Abstract

In the last two decades, the data generated by different Internet of Things (IoT) applications has increased significantly. The real-time processing, computation, and analysis of these generated data, which is termed as '*big-data*', typically demand support from geographically distributed data centers. These well-connected data centers, forming a data center network (DCN), try to optimize the load distribution among the switches. However, the traditional DCN suffers from unbalanced traffic load and low utilization of network bandwidth, which, in turn, increase energy consumption and degrade the overall performance of the DCN. On the other hand, with the advancement of IoT technologies, different IoT devices are capable of generating and processing a huge amount of data. Hence, there is a need to integrate these IoT devices into the DCN architecture. We argue that this cannot be done using traditional network architecture, as the traditional network devices, such as switches and routers, are not capable of handling different application-specific protocols and heterogeneous IoT devices, due to vendor-specific infrastructure.

We envision that the aforementioned limitations can be resolved by integrating the traditional DCN with the software-defined network (SDN) architecture, which is named as 'software-defined data center network' (SD-DCN). SD-DCN assumes the advantages of SDN by decoupling the network control tasks from the tasks of packet forwarding and processing, while dividing them into two parts – the *control plane* and the *data plane*. Due to the presence of heterogeneous IoT applications, SD-DCN needs to handle heterogeneous elephant and mice flows. The existing literature on SDN and DCN focused on the traditional networking issues. However, the implications of the presence of heterogeneous IoT flows need further investigation. In this thesis, we focus on the traffic management strategies in SD-DCN to handle heterogeneous flows generated from the IoT devices and data centers, while ensuring the quality-of-service (QoS) requirements of data traffic in terms of network-delay, -throughput, and -resource utilization. A summary of the major contributions reported in this thesis is presented as follows.

Initially, we focus on designing a probabilistic performance analysis model of an SDN OpenFlow system for data traffic management while considering that the switches are equipped with a finite size buffer. This design helps us to understand the performance of the SDN switches in terms of the probabilities of a packet to be forwarded to the controller, to the next switch, or to be dropped. Consequently, we designed a scheme to evaluate the optimal buffer size for each switch based on the number of ingress ports and the data traffic pattern, i.e., the packet arrival and processing rates, in an SDN OpenFlow system. Through simulation, we observe that with two times increase in packet processing rate, the packet arrival rate can be increased by 26.15-30.4%. We infer that for an OpenFlow system, the minimum buffer size is 0.75 million packets with the maximum packet arrival and the minimum processing rate of 0.20-0.25 million packets per second (mpps) and 0.30-0.35 mpps, respectively. Thereafter, we consider the presence of heterogeneous applications, which are associated with heterogeneous elephant and mice flows, and have different requirements in terms of network delay and throughput. To increase the flow-wise throughput in SD-DCN, we propose a throughput-optimal data traffic management scheme and evaluate the optimal association of the flows and the available one-hop switches. Additionally, we propose a delay-optimal data traffic management scheme for reducing end-to-end network delay and increasing the overall network throughput in SD-DCN. Simulation result show that the proposed schemes are capable of reducing network delay by 77.8-98.7% while ensuring 24.6-47.8% increase in network throughput compared to the existing schemes. Additionally, the proposed schemes ensure that per-flow delay is reduced by 27.7% with balanced load distribution among the SDN switches.

For the aforementioned schemes, we consider that each flow is associated with a single source-destination pair. However, in SD-DCN, each IoT data traffic can be designated to more than one destination IoT device or data center. Therefore, we focus on designing broadcast and multicast data traffic management schemes in the presence of heterogeneous IoT devices. Moreover, we consider that the IoT devices act as the source nodes and are mobile in nature. In these works, we aim to provide a QoS-guaranteed end-to-end data delivery and maximize the utilization of available network bandwidth, while maximizing the overall network throughput and reducing the flow-specific delay in SD-DCN. Through simulation, we observe that the network throughput increases by 55.32%, while ensuring at least 33% increase in the average bandwidth allocation per IoT device in data broadcast. Additionally, we observe that in data multicast, the network throughput increased by at least 6.13% using the proposed scheme than using the existing schemes, while ensuring at least 21.32% reduction in per-flow delay.

While designing the aforementioned schemes, we considered that a single SDN controller is present in SD-DCN. However, traditional DCN can have multiple network vendors. Therefore, there can be multiple SDN controllers in SD-DCN. In the existing literature, the traditional multi-tenant SDN is visualized to be equipped with an additional centralized controller, named 'proxy controller' for ensuring optimal flow-table partitioning. However, the presence of the proxy controller gives rise to a single point of failure and bottleneck problems. Hence, to solve these problems, we propose a flow-table partitioning scheme for distributed multi-tenant SD-DCN, while ensuring high throughput and network satisfaction, and reducing flow-setup delay in SD-DCN. Finally, we conclude the thesis, while highlighting the limitations of the aforementioned works and the possible future research directions.

Keywords: Traffic Management, Internet of Things, Heterogeneous Flows, Quality-of-service, Game Theory, Software-Defined Network, Data Center Network, Software-Defined Data Center Network