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ORIGINAL ARTICLE

A resource-sharing model based on a repeated game in fog computing

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Abstract With the rapid development of cloud computing techniques, the number of users is undergoing exponential growth. It is difficult for traditional data centers to perform many tasks in real time because of the limited bandwidth of resources. The concept of fog computing is proposed to support traditional cloud computing and to provide cloud services. In fog computing, the resource pool is composed of sporadic distributed resources that are more flexible and movable than a traditional data center. In this paper, we propose a fog computing structure and present a crowd-funding algorithm to integrate spare resources in the network. Furthermore, to encourage more resource owners to share their resources with the resource pool and to supervise the resource supporters as they actively perform their tasks, we propose an incentive mechanism in our algorithm. Simulation results show that our proposed incentive mechanism can effectively reduce the SLA violation rate and accelerate the completion of tasks.

1. Introduction

Cloud computing is a new service mode that can provide available and convenient network visits (Mell and Tim, 2011). It only took several years to integrate in people's lives. At the far cloud end, data centers keep users from the bottom physical framework through virtualization technology and form a virtual resource pool for external services. The cloud data center is composed of many large servers that meet pay-as-you-go demand. These large-scale data centers are constructed by well-capitalized big companies, such as Google, Yahoo, etc. They possess the absolute right of control over resources, and users can only use resources. With the development of mobile internet, more and more heterogeneous devices are connected to the network (Zhang et al., 2011). Although large-scale cloud data centers can meet the complicated requests of users, bandwidth limits may cause network congestion and even service interruptions when many users request services from the data center at the same time. The QoS (quality of service) cannot be ensured if the request has to be processed by the far cloud end. Under this circumstance, fog computing was developed (Bonomi et al., 2012).

Fog computing is a new resource provision mode in which the users not only can use the virtualized resources but can also provide services. In fog computing, some simple requests with high time sensitivity could be processed by geographically

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distributed devices that can absorb some pressure of the cloud data center. All devices with spare resources can be resource supporters of fog computing, even some sensors and smart phones. Since the resource supporter is closer to the resource consumer, fog computing is superior to cloud computing in terms of response speed.

The resource supporters are all rational and would like to achieve some benefit for their resource contributions. If there is not an effective incentive mechanism, the resource owners will not contribute their resources (Vaquero and Rodero-Merino, 2014). Based on the above problems, the main contributions of this paper are presented as follows:

(1) A system structure based on the neural network of the human body is put forward according to the characteristics of cloud and fog data centers. The reasonability of this system structure is analyzed.
(2) Based on the idea of crowd-funding, a reward and punishment mechanism was established by integrating the computing capacity of geographically distributed devices. This mechanism encourages resource owners to contribute their spare resources and monitors the resource supporters to execute tasks positively; it then increases the working efficiency and reduces the SLA violation rate.

In Section 2, we present the architecture of fog computing based on the human neural network, and describe related issues about crowd-funding. Then, we elaborate the crowd-funding algorithm flow and analyze it mathematically using repeated game theory. In Section 3, simulations are used to show the effects of this algorithm on reducing the SLA violation rate and decreasing task execution time. Our work is concluded, and future research directions are proposed in Section 4. In Section 5, the related work of fog computing is introduced.

2. Related works

Due to continuous development of the internet of things technology, more intelligent devices are used in people's daily lives. These geographically distributed devices possess tremendous idle resources. There are plenty of resources available for users in data centers. Therefore, coordinated management of these resources in a fog environment for automatic deployment, dynamic expansion and distribution according to user needs is a research hotspot.

Many experts and scholars have explored coordinated resources management in the cloud and fog environment. Zhen et al. (2013) introduced the concept of "skewness." By minimizing skewness, the overall utilization of server resources is improved to enhance the ability of the cloud data centers to provide resources to serve the users. They also developed a set of heuristics that effectively prevent system overload and conserve energy. Beloglazov et al. (2012) investigated the issue of virtual machine consolidation in heterogeneous data centers and presented an energy-efficient virtual machine deployment algorithm called MBFD. The algorithm selects the physical machine that increases the energy consumption of the system the least after placing a virtual machine as the destination host where a virtual machine should be placed. The algorithm plays an energy-saving role. Lee and Zomaya, 2012 generated two heuristic algorithms for task integration, ECTCC and MaxUtil. The goal of these heuristic algorithms is to reduce the energy consumption of data centers by improving resource utilization of the physical machines to turn on as few physical machines as possible. Hsu et al. (2014) proposed an energy-aware task consolidation (ETC) technique. The ETC minimizes energy consumption by restricting CPU use below a specified peak threshold and by consolidating tasks among virtual clusters. The network latency when a task migrates to another virtual cluster has been considered in the energy cost model. Gao et al. (2013) investigated the deployment of virtual machines under the homogeneous data center, regarding it as a multi-objective optimization problem. System resource utilization and energy consumption were optimized and a multi-objective ant colony algorithm was presented. Dong et al. (2013) designed a hierarchical heuristic algorithm that considers the communication between virtual machines when analyzing the virtual machine deployment problem. The energy consumption of physical and network resources is optimized. Wu et al. (2014) presented a green energy-efficient scheduling algorithm that efficiently assigns proper resources to users according to the users' requirements in the cloud data center. Their algorithm increases resource utilization by meeting the minimum resource requirement of a job and prevents the excess use of resources. The DVFS technique is used to reduce energy consumption of servers in data centers.

Aazam and Hum (2015a,b) proposed a resources management model based on fog computing. The model in (Aazam and Hum (2015a,b)) considered resource prediction and allocation as well as user type and characteristics in a realistic and dynamic way, thus enabling to adaption to different telecom operators according to requirements. However, their resources management model neglected heterogeneous services, service quality and device movement. In (Aazam and Hum (2015a,b)), the authors proposed a high-efficiency resources management framework. Since fog computing involves different types of objects and devices, how many resources will be consumed and whether request node, device or sensor will make full use of requested resources are unpredictable. Therefore, they developed a resources evaluation and management method by comparing the abandonment probability of fluctuating users to service type and service prices as well as the variance of abandonment probability. This method was conducive to determining correct resource demand and avoiding resource waste. Nevertheless, their resources management model analyzed from the perspective of only the service supplier, and neglected the economic benefits of service users. In (Do et al., 2015), the authors studied resource co-allocation in fog computing and reducing carbon emissions. A high-efficiency distributed algorithm based on the near-end algorithm was developed that decomposed large-scale global problems into several sub problems that can be solved quickly. However, this algorithm only focused on a single data center and neglected the fact that there are multiple small data centers in fog computing. SU et al. analyzed how to share or cache resources between servers effectively using the Steiner tree theory (Su et al., 2015). When the fog server is caching resources, a Steiner tree is produced first to minimize the total path cost. Next, the Steiner tree is compared with a traditional shortest path scheme, which proved that the Steiner tree is more efficient. However, they