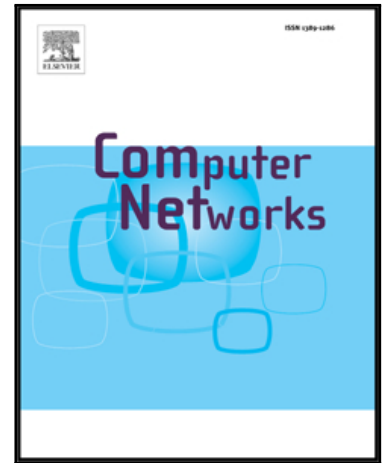


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Software-Defined Networks for Resource Allocation in Cloud Computing: A Survey

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Highlights

- A comprehensive literature review of pertinent studies on Resource allocation in Cloud Computing based on Software Defined Networks.
- Thematic taxonomy for classifying current Software-Defined Networks for Resource Allocation in Cloud Computing.
- Lesson learned from in-depth critical review based on proposed taxonomy.
- Major future trends are discussed based on SDN adaptation in the cloud environment.

Abstract: *Cloud computing has a shared set of resources, including physical servers, networks, storage, and user applications. Resource allocation is a critical issue for cloud computing, especially in Infrastructure-as-a-Service (IaaS). The decision-making process in the cloud computing network is non-trivial as it is handled by switches and routers. Moreover, the network concept drifts resulting from changing user demands are among the problems affecting cloud computing. The cloud data center needs agile and elastic network control functions with control of computing resources to ensure proper virtual machine (VM) operations, traffic performance, and energy conservation. Software-Defined Network (SDN) proffers new opportunities to blueprint resource management to handle cloud services allocation while dynamically updating traffic requirements of running VMs. The inclusion of an SDN for managing the infrastructure in a cloud data center better empowers cloud computing, making it easier to allocate resources. In this survey, we discuss and survey resource allocation in cloud computing based on SDN. It is noted that various related studies did not contain all the required requirements. This study is intended to enhance resource allocation mechanisms that involve both cloud computing and SDN domains. Consequently, we analyze resource allocation mechanisms utilized by various researchers; we categorize and evaluate them based on the measured parameters and the problems presented. This survey also contributes to a better understanding of the core of current research that will allow researchers to obtain further information about the possible cloud computing strategies relevant to IaaS resource allocation.*

Keywords— Resource Allocation; Software-Defined Networks; Cloud Computing; Data Center Network; Edge-Computing; 5G.

1. Introduction

Cloud Computing (CC) has recently come out, and it has been viewed as allowing a common collection of configurable computing services to be made accessible and released as specified by the National Institute of Standards and Technology (NIST) [1], It also allows easy and on-demand network access. Thus, networks, servers, storage, applications, and services resources are pooled in the cloud to serving several tenants. Services providers, e.g., Microsoft Azure, Amazon, and Google Cloud, provide access through the internet to CC resources based on a pay-per-use policy. Nowadays, in a few hours, anyone can pay for cloud services, deploy and sets up servers for an application. The physical infrastructure is leased out to CC clients based on leasing it from an external cloud service provider. Therefore, they only pay for the resources they use.

NIST classifies CC into three operation models and four deployment models. The CC operational models are divided into three specific categories: Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS). In IaaS, the underlying cloud infrastructure can not be managed or control by clients. Other than

that, clients can set up and run the software, control operating systems via administrative access to VMs and programs, and allocate processing, storage, networks, and other essential computing resources. On the other hand, PaaS allows developers to deploy web-based applications without purchasing and setting up physical servers. Meanwhile, SaaS provides host applications and makes them accessible to customers over the internet, e.g., Google, Salesforce, Microsoft, and Zoho. Development models define how customers and cloud providers communicate with each other through private, public, hybrid, and community clouds.

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A public cloud is operated by a single corporation and is open to the public or a broad business group. A private cloud is own by a specific organization. Cost-effectiveness, reliability, flexibility, and high scalability are the main benefits of the public cloud. Still, it lacks security compared to a private cloud that guarantees high security but suffers from high cost and limited scalability. A community cloud shares a small number of relationships and builds specific groups with a common duty. An infrastructure that contains several clouds of any kind is called a hybrid cloud, which they communicate between them to allow the transfer of data and applications from one cloud to another through their interfaces.

CC built on data center infrastructure is designed with the ability to apply virtualization technology [2]. Virtualization technologies enable flexible resource allocation to virtual machines (VMs), enabling flexible resource provision on-demand. Moreover, virtualization allows multiple applications to be integrated on fewer physical servers, which promises to be significant cost-savings due to increased energy efficiency and lower system administration costs. Compared to sharing the main computational resources in cloud computing, sharing network resources is more difficult. Conventional routing schemes in Data Center Networks (DCNs), including the Open Shortest Path First (OSPF) [3] and Routing Information Protocol (RIP) [4], are based on static routing; and therefore loses flexibility in identifying flow paths for different network states. Likewise, VM scalability causes some bottlenecks to result from across-VM communication on a single host due to virtual bridges. Furthermore, the conventional routing process limits the efficient use of resource capacity. Hence, it cannot build an improved network knowing that the general cost of fixing and configuration these networks is very high.

Software-Defined Networks (SDN) [5] is an advanced network model that improves the shortcomings of the conventional network infrastructures by separating the control plane and the data plane from switches and routers. SDN technology enables network control through centralized software controllers and makes network management more efficient, fast, and flexible. The SDN central controller has a global network view to deal with the dynamic changes in the network topology. Simultaneously, the SDN controller communicates to the forwarding device through the OpenFlow protocol [6]. The flexibility of SDN-managed networks has opened up new opportunities for the research community to incorporate IaaS and Cloud Data Center (CDC) capabilities into the SDN [7]. SDN also provides resource management systems that allow cloud services provision while attaining dynamic traffic requirements when running VMs. Furthermore, SDN and Network Function Virtualization (NFV) [8] enable much greater network flexibility by splitting network architectures into virtual slices, a process is known as network slicing, which aids 5G wireless technology innovation [9].

CDC systems require agile and flexible network control functions with computing resource control to ensure characteristics of traffic performance for the VM operations are adequate and attainable by the SDN [10]. Also, SDN virtualizes on-demand network resources to utilize resources and satisfy user application restrictions efficiently. Resource allocation has become one of the obstacles of cloud computing arising from users sharing computing and network resources, and the network often adopts the best-effort transmission mechanism [11] and Shortest-Path-First (SPF) routing mechanism [12] for data transmission, leading to a link load imbalance and high possibility of link congestion. Indeed, the network topology and routing mechanism have a major effect on the Service Level Agreement (SLA), the Quality-of-Service (QoS), and the network latency [13] that negatively affect the energy usage of Cloud Computing Data Centers Networks (CCDCNs). In turn, the ineffective allocation of computing resources leads to an overprovisioning or an underprovisioning, negatively impacting the SLA. Consequently, it reduces the profit for the cloud provider and increases the user's cost [14]. Figure 1 depicts the resource allocation process.

In CC, unpredictable and changing requests of resources among end-users depending on their application usage style are the key challenge of CC. Moreover, resource allocation aims to optimize applications, i.e., QoS, improved resource utilization, and power efficiency, no matter what type of Information and Communication Technologies (ICT)

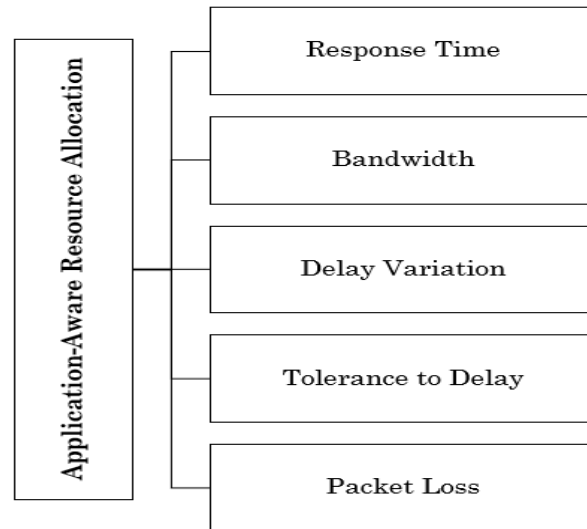


Figure 9: Application-Aware Resource Allocation Parameters.

Table 6: Application-Aware Resource Allocation.

Reference/Year	Algorithm	Parameters	Improvement	Weakness
Hong[146] (2014)	Neural network based.	Response time	Meet SLAs, allocate and predictive resources (VMs and network) effectively, reduce application power consumption, and adapt all application types to a cloud data center-based SDN.	This technique focuses only on the response time parameter to check violation of application and predict just VMs resources.
Cheng [148] (2015)	Dijkstra's algorithm and Lagrange relaxation based aggregated cost algorithm.	Tolerance to delay, bandwidth ratio, delay variation, and packet loss rate.	A QoS-conscious routing strategy has been optimized for many groups of applications to satisfy the network requirements of SDN-based cloud data centers.	This mechanism does not solve the SDN problem related to the limiting flow table size of the switch.
Aziz [90] (2017)	REST APIS.	Bandwidth.	Build a new structure of DC-based on SDN.	—
Egilmez [149] (2013)	Lagrangian Relaxation Based Aggregated Cost (LARAC) algorithm.	Delay variation.	Enhance QoS for video application.	This study focuses on one application and takes one SLA parameter.
Cucinotta [150] (2014)	Integer Linear Programming (ILP).	Response times.	Offers high performance in a multi-tenant data center.	This work focuses on cloud computing only.

6.4 Edge -Aware Resource Allocation

Allocate resources in Edge- cloud technology to fulfill the QoS requirement and save power consumption fully is addressed as well as the measured parameters illustrated in Figure 10.

Workload slicing scheme is built-in [151] to manipulate large data applications in an edge cloud environment. SDN-based control is used to perform the inter-DC migrations and guarantees traffic flow scheduling with power optimization. Also, the Stackelberg game is executed to deliver the best inter-DC migrations. Likewise, MEnSuS [152] design to handle the different incoming workloads from consumers, which can classify types of jobs using an SVM-based scheme. This design reduces SLA violation by using renewable energy sources RES. The switch consolidation strategy has been introduced to save energy usage, delay, and increase bandwidth utilization.

The latency-aware policy was presented by [153], which aims to handle fog traffic steered to DCs. It also offers dynamic resource savings in an optical wide-area SDN that facilitates energy-conscious interaction between cloud and fog. Cao *et al.* [154] and others suggested a new 5G IoV architecture based on fog computing and SDN to address the needs of IoV. Whereas the effective use of heterogeneous computing resources to guarantee QoS is a critical problem with this system. Consequently, the authors improved the two architecture algorithms by using the concept of hierarchical clustering to overcome the shortcomings. Noteworthy, experiential results show that the optimized algorithm is capable of obtaining the best experiments. Likewise, IoV setting, the resource allocation scheme derived from other algorithms improves service delay, task execution stability, power consumption, and load balancing.

The research work carried out in [155] introduced a resource allocation framework called IaaS-SDN to interconnecting the edge cloud data center. IaaS-SDN used mathematical modelling that implements IaaS allocating of IaaS requests. Metro Optical Network topology is used to implement the framework under the management of the SDN controller. The authors are also concerned with the position of the SDN controller, and thus they compute several parameters that aid in the process of selecting the position of the SDN controller.

Hierarchical edge-cloud SDN (HECSDN) is proposed by [156] to solve the problem of delay resulting from congested by heavy flows related to the limited controller of computation-resource. The suggested model was tested using the MATLAB optimization toolbox, and the results showed the effectiveness of the control system over a large-scale SDN network despite affecting the efficiency and QoS of different network applications. Table 7 illustrate the summary of researchers in edge cloud computing based on SDN.

As in edge clouds, the resource allocation issue must be determined by the location of the user, as well as the wireless network between both the user and the edge server, and the wireless connectivity between the edge server and the cloud server, taking into account the position of the SDN controller. In other words, taking into account the combination of every one of the various QoS parameters and the power consumption will make it very difficult to solve this problem and motivate us to look for it in future work.

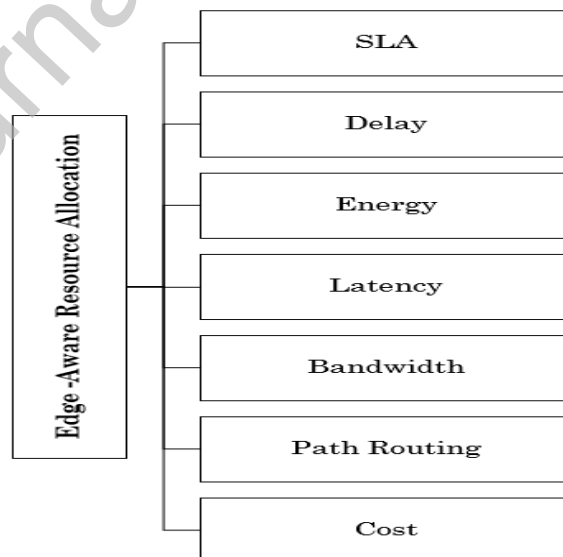


Figure 10: Edge -Aware Resource Allocation Parameters.

Table 7: Edge-Aware Resource Allocation.

Reference/Year	Algorithm	Parameters	Improvement	Environment
Aujla [152] (2018)	Workload slicing and scheduling algorithm, Energy-aware flow scheduling algorithm, and Stackelberg game for inter-DC migration.	Energy, delay, SLA violations, migration rate, and cost.	Save energy and reduce the delay and cost of the inter-DC relay process.	Edge 2cloud computing.
Zaman [155] (2019)	Linearization of quadratic, column generation formulation.	QoS, cost, and path routing.	Provisioning IaaS requests in ECDC, and optimal location to select SDN controller placement.	Edge 2cloud computing.
Aujla, [151] (2018)	Workload classification algorithm, server consolidation scheme, and two-stage game for workload scheduling.	Energy, SLA, delay, and bandwidth.	Lesser violations of the SLA, delays, migration costs, and power.	Edge 2cloud computing.
Borylo [153] (2016)	Latency Aware policy.	Latency and power.	Reduce latency and carbon footprint.	Fog computing.
Lin [156] (2020)	Edge-cloud SDN (ECSDN) algorithm.	Delay.	Overall performance and QoS of different applications with Various traffic patterns.	-----
Cao [154] (2021)	Two-architecture algorithm.	Service delay, stability of task execution, and energy consumption.	Better resource allocation in 5G IoV.	5G and fog computing.

7. Open Research Challenges and Future Directions

The difficulties of allocating cloud resources revolve around hardware heterogeneity, workload prediction, and requirements of cloud providers and consumers. In this sense, the availability of resources and the optimum use of usable resources for applications to meet the QoS performance objectives in compliance with the SLA is an important issue. In contrast, QoS describes the level of consistency, reliability, and availability provided by the services. Also, it is difficult to delegate due to changing workloads over time that affect various resource requirements of cloud service providers. Likewise, the heterogeneity of the devices and technologies used within the cloud makes resource allocation a challenge. It is worth noting that there are several concerns related to resource allocation in cloud computing systems, including QoS, energy usage, VM migration, provider earnings, utilization expenses, and multi-agent technologies [157].

Even as SDN technology has been implemented into cloud computing, several negatives have arisen. They can be summarized as follows:

1. The size-limited flow table is incorporated in the physical switch.

2. The placement of the SDN controller increases the round-trip time when a flow-table miss occurs.
3. And long host routes.

In the future, we expect the need for modelling components to predict resource requirements, assigning an optimum VM for each application, and choosing the appropriate link to minimize congestion and power consumption. Furthermore, forecasting technology may also be used to predict QoS for each application that interacts dynamically with network boundaries in a cloud-based manner in an effective manner. Worthwhile, most of the methods that were applied to achieve resource allocation in cloud-based on SDN are applied to small-scale experimental and simulation environments, as shown in Figure 11.

We also need to use meta-heuristic algorithms in the allocation process as they help find the solution in a fast and correct way by combining them with other algorithms that depend on the population, or depend on nature, or rely on biology some exploratory and meta-algorithms based on local search. One of the benefits of integrating two population-based meta-heuristic algorithms would be that the abilities of another algorithm can balance the deficiencies from one algorithm. Furthermore, more research is needed to examine other parameters regardless of power, bandwidth, and predominant usage. The researchers also recommend more research on the following points.

Edge computing: We need to move a massive amount of data across geographically dispersed data centers using backbone networks to efficiently handle big data and the IoT [95][158]. Therefore, the overheads generated by migration between inter-DC cause a high speed of data movements across various DCs and may incur significant costs [159]. Moreover, the positioning of SDN controllers is one of the big issues in the edge cloud data center. Even of many advantages of edge computing, such as location, user mobility, and network connectivity [160], numerous interactions and computing-related issues for future IoT systems now have to be answered [91]. Furthermore, workload forecasting and resource utilization efficiency at both the hardware and software levels require more study.

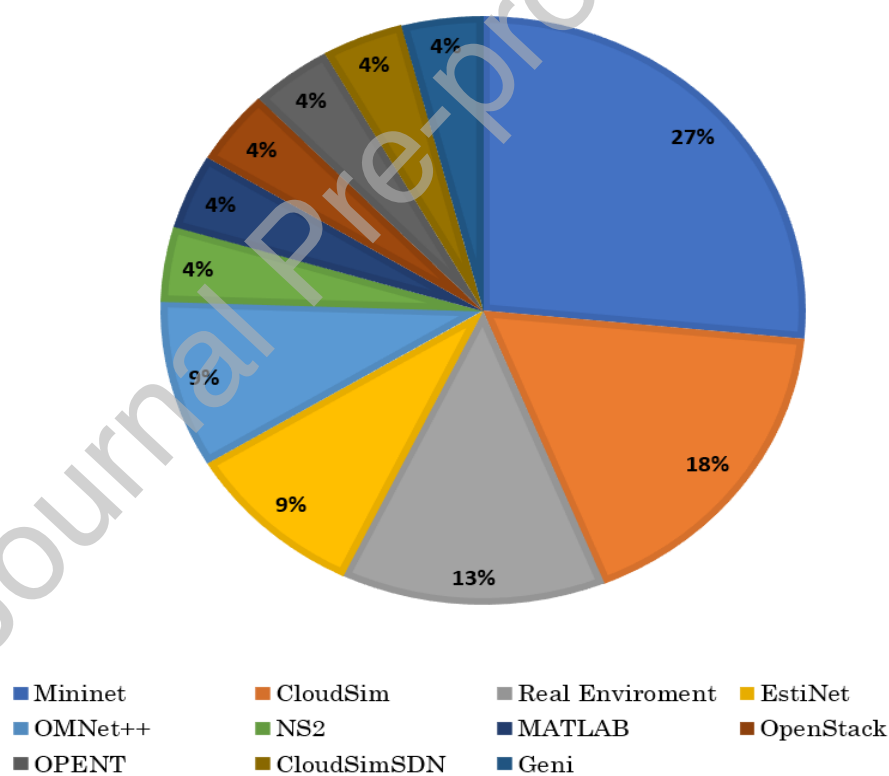


Figure 11: Types of Simulation used in Resource Allocation.

QoS parameters: Adaptation of SDNs within the cloud computing environment presents new challenges for physical switches and network topology. These points must be considered, including the measurement parameters to ensure the QoS within the cloud computing environment.

Virtual machines allocation: It is the process of placement and migrating a VM. This process is an important issue as it achieves efficient cloud resource scheduling. Although VMs allocations may cause the scarcest bandwidth network resources and congestion resulting from traffic dynamics in the network. Consolidation methods affect the performance and scarcity of resources. Furthermore, flow scheduling mechanisms disregard the specific QoS needed by each VM, which means that they specifically handle each VM's network resources. All these issues pose challenges

when allocating VMs and trade-offs to solve them. As most solutions are separately addressed, there must be a mechanism that works to trade-off the solution. Besides, future research needs to be stepped up in this process, which impacts the level of safety risk exposed to VM placement because each VM will have a various level of protection risk [161].

Energy optimization: The energy consumption resulted from network and computing resources is still very large, which negatively affects the total costs of the providers and the users, in addition to environmental pollution [162]. The use of more meta-heuristic algorithms helps to minimize the issue of ensuring the fulfilment of the SLA and energy-saving when taking into account that one is not influenced by the other.

Traffic engineering: The impact of traffic engineering issues in CC based on SDN can be found in [163] [164] [165] [166]. These studies only look at network traffic engineering; further research into the traffic or workload of VMs is required.

Resource billing: In cloud computing, it calculates the value of cloud services based on the community and the environment. It is important because the way resources are priced is concerned with distributing limited resources among different cloud users to optimize resource usage. It lowers cloud users' operating expenses while rising cloud providers' benefit and income by optimizing resource usage [167] [127] [168] [169].

Resource prediction: It is necessary for a collection of workloads running on VMs or PMs to predict the use of computing and network resources (such as CPU, storage, connection bandwidth, and so on) that are required to improve performance. It is also necessary for SLA to calculate the cost of resource use, decide which resource is appropriate for meeting SLA, and evaluate the resources needed [170] [171] [172] [173].

Heterogeneous Computing: To provide adequate computing capacity, a modern cloud data center includes many autonomous machines. These machines, on the other hand, may be fitted with a range of devices. Some devices, for instance, have highly powerful GPUs to process artificial intelligence applications, whereas others only have consumer CPUs. In the meantime, network topology might become heterogeneous [174]: Several devices use a gigabit Ethernet network, and others use a wireless mobile network [175] [176]. This inconsistency will obstruct system reliability and resource allocation significantly. As a result, coping with device heterogeneity is a key problem that requires more study for resource allocation mechanisms.

8. Conclusion

In recent years, the effective allocation of resources in the Cloud Data Center (CDC) has emerged as one of the main research issues. This study is aimed to explore and solve the resource allocation concept, which serves as a framework for further research on cloud computing based on SDN in the implementation of resource allocation strategies and to assist future researchers. We investigated resource allocation in Cloud Computing (CC) based on Software-defined Networks (SDN) analysis. We presented new taxonomies based on parameters, algorithms, and optimization techniques based on a comprehensive review of related techniques in literature based on their merits and drawbacks. We addressed the topic of CC in general, along with the related problems and issues that make SDNs to be suitable to be adapted to the CC environment. Moreover, we analyzed the pros and cons of the research allocation of resources mechanisms in two combinations filed and outlined open issues and potential directions.

Conflict of Interest

The authors declared that there is no conflict of interest among any authors.

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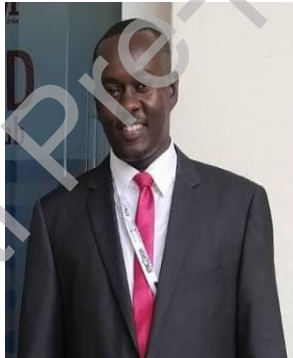
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ng research, focusing on multicore/manycore system-on-chip, network-on-chip, design space exploration, mapping, and prototyping of the homogeneous and heterogeneous manycore SoC.

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