International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

A Comparative Analysis of Cloud Computing and Fog Computing: Advancing Towards Edge Intelligence

Soumak Das

Student of MCA, Department of Computer Science, Academy of Technology, Adisaptagram

ABSTRACT

Cloud computing has altered the method we hoard, process, and access data, permitting ascendable and on-demand computing resources. However, with the rise of Internet of Things (IoT) devices and the cumulative prerequisite for real-time data dispensation, the margins of cloud computing in terms of latency, bandwidth, and network mobbing have developed superficial. To address these tasks, fog computing has occurred as a delay of cloud computing, fetching computation closer to the network superiority. In this article, we delve into a comprehensive comparison of cloud, fog, and edge computing. Moreover, the article highlights the systematic shift towards edge computing, where intelligence is distributed across edge devices, gateways, and fog nodes. To facilitate accurate evaluations and analyses, we introduce two simulation tools: CloudSiM for cloud computing and iFogSim for fog computing. These tools provide researchers with realistic environments to simulate cloud and fog computing scenarios, enabling performance evaluation and optimization. Through these simulations, researchers can study critical system of measurement such as response time, energy consumption, and resource utilization.

Keywords: Cloud computing, edge intelligence, Internet of Things (IoT),simulation tools, Fog computing, CloudSiM, iFogSim.

I. INTRODUCTION

Cloud computing has occurred as the dominant force in the area of massive processing capabilities, redefining how businesses manage their data and applications. Its origins may be traced back to the emergence of Cluster and Grid computing [1], with cloud computing gaining acceptance in recent years. It is important to memorandum that cloud computing, grid computing, and fog computing all fall under the wide-ranging umbrella of Distributed computing[2], each helping distinct purposes. By the side of the core of cloud computing lies virtualization[3], which forms the foundation for its scalability and flexibility. National Institute of Standards and Technology (NIST) [4] has outlined tetrad disposition representations for cloud computing: *Private, Public, Hybrid, Community*.

A private cloud, also known as an internal or corporate clouds, is exclusively used by private users or organizations. It confirms that only authorized individuals within the organization can admission the cloud services. Other, public cloud services are accessible to anyone globally, providing a platform for users from assorted backgrounds. A hybrid cloud, as the name suggests, syndicates elements of together private and public clouds, permitting organizations to control the benefits of together models. In the case of a community cloud, multiple organizations share the infrastructure, fostering collaboration and resource optimization.

In terms of service models, cloud computing can be measured into three major apparatuses: *Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS)*[5]. IaaS suggests virtualized infrastructure resources such as storage, networks, and servers on demand. PaaS offers a platform for inventors to build, test, and arrange applications, abolishing the need for widespread structure management. SaaS carries software applications over the internet, permitting handlers to admittance and exploit them without the prerequisite for installation or upkeep.

Cloud computing has turned out to be the go-to solution for organizations looking for powerful computational competencies. Its disposition models and service models, including private, public, hybrid, and community clouds, as well as IaaS, PaaS, and SaaS, provide a wide range of options to ensemble different requirements. Understanding these ideas is crucial for officialdoms aiming to influence the benefits of cloud computing and make well-versed decisions concerning their computing infrastructure.

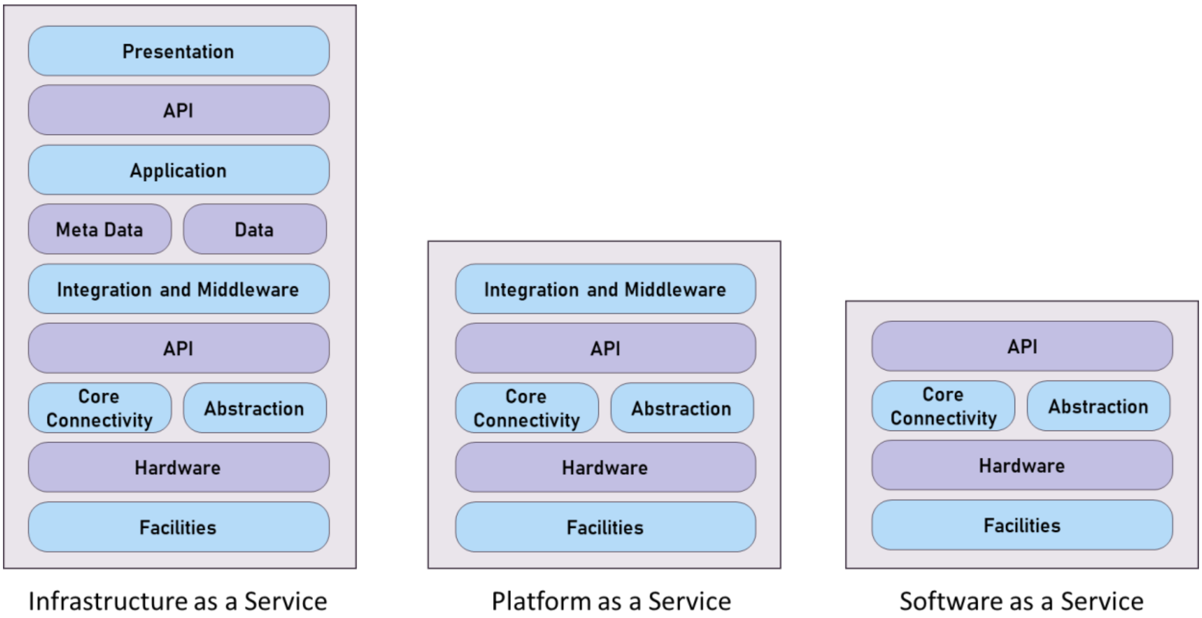

Figure 1: Service Models

II. Unlocking the Potential of Fog Computing

Fog computing has gained significance as postponement of cloud computing[6], driven by various compelling reasons. The invention of fog computing addresses critical issues encountered when dealing with IoT-generated data.One key factor is the time sensitivity of data generated by IoT devices. Quick and precise results are often required, with response times measured in milliseconds. Current cloud computing models are not optimized to handle the 3V characteristics [7](variety, velocity, volume) of the data generated by IoT devices. This limitation is particularly evident as IoT devices continuously generate data through sensors, which subsequently trigger actions by the device's actuators. In time-critical situations, where decisions must be made within seconds, cloud computing reductions short of meeting these requirements.

Latency reduction is a major challenge in cloud computing, especially in scenarios where fractions of a second can have life-saving implications. To overcome this, fog computing proposes giving out data nearer to the edge devices, minimizing latency and ensuring faster response times.

Another benefit of fog computing is the reduction in network bandwidth requirements. Transferring vast amounts of data produced by IoT devices to a centralized cloud data center demands substantial network connectivity. By leveraging fog computing, the burden on network bandwidth can be alleviated, reducing associated costs.

Data security is a substantial concern in cloud computing. Cloud data centers are geographically distributed, necessitating additional security measures to protect sensitive IoT data. In contrast, fog computing allows for localized processing on nearby distributed fog nodes, enabling enhanced data security and reducing the need for extensive encryption measures.

Host selection poses another challenge in cloud computing. In fog computing, sensor-generated data is directed to nearby fog nodes for processing, ensuring faster data processing. However, not all data is time-sensitive, and in such cases, transferring the data to the cloud for further breakdown and storage becomes necessary.

In summary, fog computing addresses critical drawbacks of cloud computing when dealing with IoT-generated data. It offers benefits such as reduced latency, minimized network bandwidth requirements, improved data security, and efficient host selection. By embracing fog computing, organizations can effectively harness the power of IoT devices and ensure timely and secure processing of data in diverse scenarios.

III. Edge Computing: Empowering Real-Time and Distributed Intelligence at the Network Edge

In recent years, edge computing[8] has occurred as a game-changer, fluctuating the archetype of data given out toward the network edge. Although the idea of edge computing comes first in cloud computing, its significance upsurged abruptly with the extensive adoption of Internet of Things (IoT) technology. According to experts, edge computing necessitates giving out data at the network's edge, either at bottom layer for cloud services or at the top layer for IoT services. The aim is to enhance cloud services by carrying processing competencies closer to data sources, specifically IoT devices.

Edge computing applications offer several notable features,[9] including the extension of cloud functionalities to the edge, decentralized frameworks, location besides context consciousness, low latency, mobility assistance, obtainability, high scalability. In industrial computing scenarios, the data is generated at client endpoints, such as user systems, while edging computing provisions servers and storage at the network edge to handle and analyze the data. This setup often requires dedicated infrastructure, housed in secure enclosures to protect against extreme temperatures and other environmental conditions. Data processing typically involves normalization and analysis, with only the relevant insights transmitted back to the central data center.

The assistances of edge computing are considerable and can address critical architectural challenges, such as latency, bandwidth limitations, and network traffic. Dominion is achieved by giving out data at the edge, falling the amount of data that wants to be conveyed over the network. Data independence is ensured as edge computing enables data to be stored closer to its source, mitigating privacy besides security concerns associated with data transfer across geographical and regional boundaries. Moreover, edge computing offers enhanced security at the edge itself, leveraging encryption techniques and providing robust protection against attacks and unauthorized activities, even in resource-constrained device environments.

IV. Exploring the Integrated Fog and Cloud Computing Framework for IoT Environments

Cloud and fog computing architectures exhibit certain similarities, with fog computing being an extension of cloud computing[10]. Figure 2 illustrates a combined architecture that integrates fog and cloud elements. In this architecture, the bottom layer is stated to as the edge layer, where multiple edge devices (IoT devices) are connected to the nearest fog node for immediate processing.

Above the edge layer lies the fog layer, which encompasses a small-scale data center offering cloud-like services to the edge layer. The fog layer serves as an aggregator, catering toward the service requirements of numerous edge devices. In situations where user tasks are extensive or demand significant computational resources, the fog layer acts as a transitional flanked by the cloud and users. Additionally, fog layer is responsible for delivering the processed results from the cloud back to the users.

The uppermost layer represents the cloud, with the data center serving as its backbone. Within the data center, multiple physical nodes or hosts exist, providing the necessary infrastructure for Virtual Machines (VMs). VMs are logical machines created to execute user-requested tasks. Computation primarily takes place within these VMs located within the data center. The allocation of specific tasks to particular VMs for processing is determined by the Datacenter Broker (DCB).

To summarize, the integrated fog and cloud architecture consists of the edge layer, fog layer, cloud layer. Edge layer connects IoT devices toward nearest fog nodes, while the fog layer acts as per an aggregator and intermediator between the cloud and users. The cloud layer encompasses the data center, housing physical nodes and VMs responsible for processing user tasks. The coordination and allocation of tasks within the cloud infrastructure are managed by the Datacenter Broker (DCB).

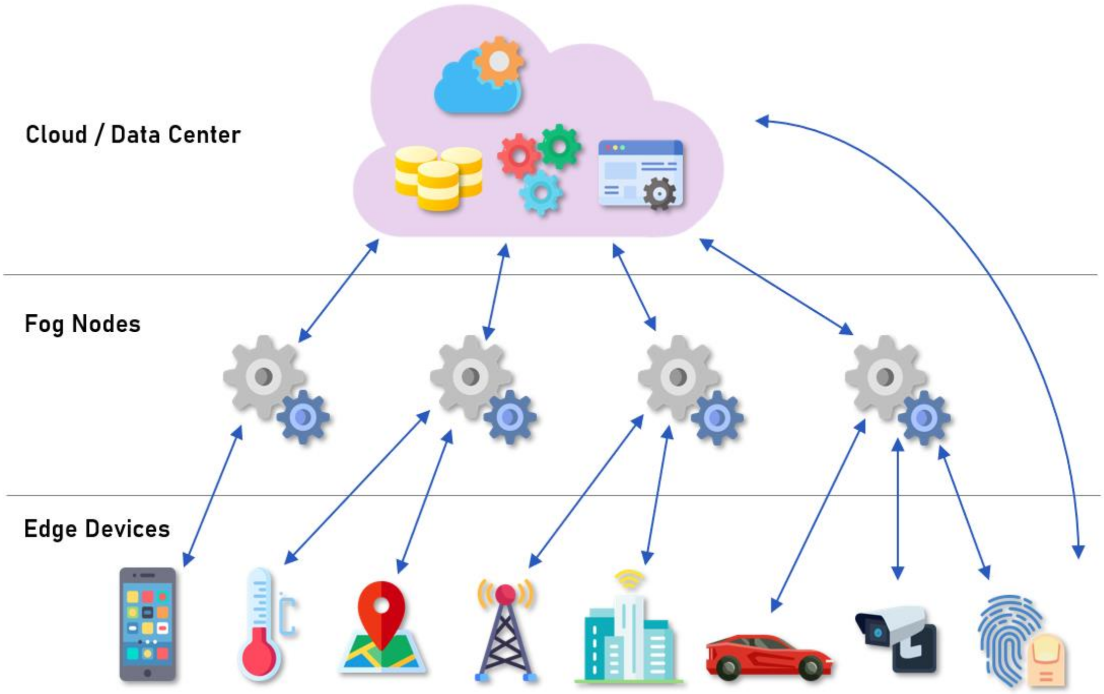

Figure 2: Cloud, Fog, Edge

Edge Devices: Found at the lowest layer of the fog computing architecture, edge devices play a crucial role. These devices primarily consist of time-sensitive IoT devices that require rapid data processing. Equipped with embedded processors, edge devices can perform data processing tasks locally, aiming to achieve results within milliseconds.

Fog Layer: Positioned above the edge devices, the fog layer serves as the upper layer in the architecture. Data is directed to the fog layer based on factors such as time sensitivity, required computation, and bandwidth dependencies. While the fog layer can handle a significant portion of data analysis, there are scenarios where additional assistance is required from the cloud layer. As a result, the fog layer acts as an intermediary between the fog and cloud components.[11]

Cloud Core: At the heart of the cloud computing archetype falsehoods the cloud core[12], encompassing data centers. Data centers assist as the backbone of the cloud infrastructure, only if a wide array of amenities such as computation, storage, infrastructure provisioning, platform provisioning, and software provisioning. Cloud services are characteristically presented under a "pay as you go" policy, permitting users to utilize resources based on their specific needs.

V. A Comparative Analysis: Cloud-Fog-Edge Computing in IoT Environments

In the following table, we illustrate the key variances among Cloud, fog computing, and Edge computing, shedding light on their distinct characteristics.

Topic	***Cloud Computing***	***Fog Computing***	***Edge Computing***
Data Processing	Over Internet	Data Managed at Fog Bulge	Closer to the source of data
Security	A lesser amount of Secured	Extra Secured	More Secured than Cloud
Response time	In Minutes	In Milliseconds	In seconds
Architecture	Unified	Dispersed	Dispersed
Communication	Long distance	Direct with fog node	On the verge of a device
Scope	Global	Limited	Depends on the type of applications
Latency	High	Low	Low

Table 1: Comparative Analysis between Cloud, Fog, and Edge

VI. Simulation Tools

Simulation plays a vital role in applied research, especially in the field of cloud computing where deploying a real data center for experimentation is prohibitively expensive. To overcome this challenge, researchers rely on simulators[13] to create a virtual environment that emulates the behavior of a data center.Among the available simulators, CloudSim stands out as a widely recognized and highly regarded tool for cloud-related research. It provides a realistic simulation environment for studying cloud computing scenarios. By using CloudSim, researchers can explore various aspects of cloud computing, such as resource provisioning, scheduling algorithms, and energy management, without the need for physical infrastructure.Similarly, in the context of fog and edge computing, simulators like iFogSim offer researchers the ability to model and analyze complex scenarios. iFogSim is an extension of the CloudSim project and offers a wide-ranging simulation platform for fog computing research. With iFogSim, researchers can examine the performance of fog computing architectures, analyze data giving out and communication patterns, and evaluate resource management strategies.These simulators are executed in JAVA and offer an extensive range of functionalities. They support multiple platforms, permitting researchers to behavior experiments on different operating systems. Additionally, these simulators provide sample datasets that simulate data generated by IoT devices, allowing researchers to evaluate the performance of their proposed solutions using realistic data.Given their widespread adoption and positive recommendations from numerous researchers, CloudSim and iFogSim[14] have become go-to simulators for conducting cloud and fog computing research. Researchers can leverage these simulators to design experiments, formulate problem statements, and validate their proposed algorithms and techniques in a controlled and cost-effective manner.

VII. Conclusion

While cloud computing remains a popular choice for storage and data processing, there is a growing trend among organizations to explore edge, fog computing for improved proficiency and computing power. The initial intention behind these infrastructure transformations was not to completely change cloud computing nevertheless rather distinguish critical information and processes from the main cloud infrastructure. Based on this study, it can be determined that fog computing is more suitable for organizations that heavily rely on data processing. On the other hand, edge computing is endorsed for middleware organizations that function as the backend of a network. This review aimed to compare fog computing, cloud computing, edge computing, and based on the findings, it suggests that fog computing can offer a more efficient alternative to traditional cloud computing. Looking ahead, the future scope of the research includes identifying the most appropriate computing environment for real-time applications. It is significant to deliberate the specific requirements and features of different applications and select the right computing infrastructure accordingly. By leveraging the strengths of fog computing, cloud computing, edge computing, organizations can optimize their operations and achieve better performance and efficiency in their computing processes.

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