RESEARCH STATEMENT

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To leverage the elastic resource allocation of cloud computing and enhance the service availability and productivity, numerous applications and businesses have been moved from the traditional data centers into the cloud during the past decade. Despite the benefits introduced by virtualization, such as high resource utilization, flexible resource management and operation cost reduction, it also incurs additional overhead, scheduling delays as well as semantic gaps among hardware, operating system and applications. These issues can cause non-negligible impact on the performance and quality-of-service of the cloud applications, especially for the I/O-intensive services. Meanwhile, the increasing scale and complexity of the cloud infrastructure aggravate the above problems, making both characterization and optimization of the virtualized network performance much more difficult.

My research tries to explore the potential opportunities in various cloud infrastructures, including the traditional virtual machines (VMs), emerging containers as well as the application runtime, and present lightweight and efficient approaches to characterize and optimize the network performance in virtualized environments. From the perspective of characterization in virtualized networks, I designed and developed several tools to trace the network activities in virtualized systems with negligible overhead. These tools shed light on the virtualized network monitoring and can help users analyze, identify and localize potential issues inside virtualized networks. From the perspective of optimization, I proposed and developed several approaches for improving the performance of I/O-intensive applications in various virtualized environments, such as the virtual machines in Xen or KVM, the Docker containers and the Java virtual machines (JVM). All of these attempts not only provide better quality-of-service guarantees for the end users, but also improve the resource utilization as well as the system efficiency for the cloud providers.

As a system guy, my research interests broadly lie in solving real problems inside the cloud computing, operating systems, distributed systems, software defined network as well as the network function virtualization. Besides the above, I am also enthusiastic in learning and exploring the new network issues when the traditional solutions meet the tomorrow era of technologies, including the serverless computing, internet of things (IoT), edge computing and machine learning.

1 Current Ph.D. Research

1.1 Characterizing the Network Performance of Popular Virtualized Systems

Due to the rapid growing scale and increasing complexity, the cloud services usually exhibit inefficient and unpredictable performance, especially for I/O-intensive applications. However, compared to traditional systems, it is more challenging to trace I/O workloads and troubleshoot network problems in virtualized systems. Existing efforts are either built on analyzing massive system logs or limited to use within a certain boundary. To solve the issue, I built an in-band packet profiler named Time Capsule, which traces packet level activities across different boundaries in virtualized systems and incurs negligible overhead with no changes to applications [1]. With the tool, I successfully identified several bugs inside Xen's credit scheduler, reported the findings to the open source community and finally got positive feedbacks from the Citrix engineers.

Another trend in recent years is the raise of containers and an increasing number of applications are being deployed inside containers in the cloud. To provide better performance and specific features, I found that there exist lots of container network solutions in the market to connect the containers either inside one server or across multiple hosts. In order to help users select the appropriate network for their workloads and guide the optimization of the existing container networks, I made a detailed analysis of available container networks in Docker and performed an empirical study of their performance [3]. To the best of my knowledge, it is the first paper which conducts a systematic investigation and study on the container networks.

Results of the above researches have been published in ACM Asia-Pacific Workshop on Systems (APSys) 2016 and IEEE International Conference on Computer Communications (INFOCOM) 2018.

1.2 Optimizing the Inefficient and Nonoptimal Parts inside Virtualized Networks

Modern datacenters hosting online services face significant challenges due to the inefficiency of virtualized networks. A key goal of network virtualization is to efficiently manage and utilize the network resources while providing the best of application performance and user experience. However, due to the scalability and complexity, there exist lots of obstacles in realizing the above goal. For instance, the inefficiency in the VM scheduling, the prolong data path in the container network, the interaction between the hardware and the software will all contribute to the poor and unpredictable network performance. To address the above issues, I focused on investigating the bottlenecks in various layers along the virtualized network stack and optimizing the network performance in different virtualized environments of the cloud.

Sponsored by NSF grant CNS-1649502 and IIS-1633753, I investigated the suboptimal I/O performance of applications in the VMs or containers, and discovered the CPU discontinuity caused priority inversions and rendered existing I/O prioritization in the guest OS ineffective. Thus, I proposed and designed a lightweight approach named xBalloon to preserving static and dynamic priorities between I/O-bound and compute-bound tasks and boosting the I/O performance under discontinuous time [5]. As a popular runtime environment and the base of big data applications, Java virtual machine (JVM) suffers from suboptimal performance and poor scalability on the multicore systems. I presented an in-depth performance analysis of the JVM and found the existing design of JVM incurred inefficient garbage collection, which introduced the low throughput and long tail latency for the applications. To mitigate the overhead, I proposed a number of solutions including enforcing GC thread affinity to aid multicore load balancing and designing a more efficient work stealing algorithm [2]. I also reported our findings to engineers from Oracle and Redhat and they all confirmed our discoveries and contributions. For the emerging container networks, I found that its poor performance on multiple hosts come from massive interrupt processing along the data path as well as the imbalance of interrupt distribution. To address such issues, I proposed several optimizations including the software interrupt rebalancing and pipeline processing on multicore. Based on our preliminary results, the above optimizations can efficiently tackle single core processing bottleneck and improve the container network performance.

Results of the above researches have been published in ACM Symposium on Cloud Computing (SoCC) 2017 and ACM European Conference on Computer Systems (EuroSys) 2018.

1.3 Efficient and Programmable Packet Tracing in Virtualized Networks (Industry Intern in Huawei Research Labs)

As the scale and complexity of the cloud systems continue to grow, virtualized networks that provide connectivity between services within or across data centers, are becoming increasingly important to the performance and reliability of the cloud. However, virtualized networks present unique challenges to performance tracing, including lots of hardware or software boundaries, performance constrains, flexibility, etc. In this project, I proposed an eBPF-based tracing framework named vNetTracer that enables efficient, flexible and end-to-end network performance monitoring for applications in virtualized environments [4]. To minimize the runtime overhead during the network tracing, I made several optimizations including customizing tracing rules to filter monitoring data and using sharing memory to temporary store the intermediate results. To provide the rich and flexible performance tracing, I developed a set of metrics using eBPF scripts to characterize the various scenarios of virtualized networks. I used the tool to trace network performance in various virtualized systems such as the VMs, containers, virtualized network bridges, etc. The findings not only help me find issues and locate bugs in the popular virtualized systems, but also shed light on the direction of my new research.

Results of the above research has been published in IEEE International Conference on Distributed Computing Systems (ICDCS) 2018.

2 Future Research Directions

In my future research, I will continue my effort on the improvement of application performance and system efficiency in various virtualized network systems. In the near term, I plan to further explore more advanced solutions which integrated the hardware, hypervisor, operating systems and applications to deliver better virtualized network performance and system utilization. Specifically, I am interested in (1) characterizing the complicated virtualized systems with high efficiency and low cost; (2) improving the underlying cloud infrastructure for better Quality-of-Service, more predictable performance and better fairness guarantee. In the following, I outline my vision for setting up an active research group and establishing myself as an independent researcher toward this direction.

2.1 Low Overhead Profiling for Cloud Networks

Network performance problems or bottlenecks are notoriously tricky to diagnose, and this is magnified when applications are running on top of the increasing complex and consolidated virtualized network in the data centers. However, it is necessary to instrument and monitor the system and the applications in order to guarantee its normal execution and trouble shooting. This semantic gap raises the requirement of a highly efficient and low overhead network profiling for services in the cloud environment. In Time Capsule [1] and vNetTracer [4] project, I have proposed a few solutions for addressing the challenges of tracing the cloud networks. Meanwhile, many new techniques, such as containers, Kubernetes, microservices, etc. have been widely adopted in recent years, which requires new and advanced solutions to monitor their performance and identify their issues in cloud networks. Therefore, I plan to extend my current research into these new areas and explore the efficient solutions for profiling and monitoring services in the latest cloud environment.

2.2 High Performance Cloud Network

Network performance is always one of the top concerns for both service customers and cloud providers. As the cloud economy increases and the cloud ecology grows, both horizontal and vertical scope of cloud are expanding. On one hand, the scale of cloud keeps increasing with more servers involved, more data centers built and more customers connected. On the other hand, the hierarchy of network as well as the software stack becomes much thicker and more complicated compared to the early era of cloud. All of the above make the network less efficient and more unpredictable for the cloud services. In xBalloon [5] and OptJVM [2] project, I have identified and addressed a few critical network performance bottlenecks in VMs, containers and application runtime. The ultimate goal of my research is to mitigate or even eliminate the abstraction overhead of virtualization in different layers inside the entire systems. Based on my previous experiences in building systems, application profiling and problem solving, I will continue leveraging my expertise to carry out influential work for this goal.

In the long term, my research aims to expand the current experience in improving the virtualized network into the new forms of services and technologies. Specifically, I am interested in studying the network performance in edge computing or IoT devices, and investigating the possibilities of integrating machine learning with the network optimization.

2.3 Optimizing Network Performance in Edge Computing

As the emerging applications and services such as 5G networks, Internet of Things (IoT), serverless architecture, embedded artificial intelligence appear, the traditional cloud is becoming increasingly inadequate to support such new technologies. To meet the latest requirements including real-time analytics, local control, constrained network bandwidth, data security and so forth, edge computing has been proposed in recent years by integrating the local computing, storage, networking and resource management together with the applications. With such a design, the edge cloud can effectively address the challenges that the traditional cloud cannot handle. Similar with the development of cloud in the past ten years, there exist massive business opportunities as well as research challenges in the future edge computing. For example, academia experts should rethink the traditional network designs and reshape the network architectures to meet the tomorrow cloud. As a network researcher, I am interested in studying the unique network challenges inside the edge computing and exploring the potential solutions to meet the growing demands.

2.4 Machine Learning in Networking

As the scale and the complexity of cloud grow, it is becoming increasingly struggling to effectively monitor and manage the immense system network, let alone providing comprehensive and actionable insights. On the other hand, there exist massive inefficient parts inside the whole system. Misconfigurations, failures, security attacks interfere the execution of the cloud network all the time. In recent years, the emergence of machine learning and artificial intelligence (AI) promise new opportunities to tackle the above challenges in understanding and managing cloud networks. In my future research, I am interested in exploring the possibilities of integrating machine learning and AI with the network optimization. For instance, questions such as ”What are good target problems in networking that might be solved by machine learning?”, ”What developments in artificial intelligence can impact networking?”, ”How to balance the human and machine role in managing the cloud networks?” are waited to investigate and I plan to answer these questions with my students in our future research.

Last but not least, I deeply understand that teamwork is necessary to achieve all the above explorations. I will recruit new students and build my research group. Besides, I will proactively collaborate with other researchers in areas of systems, machine learning, security, etc. Also, I will seek to work with industrial researchers to make my research influential and meaningful. With my previous research experience, I am confident that I am competent for achieving the above goals and receiving productive results.

References

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