scale shared experimental facility to foster the emergence of next generation information technology research in China. The SCIE includes experiment service system, resource control system, and measurement system. It deployed Smart-Flow Switch (OpenFlow) and SCIE RACK in 7 cities including 16 sites. At the same time, several new features in SCIE have been developed, including experiment workflow control program based on Java & Python language, experiment visualization, and light-weight VM management tools.

Comparing with other experimental environments, such as Amazon EC2 used in [9], the SCIE is established based on real networking resources. We choose the SCIE not only because it is the leading provider of virtual experimental environment in China, but also it can be accessed and used worldwide. Besides, the SCIE can be strong controllable, programmable, as well as observable on experiment configuration and progress.

B. Host deployment

The operating systems of physical hosts and VMs are Ubuntu 12.04 64 bits, the kernel version is more than 3.13.0. The number CPU of physical host is 2 and the memory of physical host is more than 8G.

As KVM has become the norm in the VM community, its version 2.0.0 is installed on the physical hosts. For each physical host, 8 VMs are installed and could communicate with VMs installed on other physical hosts simultaneously.

C. Network deployment

The experiments are deployed in the virtual networks and physical networks based on VMs and physical hosts, respectively. VMs communicate with each other through GRE tunnel technology [14] built upon two OVSs in two physical hosts. The communication between physical hosts is the same as VMs. Fig.1 depicts the deployment of OVSs. The br-data in Fig.1 is a virtual switch created by OVS located in the physical host, through which the devices in intra-domain and inter-domain can communicate and perform data transmissions with each other.

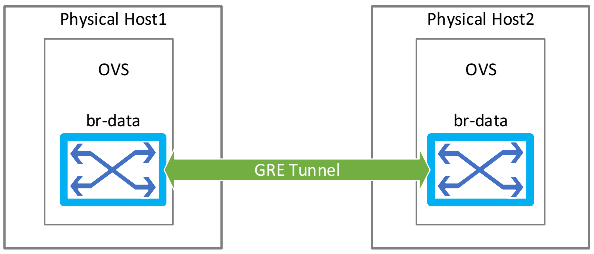


Fig. 1. The deployment of OVS

Both virtual network and physical network environments are deployed in SCIE with two scenarios: single-thread and multi-thread. For each scenario, the intra-domain case, from Beijing to Xinjiang in China, and the inter-domain case, from Beijing in China to Michigan in US are investigated.

In intra-domain case, single-thread means one VM to one VM, i.e., one-to-one virtual network scheme, and one physical host to one physical host, i.e., one-to-one physical network scheme. In single-thread virtual network scheme, one VM located in Beijing, China is the Client, and the other one deployed in Xinjiang, China is the Server, as shown in Fig. 2. In contrast, multi-thread means multiple VMs communicate with multiple VMs. In multi-thread virtual network scheme, eight pairs of VMs communicate simultaneously in our proposed experiments, as shown in Fig. 3. In single-thread physical network scheme, a Client and a Server are involved similarly. The single-thread physical network scheme is shown in Fig. 4, where the Client and the Server are the physical hosts located in Beijing and Xinjiang in China, respectively.

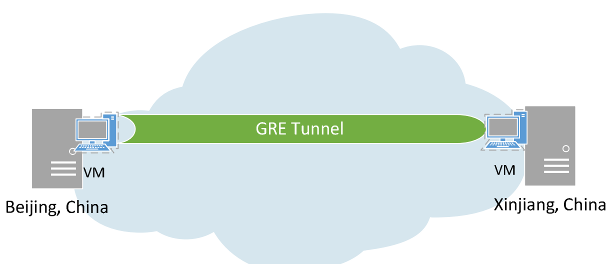


Fig. 2. Single-thread virtual network scheme in intra-domain environment

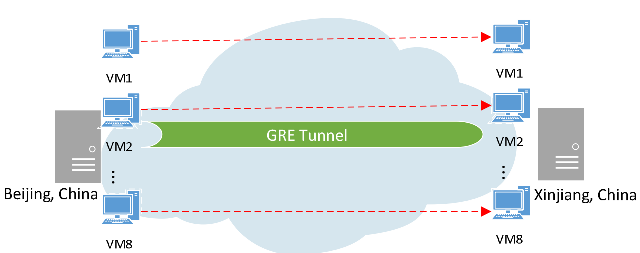


Fig. 3. Multi-thread virtual network scheme in intra-domain environment

Fig. 4. Single-thread physical network scheme in intra-domain environment

The inter-domain case is the same as the intra-domain case, including single-thread virtual network and physical network schemes and multi-thread virtual network schemes. These schemes are shown in Figs. 5-7. The only difference is that the Server is located in Michigan, US in inter-domain case.

Fig. 5. Single-thread virtual network scheme in inter-domain environment

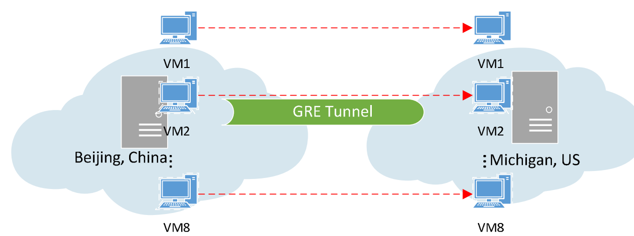


Fig. 6. Multi-thread virtual network scheme in inter-domain environment

Fig. 7. Single-thread physical network scheme in inter-domain environment

To deeply understand the authenticity of virtual networks, we conduct extensive performance evaluation tests for UDP and TCP traffic in idle and non-idle period, respectively. To estimate the authenticity in comparison with the physical experimental environment, we measure the key performance metrics, including round trip time (RTT), throughput, packet loss, and jitter for UDP traffic, and measure RTT and throughput for TCP traffic. The experimental results for the idle and non-idle period could help to identify the effects of background traffic.

The key parameters for experimentation are listed in Table I. The experimentation time is 360 seconds. For UDP traffic, the Bandwidth is set to be 32 Mbps in intra-domain case. But because of the limitation of hardware network card, we set Bandwidth to 8 Mbps in inter-domain case. To measure the performance of virtual networks, the popular performance testing tool, Iperf [15], is used to test the metrics such as throughput, packet loss, and jitter, and the command, Ping, is used to test the RTT from the request time to receive the response from the server by sending ICMP packets.

TABLE I. EXPERIMENTAL PARAMETERS

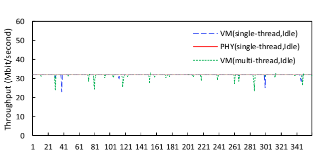
Parameter	value
VM type	KVM
Experimental Time	360 seconds
Background traffic	Idle, Non-idle
Protocol type	UDP, TCP
Bandwidth (UDP)	32 Mbps,8Mbps
Communication mode	GRE tunnel
Switch	OVS
Network benchmark	Iperf version 2.0.5

IV. EXPERIMENTS AND ANALYSIS

In what follows, the performance of virtual networks with UDP traffic for intra-domain and inter-domain is discussed. The delay and throughput of virtual networks under TCP traffic is then analyzed. The performance of virtual networks is evaluated based on four key metrics: RTT, throughput, packet loss, and jitter. For convenience, Beijing, Xinjiang, and Michigan are hereinafter referred to as BJ, XJ, and MI in Figs. 8-13, respectively.

A. *UDP traffic*

Fig. 8 shows the throughput when the network is subject to UDP traffic. It can be seen that the throughput of single-thread and multi-thread virtual network scheme are very similar to single-thread physical network scheme in intra-domain environment (i.e., from Beijing to Xinjiang) and in inter-domain environment (i.e., from Beijing to Michigan), where the deviation in intra-domain is less than 0.35% and it is about 0.21% in inter-domain. From the Figs. 8(a) - 8(d), we can see that the deviation between multi-thread virtual network and single-thread physical network is stable. Thus, we are able to get the similar performance of the real physical network in virtual network with certain modification.



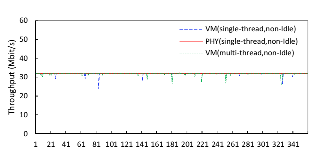
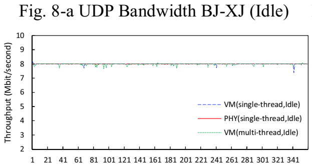


Fig. 8-a UDP Bandwidth BJ-XJ (Idle) Fig. 8-b UDP Bandwidth BJ-XJ (Non-Idle)



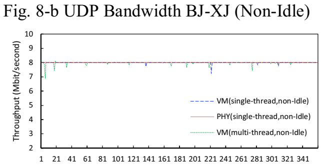
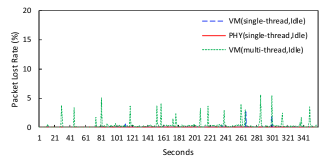


Fig. 8-c UDP Bandwidth BJ-MI (Idle) Fig. 8-d UDP Bandwidth BJ-MI (Non-Idle)

Fig. 9 shows the packet loss rate when the network is under UDP traffic. It shows that the packet loss rate of single-thread virtual network and physical network schemes are better than multi-thread virtual network scheme in all cases. The deviation of the packet loss rate between multi-thread virtual network and single-thread physical network in intra-domain is 0.17% and it is about 0.23% in inter-domain. From these results, we can get a conclusion that the network packet loss rate based on the multi-thread virtual networks can be affected by transfer distance.



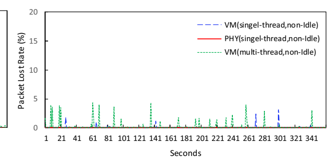
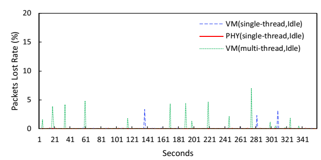


Fig. 9-a UDP Packet Loss BJ-XJ (Idle) Fig. 9-b UDP Packet Loss BJ-XJ (Non-Idle)



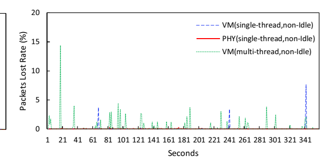
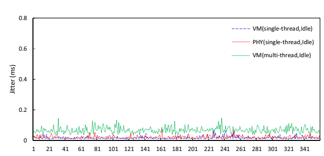


Fig. 9-c UDP Packet Loss BJ-MI (Idle) Fig. 9-d UDP Packet Loss BJ-MI (Non-Idle)

Fig. 10 presents the jitter when the network is under UDP traffic. It is easy to find that the jitter of inter-domain environment was higher than that of intra-domain environment with about 13.5%. In addition, the jitter of multi-thread virtual network scheme is 2.6% higher than that of single-thread physical network scheme in intra-domain environment, and the jitter of multi-thread virtual network scheme is 10.2 % larger than that of single-thread physical network scheme in inter-domain environment. Therefore, the distance is the main factor affecting the jitter, resulting in the requirement of optimization for network environment in multi-thread virtual network scheme.



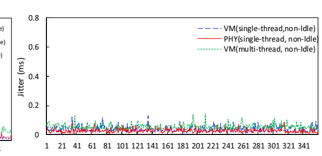
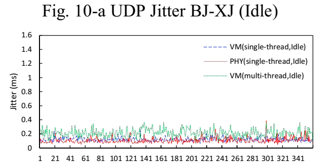


Fig. 10-a UDP Jitter BJ-XJ (Idle) Fig. 10-b UDP Jitter BJ-XJ (Non-Idle)



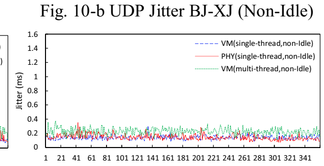


Fig. 10-c UDP Jitter BJ-MI (Idle) Fig. 10-d UDP Jitter BJ-MI (Non-Idle)

Fig. 11 shows the RTT when the network is subject to the UDP traffic. It can be seen that the RTT of single-thread physical network scheme is most stable and lowest in all cases, which is about 3.3% smaller than the RTT of single-thread and multi-thread virtual network schemes. In contrast, the RTT is not so stable in non-idle scenario, and the RTT deviation between idle and non-idle cases is 0.1%. Thus, the background traffic is the key influence factor of RTT, and it affects the performance of network experiment in virtual network environment.

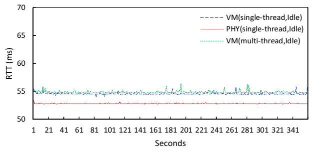


Fig. 11-a UDP RTT BJ-XJ (Idle)

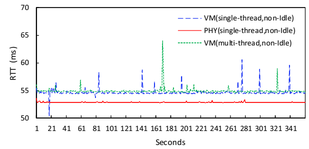


Fig. 11-b UDP RTT BJ-XJ (Non-Idle)

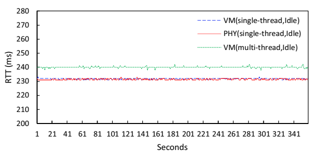


Fig. 11-c UDP RTT BJ-MI (Idle)

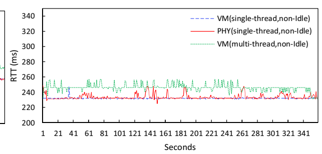


Fig. 11-d UDP RTT BJ-MI (Non-Idle)

B. *TCP traffic*

Fig. 12 presents the throughput when the network is with TCP traffic. It shows that the throughput of the network in idle case is better than that in non-idle case, and the throughput of intra-domain environment is higher than that of inter-domain environment. After slow start, the throughput of single-thread physical network scheme is higher than that of single-thread and multi-thread virtual network scheme. Therefore, the TCP performance optimization based on virtualized experimental environment is required. On the other hand, the throughput of single-thread virtual network scheme is the most stable and is very similar to single-thread physical network scheme in non-idle case.

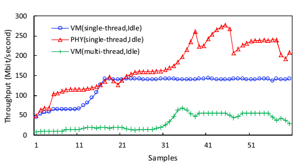


Fig. 12-a TCP Throughput BJ-XJ (Idle)

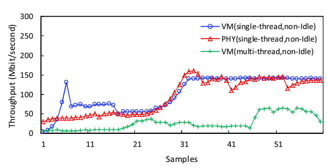


Fig. 12-b TCP Throughput BJ-XJ (Non-Idle)

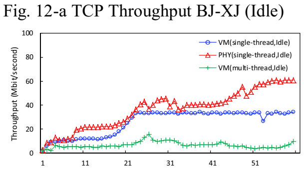


Fig. 12-c TCP Throughput BJ-MI (Idle)

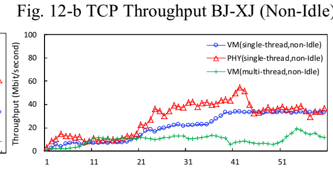


Fig. 12-d TCP Throughput BJ-MI (Non-Idle)

Fig. 13 shows the RTT when the network is subject to TCP traffic. It can be seen that the RTT of single-thread physical network scheme is the most stable and lowest, followed by those for single-thread virtual network scheme and multi-thread virtual network scheme. However, the difference among these three schemes is not apparent and follows some rules. In idle traffic case, the deviation between single-thread physical network scheme and single-thread virtual network scheme is 0.23%, the deviation between single-thread physical network scheme and multi-thread virtual network scheme is 0.55%. In non-idle traffic case, the deviation between single-thread physical network scheme and single-thread virtual network scheme is 3.7%, the deviation between single-thread physical network scheme and multi-thread virtual network scheme is 4.5%.

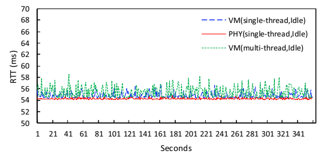


Fig. 13-a TCP RTT BJ-XJ (Idle)

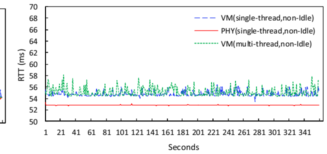


Fig. 13-b TCP RTT BJ-XJ (Non-Idle)

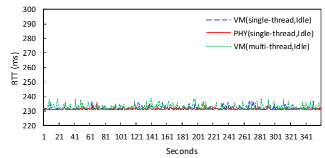


Fig. 13-c TCP RTT BJ-MI (Idle)

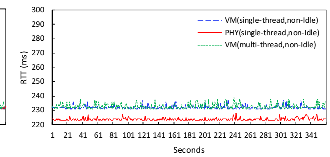


Fig. 13-d TCP RTT BJ-MI (Non-Idle)

V. CONCLUSION

In this paper, we have deployed the experiment based on virtual resources in our advanced testbed, called Sea-Cloud Innovation Environment (SCIE), and compared the network performance between the existing physical networks and virtual networks through several key performance metrics including round trip time (RTT), throughput, packet loss, and jitter, under intra-domain (i.e., national network) and inter-domain (i.e., international network) environment with idle and non-idle scenarios. Through analyzing the performance results, we have found that 1) the RTT and jitter of virtual networks have little deviation from physical networks, 2) the throughput and packet loss rate of virtual networks are similar to physical networks, 3) the performance of single-thread virtual network is more similar to the existing physical network than the multi-thread virtual networks, and 4) the multi-thread virtual networks have certain deviation from physical networks, but the deviation is stable and shows certain characteristics. Thus, it is possible to get the performance of real physical networks in virtual networks.

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