Introduction

Large-scale data centers always act as a bedrock to provide support for a considerable number of cloud computing services (i.e., remote meeting and social networking) and infrastructure services (i.e., GFS , MapReduce and HDFS). However, the network connecting millions of servers in data centers plays a critical role in the whole system, especially when those various popular cloud-based services are generated, which presents much higher requirements to capability of network than ever, such as reliability and scalability. Therefore, the research into various aspects of networks in cloud data centers has long been an inevitable challenge and accordingly a crucial topic.

In conventional distributed computing architectures, specific applications are exclusively served by physically dividing network resources. In contrast, cloud service data center networks (DCNs) employ virtualization technologies to allocate various applications across multiple Virtual Machines (VMs)[pkpadmin,+36]. This process involves an advanced degree of autonomous resource management, facilitated by a range of virtualization software. This network responds effectively to variations in demand and alterations in network conditions, thereby optimizing resource usage and enhancing the quality of services provided.

Related work

Research of cloud data center networks can be broadly segmented into four paramount facets: the physical architecture of the CDN, the techniques of virtualization,and the routing protocols and traffic engineering.

Physical Architectures:

The architecture of DCN is considered as the most significant factor due to its ability to determine the reliability of a DC and its predominant roles in fault tolerance, routing efficiency, latency, and network capacity.[3] In light of the drawbacks and limitations of traditional Three-Tier network architectures, including increased network costs and significant bandwidth oversubscription towards the core tier, considerable research has been undertaken to identify an efficient interconnection architecture for cloud data center networks. This has resulted in three predominant categories: server-centric, switch-centric, and the recently proposed dual-centric architectures.

Switch-Centric Architectures

Within the switch-centric architecture, network intelligence is predominantly situated on the switches. Each server typically engages a single NIC (Network Interface Card) port to connect to a Top-of-Rack (ToR) switch, which interconnects via aggregation switches linked through core switches. In these schemas, servers function as endpoint hosts for data transmission and reception, with switches managing end-to-end routing, the most popular switch-centric schemes are Fat-Tree[5] and V L2[6].

（之后比较加上）While the switch-centric architectures are relatively low-cost, certain switch-centric designs grapple with significant scalability constraints when necessitating expansion or the integration of new servers. Essentially, these designs are profoundly contingent upon the port-count of the deployed switches, leading to an intricate wiring complexity and an inherent limitation in scalability due to the port-count of the core switches.

1. *Server-Centric Architectures*

The server-centric architecture, a category of DCNs, positions network intelligence primarily on servers, which function as both forwarding and computing units. In this structure, exemplified by DCell[10] and BCube[13] servers employ multiple NIC ports to connect to various switch layers and potentially other servers. Switches, if present, typically serve as basic crossbars. Servers assume dual roles in this architecture, functioning as end hosts while also acting as relays for other servers, with their core task being the selection of the next forwarder in the network. Benefitting from substantial bisection bandwidth and amplified aggregate throughput, BCube nonetheless grapples with deficient scalability. DCell, expanding in a double exponential manner, utilizes a fault-tolerant routing protocol , thereby enhancing network performance. This robust protocol asserts its capability to efficiently manage a multitude of failures, spanning across hardware, software, and power-related disruptions.Nevertheless, it confronts issues due to variable traffic loads on different link levels, transforming highly utilized lower-level links into network bottlenecks, which subsequently impairs performance. Consequently, DCell falls short in certain network capacity evaluation metrics, particularly aggregate bottleneck throughput .

C. Dual-centric architectures

In the dual-centric architecture, the task of routing intelligence is distributed between servers and switches. This configuration can concurrently harness the high programmability of servers and the significant switching capability of switches. This architecture facilitates all permutations of connectivity, encompassing server-to-server, server-to-switch, and switch-to-switch connections. Key examples are RibsNet[3] and Crystal[4], which are 2 recent advancements.

**Design priciples**

Primarily, the paramount objectives for efficacious architectures of data center networks that can support tremendous cloud services encompass significant reliability, extensive scalability, minimized latency, substantial network capacity, and judicious energy consumption[1-s2.0].

Reliability: Proposed DCNs architectures must exhibit high reliability and resilience against network failures. Redundant elements enhance fault-tolerance, but also inflate costs; thus, a judicious balance is crucial. A robust topology is fortified by implementing a dynamic, fault-tolerant routing algorithm that swiftly reacts to abrupt network infrastructure changes.

Scalability: The advent of numerous emergent cloud services necessitates that DCNs are designed to accommodate a burgeoning number of servers within their infrastructures. The integration of novel elements into the network should not impede the efficient functionality of extant servers within the system. Furthermore, the routing algorithm employed ought to demonstrate facile adaptability to a substantial influx of servers, or the introduction of new components into the network.

Capacity: To accommodate substantial network traffic generated by data-intensive services like GFS and MapReduce, DCNs with ample capacity are crucial. Given that over three-quarters of DCN traffic remains within the network, the necessity for heightened network bandwidth becomes increasingly imperative.[1]

Latency: To facilitate time-sensitive applications like web search, online gaming, and multimedia services, data must be transmitted within strict deadlines, necessitating a limited network diameter and number of hops between server pairs. This design approach minimizes overall latency, enabling the DCNs to efficiently support interactive cloud services and meet the stringent requirements of latency-sensitive applications.

Energy consumption: The significant energy consumption of data centers, comparable to household clusters, cities, or nuclear power stations, underscores the imperative for the design of power-efficient infrastructures [2]. As major contributors to greenhouse emissions and carbon footprints, with network usage accounting for 40% of total power, developing energy-efficient network architectures is crucial for reducing both environmental impact and electricity costs.

Routing schemes and traffic engineering

Routing schemes

An important player in the efficiency of such interconnection structures is the routing protocols. Each network architecture exhibits distinct characteristics, and encompassing its individual topology, hence they have their own specific routing algorithm and traffic control solution. Unlike traditional Internet link-state routing protocols, the majority of prevailing data center network routing protocols are tailored explicitly for specific network topologies.

Broadly, the interconnection structures of Data Center Networks (DCNs) can be primarily divided into two principal schemes, which are routing in server-centric structure and routing in switch-centric structure respectively.

Traffic engineering

Although rudimentary routing schemes primarily pursue low-latency paths between servers, advanced DCN routing necessitates comprehensive optimization encompassing latency, reliability, throughput, and energy efficiency, among other factors. This multidimensional optimization represents the traffic engineering (TE) problem.

The traffic in DCNs is divided into two primary parts, inter-DCN and intra-DCN traffic.Given the predominance of within-data-center communications in overall data center network activity, the overall performance of a DCN largely rely on inter-DCN TE.

It's noteworthy that numerous scholars have employed various sophisticated machine learning-based models for traffic forecasting, enabling precise real-time prediction and scientific control of intra-cloud data center traffic. Li et al. [14] conducted research on traffic transmission within data centers, integrating the wavelet transform technique with a neural network. Additionally, they utilized the interpolation filling method to mitigate the monitoring overhead instigated by the irregular spatial distribution of data center traffic.

**Design priciples**

In the process of designing a TE model, the following design principles should be considered.

Reliability:The first objective both providers and subscribers in DCNs, is paramount in ensuring robust data transmission for essential services and business operations. Effective TE models optimize routing patterns, enhancing network resilience through multi-pathing and fault-tolerance, thereby rendering the DCNs reliable, robust, and indispensable to its users.

Load-balancing: The second objective is to optimize link capacity usage to address the latency-throughput trade-off. With a multitude of cloud applications and services running concurrently in a data center, an intelligent routing protocol should ensure optimal performance for each by judiciously distributing traffic across intra-data center links, thereby maximizing capacity utilization and achieving even traffic dispersion.

Power expenses: A critical objective for competitive service pricing in DCNs. Thus, proficient TE models should drive routing strategies to minimize the usage of links and switches, reducing energy consumption. This approach not only maximizes profits for DCNs but also enables them to maintain market-competitive service costs.

路由方法方面

虚拟化方法方面

网络结构方面

Research of cloud data center networks can be broadly divided into three major issues: physical data center architecture, virtualization techniques, and routing algorithms either physical or virtual.

Virtualization：Virtualization techniques offer virtual services through partitioning available resources and sharing them among users. There are various types of virtualization, such as server virtualization, network I/O virtualization, network virtualization, and resource virtualization

routing algorithms：To support the needs of ever-growing cloud-based services, a considerable number of novel and creative machine learning based (ML-based) research works have been put forward , which helps the data center network to improve the network service quality and the efficiency of operation and maintenance (O&M), so as to cope with the new challenges brought by the increasingly complex network management and dynamic flexible services.

physical architecture is one of the essential topics of cloud data center networks.

The physical architecture composed of switches, servers, and cables, is mainly responsible for offering hardware re- sources such as CPU, memory, and bandwidth. A favorable data center network should have high scalability, efficient switch and server utilization, and high fault tolerance. The existing data center network structures can be classified into three type: switch-centric, switch-centric, and hybrid electrical/optical.

三种类型网络

Comparison of Key Approaches

在不同方面的比较

路由方法的比较

虚拟化方法的比较

网络结构的比较

总结和未来的方向：

As the data center service scenarios become more and more complex, the network scale becomes larger and larger, and the requirements for user experience and service quality become

higher and higher, the traditional communication protocols have already not been qualified to cope with these challenges.

Thus, the data center network inevitably requires more efficient and intelligent communication protocols to ensure fast convergence, high bandwidth, low latency and no packet loss for network transmissions. However, the new communication

protocols proposed in recent years also fail to meet data center requirements of heterogeneous scenarios [252] and have compatibility issues with legacy protocols [175, 176]. There is no doubt that artificial intelligence can help network protocols achieve better responsiveness, predictability, and self-adjusting ability. However, there is still little research on how to achieve

a more friendly and efficient transmission protocol assisted with ML, which is an opportunity for future research.

参考：

：Cloud services are experiencing a remarkable increase in the number of users and the resource required over the past few decades. With the dependency on different services like e-business, web search, online games, and re- mote meetings, huge amounts of traffic are being generated.

To fulfill the demands, cloud services are designed to provide easy, affordable access to applications and resources, without the need for internal infrastructure or hardware.

Cloud Data center networks (CDNs) plays the most pivotal role in providing an efficient infrastructure to support increasingly popular cloud services such as GFS, Map-Reduce, Dryad, BigTable, and HDFS. Cloud computing requires the underlying network to be flexible, rapid, stable, in the meantime, handling tremendous traffic loads. This leads to emerging proposals of novel designs for frameworks and interconnections of cloud data centers. Research of cloud data center networks can be broadly divided into three major issues: physical data center architecture, virtualization techniques, and routing algorithms either physical or virtual.

The physical architecture composed of switches, servers, and cables, is mainly responsible for offering hardware re- sources such as CPU, memory, and bandwidth. A favorable data center network should have high scalability, efficient switch and server utilization, and high fault tolerance. The existing data center network structures can be classified into three type: switch-centric, switch-centric, and hybrid electrical/optical

Virtualization techniques offer virtual services through partitioning available resources and sharing them among users. There are various types of virtualization, such as server virtualization, network I/O virtualization, network virtualization, and resource virtualization

Routing algorithms regulate routing and traffic management in cloud data centers. With appropriate routing algorithms, a cloud data center can efficiently handle the connection of numerous data center servers as well as entire communications, data storage and transport. Distinct from Internet link-state routing protocols such as OSPF/ISIS or path-vector routing such as BGP, most of the existing data center network routing schemes are customized to designated topologies.

The architecture design of the DCNs directly affects the customers’ satisfaction with cloud computing services. Thus, to address the growing needs for such services, and provide efficient interconnection networks for connecting the agglomeration of servers accommodated inside the cloud data centers, many new schemes have been designed.

通常来说，五种指标用于评价一个Cloud data center是否是efficient.

Generally, the most important objectives for designing efficient DCNs are better scalability, observable fault tolerance, lower latency, high network capacity, as well as reasonable cost and energy consumption as portrayed in the sequel

Comparison of Key Approaches(benefits and disadvantages):

Conclusions and Future Directions

References

Find one that is recent and relevant. Better, find many and you will see authors look at similar but not the same set of algorithms/protocols

未来发展，使用各种机器学习神经网络强化学习算法对网络性能的优化，提高各项指标.()

节能减排，降低碳排放量的CDN（Resource-efficient load-balancing framework for cloud data center networks）

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路由部分的参考[14] Survey on Routing in Data Centers: Insights and Future Directions

In the switch-centric architecture, the network intelligence is placed thoroughly on the switches. In the switch-centric network architecture, each server usually connects using a single NIC (Network Interface Card) port to a ToR (Top of Rack) switch. Moreover, ToR switches inter- connect using aggregation switches and then the aggregation switches, are connected via core switches.

Switch-centric的评价

However, some switch-centric schemas, like Fat-tree and VL2, face significant scalability issues when expanding to accommodate new servers, due to their limitations tied to the port-count of deployed switches.

On the other hand, the system of a centralized directory meeting for hulking the network burdens and the fault tolerance weakness are serious problems with VL2.

Fat-Tree [5] is a multi-rooted, three-tier structure which provides a 1:1 oversubscription ratio to servers. By using n-port switches, n pods each accommodating *𝑛*∕2access layer and *𝑛*∕2 aggregation layer switches are constructed. Totally, the hierarchical structure of the Fat-Tree can accommodate *𝑛*2∕4, *𝑛*2∕2, *𝑛*2∕2, core, aggregation and edge switches, respectively. It can also accommodate *𝑛*3∕4 servers.