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# THE CONVERGENCE AND SYNERGY OF FOG AND CLOUD COMPUTING FOR ENHANCED PERFORMANCE AND USER EXPERIENCE

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**Abstract**

Due to the rise in connected devices and the amount of data they produce, processing data in a centralized cloud is no longer a practical solution and will not be scalable to meet the Internet of Things (IoT) environment. From a different angle, some applications are latency-sensitive and require a quick response and minimal delay while moving data to and from the cloud. Therefore, fog computing developed as a way to expand the cloud computing architecture and shift some of the cloud's processing responsibilities to edge devices. This research presents a review study of fog computing in terms of architecture, discriminating features, benefits, and challenges. Moreover, it investigates the ability to replace cloud computing with fog computing in the future.

**Keywords:** Fog computing, Cloud computing, Internet of Things (IoT)

## 1. INTRODUCTION

The IoT, known as the next industrial revolution, has an impact on how companies and people interact with the real world. In addition, its applications grow exponentially. Currently, IoT contains devices that are connected to the Internet. These devices perform specific tasks such as collecting data that could be useful if analyzed and processed. Cloud computing could help by providing storage and processing services [1] [2]. Absolutely, IoT applications offer the possibility of improving quality of life, but the large volumes of data they generate present significant challenges for traditional methods and even cloud computing in terms of analyzing and processing effectively. For applications that require low latency and immediate response, where real-time performance is crucial, the data transfer process to the cloud server may take too long in cloud computing, which is unacceptable. Moreover, the inefficiency of storing excessive data in the cloud server for processing can have a negative impact on the scalability of network bandwidth. Moreover, Addressing the concerns regarding security and privacy in cloud computing is necessary. Fog computing is a promising solution to address these issues [1] [2]. Fog computing acts as an intermediate layer positioned between the edge of the network and the cloud layer [10]. It extends but has not replaced cloud computing by allowing some of the analyzing and processing tasks to be performed locally. Fog computing offers a resolution to the issues encountered in cloud computing by permitting decisions to be made at the network edge, eliminating the requirement to transfer data to the central cloud. The conceptual framework of fog computing architecture, depicted in Figure 1, illustrates the positioning of the fog computing layer as an intermediary between the cloud computing layer and the end devices. The fog nodes have dedicated interfaces for communicating with the cloud layer. The

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end devices are reliable, low-cost sensing devices used for monitoring purposes and generating data that need to be analyzed and processed. The distribution of computational processes across the fog layer and cloud layer varies based on their level of criticality.

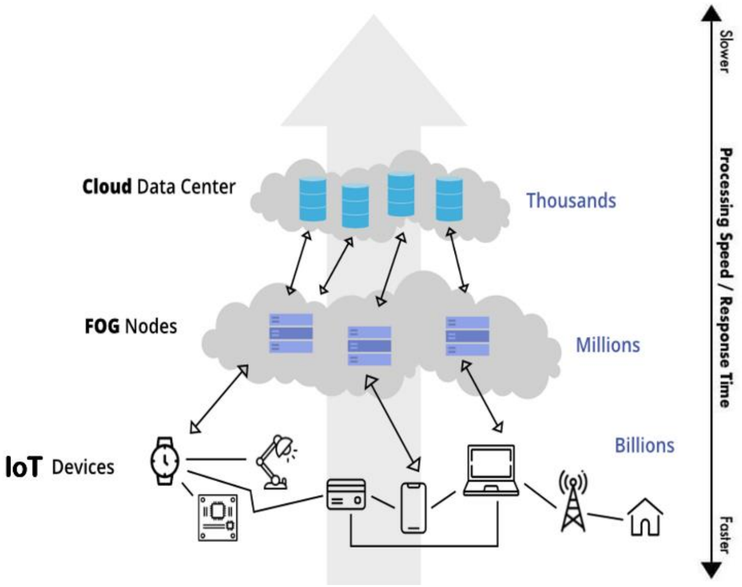


**Fig 1: Cloud and Fog Computing Layers**

The fog layer makes the computation for short-term processes that need real-time response and accurate location determination, while the cloud layer is responsible for handling complex and long-term computations.

This document is structured into three distinct sections, in section 1 we give the introduction that defines the two techniques. In section 2 we give a general view of related work, describe Fog computing and its attributes, and their applications with the challenges that fog computing faces. In section 3, we conclude our work and give our point of view about these two techniques.

## 2. BACKGROUND AND LITERATURE REVIEW

Several Comparative studies have been published to discuss fog computing technology and cloud computing with related issues. Table I shows a sample of these Comparatives with the main covered topics in their study.

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| Table 1: A comparative analysis between fog computing and cloud computing | | |
|---|---|---|
| **Article** | **Main Topic** | **Date** |
| **Kamruzaman, M. M. et.al [18]** | The main objective of the article was to provide a comprehensive evaluation of existing literature regarding the impact of the Internet of Things (IoT), blockchain technology, and fog computing on healthcare systems and practices within smart cities. | 2022 |
| **Sang-Bing Tsai.et.al [19]** | The study's goal is to gain important insights for addressing brand-new security problems that confront AI and fog in mobile edge computing. | 2021 |
| **Dheeraj Rane.et.al [20]** | The study compares virtualization security concepts for fog and cloud. | 2022 |
| **Kraemer et al. [5]** | Elaborate on the possible locations within the Internet of Things where these tasks can be performed. Analyze the tradeoffs involved in deciding the placement of computational tasks within the system. | 2017 |
| **Hu et al. [17]** | Provide a summary of the architecture, essential technologies, applications, and challenges associated with the fog computing model. | 2017 |
| **Mouradian et al. [10]** | Classified papers based on two dimensions: Architecture of fog computing and algorithms dimension. | 2017 |
| **Jaskaran Singh Saini et al. [20]** | The objective of the article is to delineate the legal challenges confronted by Cloud Service Providers (CSPs) and propose a policy strategy to address them | 2022 |
| **Gunjae Yoon et al. [21]** | A method for sensing data in a fog computing node is suggested by the study. | 2019 |
| **Jielin et al. [22]** | This article conducts a literature review on cloud computing, fog computing, and the Internet of Things (IoT). It examines the definition and characterization of both cloud and fog computing. | 2020 |

- **Fog computing**

Cisco Systems introduced the term "Fog Computing" as a novel model aimed at enabling wireless data transmission to decentralized devices within the network paradigm of the Internet of Things (IoT). Fog computing is a virtual platform positioned between end-user devices and the cloud data centers hosted on the Internet. [7]. Therefore, fog computing has the capability to enhance the quality of service by reducing delays, minimizing power consumption, and decreasing data traffic on the Internet. Numerous research investigations highlight the advantages associated with adopting a fog computing architecture. Presented below are the key advantages of fog computing:

**Low Latency:** When applying fog computing, the processing tasks are performed on fog devices that are physically closer to the sensors, which results in reducing the total latency.

**Privacy/Security:** In a device-to-cloud architecture, the cloud receives all of the sensor data that has been gathered. Implementing a fog computing architecture enhances data privacy by processing data at a local gateway instead of relying on a cloud server, thereby reducing the volume of transmitted data. Fog nodes can also serve as proxies that provide security services and carry out security functions including applying encryption techniques and detecting threats in real-time.

**Bandwidth:** Fog computing will increase the effectiveness of bandwidth utilization, as not all collected data is transmitted over the network to the cloud server, the implementation of a fog computing architecture reduces the need for data transmission. And a lot of users' requests are answered locally by fog nodes.

**Scalability:** Fog systems span across a multitude of IoT/end-user devices, encompassing a significant number of applications, fog domains, and fog nodes. So, Fog systems operate well at such large scales.

**Reliability:** The likelihood of transmission faults and packet-dropping issues would rise because the entire data set was transmitted to the cloud using a cloud-to-node architecture. Similar to the majority of health-related applications, these faults will be crucial in emergencies. When switching to fog architecture, all these problems will be resolved.

**Mobility support**: Direct communication with the edge in real-time scenarios is a distinctive and crucial feature of Fog that sets it apart from cloud computing. In many Fog applications, this capability plays a significant role. Fog computing also offers location awareness, enabling entities to accurately determine the whereabouts of the communicated edge. In the dynamic IoT environment, mobility becomes indispensable for entities to efficiently pursue diverse tasks.

**Location of Service:** In terms of the actual locations of these services, Fog computing uses smaller local devices like routers, switches, and other networking hardware, whereas cloud computing particularly refers to the storage of data on enormous server farms that are hosted by outside companies. As a result, Fog can provide quicker response times and more secure data management.

**Several Nodes:** With multiple smaller server clusters dispersed over the network, fog computing employs a far more distributed setup. Because of this, fog computing is far more resource-efficient than cloud computing, which leads to quicker communication rates and lower latency. [17]

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**Heterogeneity:**
Data generated within the Internet of Things (IoT) can stem from diverse sources, each exhibiting distinct characteristics. Efficiently managing the complexity of the generated data, alongside the diverse nature of the devices involved, calls for the implementation of innovative mechanisms that can appropriately store the data in the most suitable position. The Fog layer provides virtualized services on edge devices in a manner that ensures a seamless experience without discernible variations between different Fog nodes. For instance, when an edge device requests a data unit from its nearest Fog node, it is unconcerned about the specific storage location or the details of data transfer.

- **Cloud computing:**

Users can access computer resources including servers, storage, and apps over the internet using the cloud computing concept, which eliminates the need for on-premise infrastructure. The introduction of cloud computing has brought about a paradigm shift in how businesses function, offering an economical and scalable solution for data storage, processing, and analysis. Cloud computing architecture comprises three layers: the infrastructure layer, the platform layer, and the software layer. The infrastructure layer includes the physical resources, such as servers, storage devices, and networks that are used to provide computing services. The platform layer includes the software and tools that are used to develop and deploy applications in the cloud. The software layer includes the applications that are hosted in the cloud and accessed by users over the internet.
Cloud computing is implemented through four distinct approaches, namely public, private, community, and hybrid deployments. [4].

**Public cloud:** This type of cloud design is accessible to the general public and is created and maintained by government organizations, educational institutions, or businesses.

**Private cloud:** The public cloud is specifically designed and developed for private and the exclusive utilization of organizations such as educational institutions, businesses, and security agencies. Alternatively, it can be managed collectively by multiple organizations to cater to consumer needs

**Community cloud:** A community cloud denotes a cloud-based setting established and managed by a specific community to address their distinct business or security requirements. The maintenance of the community cloud is typically carried out by one or two designated groups, depending on the community involved.

**Hybrid cloud:** This framework relies on the combination of various cloud designs, including public, community, or private clouds, working together to enable the portability of computing resources, information, and applications.

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| Table 2: Comparison Between attributes of cloud and Fog computing | | |
|---|---|---|
| **Parameters** | **Cloud** | **Fog** |
| **Latency** | Distance from the data center may cause latency to be influenced | proximity to the data source results in lower latency |
| **Location** | In central data centers, resources are located. | Resources are distributed across the network |
| **Scalability** | When necessary, resources can be scaled up or down. | When necessary, resources can be scaled up or down. |
| **Cost** | Because it requires specialized hardware and software, the cost may be high. | As a result of the usage of generic hardware and software, it may be less expensive. |
| **Bandwidth** | Due to the necessity of transferring data over great distances, this could be higher | Since there is no need for long-distance data transfers, the cost is lower. |
| **Response time** | Due to the distance separating users and data, it could be slower. | faster as a result of the proximity of users and data |
| **Management** | Resource management is under the control of a central authority. | Management of resources is decentralized among distributed nodes within the network. |

Table II illustrates the distinction between cloud computing and fog computing. [2] [16].

- **Fog Computing Applications**

Numerous applications stand to gain advantages from the utilization of fog computing. Fog computing is a highly innovative technology that is still in its nascent stages, therefore there are not many real-world applications for it yet, and those that do tend to be in their early phase.[5] [8] [13]

**a) Healthcare applications**

Fog computing plays a vital role in enhancing the healthcare system as it introduces a dynamic architecture that reduces latencies and provides mobility support, resulting in improved real-time performance. Since IoT-healthcare devices continually generate vast amounts of data, storage, and security become issues. Cloud computing and Fog technology are emerging as the fundamental pillars for the effective functioning of healthcare systems. Cloud computing offers extensive storage and processing capabilities. Because of latency concerns, the cloud is not practical for real-time operations involving health wearables such as smartwatches that monitor blood sugar, heart rate, and blood pressure levels. Fog is the best platform for such operations. [9].

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**b) Smart Cities:**

Smart cities are one of the finest settings for the broad use of fog computing, as they generate heterogeneous data on a range of issues, such as traffic, public safety measures, waste management, air quality, and more, from tens of thousands to maybe even millions of linked devices. Fog computing enables rapid processing and analysis of vast amounts of data, this technology contributes to enhancing the effectiveness of these systems. [11]

**c) Wireless Sensors and Actuators Networks**

Wireless sensors and Actuator Networks (WSANs) built upon the foundation of fog computing combine the capabilities of sensor networks, and actuator networks, utilizing fog computing, intelligent data processing, and control can be facilitated at the network's edge. WSANs consist of many distributed wireless sensors and actuators that collaborate to monitor physical conditions, collect data, and perform localized actions in response to the sensed information. By incorporating fog computing, WSANs gain additional processing and decision-making capabilities closer to the data source. These applications primarily focus on gathering data related to weather updates, humidity, air quality, wave intensity, rainfall measurement, and providing alerts for droughts and floods.

- **Fog Computing Challenges**

**a) Security and privacy** concerns arise for fog computing devices due to their distributed nature, and lacking stringent protection measures. This exposes them to multiple security threats. So, devices become vulnerable to many types of attacks that could compromise the whole system. Cloud computing systems include many security solutions. However, these solutions will not work well in fog systems. Consequently, fog devices are exposed to a multitude of threats that are not present in cloud computing, such as man-in-the-middle attacks, authentication problems, denial-of-service (DOS) attacks, and access control.

**b) Reliability** Considering the extensive geographic distribution of devices involved in fog computing, ensuring reliability becomes a crucial factor to be taken into account during the design of fog systems. In order to establish a dependable fog computing system, it is essential to take into consideration the reliability of individual sensors, end-user devices, nodes, the application itself, and the network infrastructure. The existing reliability protocols for Wireless Sensor Networks (WSNs) can be employed, focusing on ensuring packet reliability and event reliability. [12].

**c) Programming Models**

When employing a cloud server, a programming language is used to carry out the computational activities. However, with fog computing, the computational operations are carried out in the various multi-platform fog nodes and user devices. Hence, there is a demand for a consolidated development framework specifically designed for fog computing. Computing is required. Additionally, fog systems need a dynamic setup to enable the frequent addition and removal of fog nodes (user devices).

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**d) Resource management**

The fog computing paradigm uses a variety of end-user devices (e.g., mobile devices) that have different types and do not have stable connectivity, and can leave or reconnect to the network at any time. These devices share diversified resources such as bandwidth, CPUs, and data. The challenge is in the mobility of end nodes, where resources should be allocated and deallocated dynamically.

**e) Power/energy management**

The power consumption in fog computing systems is higher than in cloud computing systems because the former consists of many distributed nodes. Hence, there is a necessity to innovate and introduce energy-saving protocols tailored for the fog computing paradigm, alongside the development of efficient communication protocols and network resource optimization techniques.

**f) Fault Tolerance:**

Fault tolerance refers to the ability to prevent data loss when a node experiences failures such as periodic restarts, shutdowns, depleted batteries, or overall system malfunctions. Various replication mechanisms have been suggested to accomplish this objective by duplicating data from one node to another, thereby guaranteeing the preservation of data integrity.[23]

In the context of Fog Computing, data loss can also pose a challenge for Fog nodes. One straightforward approach to address this issue is to duplicate all data in the Cloud. However, while the Cloud typically offers ample storage capabilities, there is still a limit to its capacity. Therefore, it becomes necessary to employ replication mechanisms not only between Fog nodes but also between Fog nodes and Cloud nodes when the need arises.

The presented in Table 3 highlight several challenges in fog computing along with their corresponding proposed solution.

**Table 3: Fog Computing Challenges And Proposed Solutions**

| | |
|---|---|
| **Challenge: Resource Management** | |
| **Lewis et al. [24]** | Offering resource allocation mechanisms for tactical cloudlets to facilitate offloading computational tasks from edge devices. |
| **Challenge: Security and Privacy** | |
| **Yi et al. [25]** | Introducing a survey of fog computing security and privacy issues, such as the problem of authentication and trust in the fog layer. |
| **Lee et al. [26]** | Proposing a hybrid intrusion detection system that uses anomaly detection in the cloud and a signature technique in the fog nodes. |
| **Dsouza et al. [17]** | Proposing a policy-driven resource access control, it used extensible Access Control Markup Language (XACML) to perform a user authentication process that depends on a set of attributes that represent the users and uniquely defined them. |

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| | |
|---|---|
| **Lu et al. [18]** | Introducing a privacy scheme referred to as Efficient and Privacy-Preserving Aggregation (EPPA) for smart grid communications. The scheme employs the Palliser cryptosystem technique, which leverages homomorphic encryption to safeguard users' privacy while minimizing computational overhead |
| **Challenge: Programming Models** | |
| **Maryam Sheikh Sofa et al. [26]** | Suggesting a dynamic Mobile Edge Computing (MEC) programming framework known as Cloud Aware, designed for offloading computational tasks to edge nodes and devices. This framework promotes the creation of scalable mobile applications that leverage edge computing, enabling reduced latency, accelerated computation, and energy and bandwidth savings |

## 3. CONCLUSION

Fog computing and cloud computing are complementary technologies, rather than direct replacements for one another. Both fog computing and cloud computing fulfill distinct purposes and possess individual strengths and weaknesses. Cloud computing involves the utilization of internet-based remote servers for the purpose of storing, managing, and processing data. It is ideal for applications that require large amounts of storage and processing power, as well as for applications that need to be accessed from anywhere in the world.

In contrast, fog computing, involves the use of local edge devices, such as routers, gateways, and sensors, to store, manage, and process data. Fog computing is well-suited for applications that demand real-time processing and minimal latency. Therefore, fog computing and cloud computing are complementary technologies that synergistically combine to offer a more efficient and all-encompassing computing solution.

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