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A Distributed Cloud Architecture Based on General De Bruijn Overlay Network

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ABSTRACT

Distributed cloud systems enable the distribution of computing resources across various geographical locations. While offering benefits like accelerated content delivery, the scalability and coherence maintenance of these systems pose significant challenges. Recent studies reveal shortcomings in existing distributed system schemes to meet modern cloud application demands and maintain coherence among heterogeneous system elements. This paper proposes a service-oriented network architecture for distributed cloud computing networks. Using a De Bruijn network as a software-defined overlay network, the architecture ensures scalability and coherence. Through service-based addressing, requests are issued to designated service address bands, streamlining service discovery. The architecture's evaluation through extensive simulations showcases sustainable scalability and inherent load-balancing properties. The paper concludes with insights into future research directions, emphasizing the extension of the proposed architecture to emerging distributed cloud use cases and decentralized security.

KEYWORDS

Cloud Computing, Distributed Cloud, Distributed Load Balance, Overlay Networks

Distributed cloud computing systems are a type of cloud computing infrastructure that allows for the distribution of computing resources across multiple geographical locations. This architecture provides many benefits, including faster content delivery, greater visibility and manageability of hybrid cloud and multicloud architectures, and easier industry or regional regulatory compliance (Atieh, 2021). However, as the size and complexity of these systems grow, coordinating and maintaining consistency among the distributed resources become increasingly challenging. (Coady et al., 2015; Ageed & Zeebaree, 2024). In a recent cloud schemes survey Angel et al. (2021) found that major distributed system schemes in practice fail to scale up to modern cloud application demands and to maintain coherency between the heterogeneous elements of the system.

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To address these challenges, we propose a new service-oriented network architecture for distributed cloud computing networks. The proposed architecture aims to provide a scalable, robust solution to face changing cloud conditions. The proposed architecture uses a de Bruijn (Chikhi et al., 2014) network as a software-defined overlay network built on top of a physical core network. The chosen overlay network is a software-defined network that can be set up on top of any weakly connected physical network and is guaranteed to self-stabilize (Feldmann & Scheideler, 2017). This set of features is crucial for ensuring network construction feasibility and adaptability to changes in the cloud environment.

The proposed architecture uses service-based addressing instead of node-based addressing; that is, the consumer nodes issue a service request to a service address band, unlike a regular cloud network architecture in which the service is requested from a known computing node. The network address space is divided into bands, and each service is allocated a specific band. This requires the consumer node to have knowledge only about the desired service band.

To evaluate the effectiveness of the proposed architecture, we created and tested a network model in multiple scenarios. The results of the simulations demonstrate the sustainable scalability of the proposed architecture while maintaining no central core of the network and the inherent load-balancing property of the proposed architecture.

Finally, the paper concludes with a discussion of future work directions, including the extension of the proposed architecture to new distributed cloud use cases, such as edge computing and internet of things (IoT) applications.

OVERLAY NETWORKS

An overlay network is a logical network built on top of a physical network that provides an abstract layer with the purpose of overlaying the existing physical network infrastructure. The goal of an overlay network is to allow more flexibility in how data is transmitted and processed, irrespective of the physical network's technical implementation. It uses the existing infrastructure to connect and allow communication between nodes, while adding an additional layer of abstraction to enable advanced routing and network management algorithms. Creating an overlay on top of an existing physical network enables new mechanisms, protocols, and services to be introduced that can enhance the overall performance and functionality of the system.

Overlay networks are commonly used in a variety of systems and applications, including peer-to-peer (P2P) file-sharing systems, content delivery networks (CDNs), virtual private networks (VPNs), and distributed cloud computing platforms. In each of these applications, the overlay network allows for application-optimized routing and network management algorithms, while abstracting out the details and limitations of the underlying physical network.

Overlay networks represent a crucial building block in the design and implementation of scalable, efficient distributed systems. Their ability to overcome the limitations of the underlying physical infrastructure and provide enhanced functionality makes them a fundamental component in modern networking architectures (Lua et al., 2005).

De Bruijn Graph

A de Bruijn graph, symbolized as $G = (V, E)$, is a form of directed graph commonly used in computer networks and bioinformatics. At its core, this graph provides a structured representation of sequential data, often DNA sequences in genomics or symbol sequences in network routing algorithms.

The set of nodes, denoted by V within a de Bruijn graph, encompasses all possible substrings of a predetermined length, typically referred to as k-mers. K-mers are contiguous sequences of symbols in which the length k determines the size of the substring. For instance, in a networking scenario, a 3-mer (k-mer of length 3) could represent a sequence of three consecutive bytes or characters within a packet payload.

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