International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 10 | Oct - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

# Fog Computing: A Systematic Review of Architecture, IoT Integration, Algorithms and Research Challenges with Insightsinto Cloud Computing Integration

**Ankit, Kartik, Priyanka, Gurashish, Sagar**
Department of Computer Science Engineering, Chandigarh University,Punjab, INDIA

***Abstract***

With the continuous evolution of technology, the prevalence of the Internet of Things (IoT) has grown significantly. However, with this rise comesa number of challenges for integrated Cloud Computing (CC), including security, performance, latency, and network issues.

Fortunately, Fog Computing is a solution that addresses these concerns by bringing CC closer to IoT devices. Essentially, fog serves as a data hub that processes and stores information locally on the fog node, rather than sending it to a cloud server. This results in faster response times and higher- quality services compared to those offered by traditional cloud servers.

Fog Computing can optimize service delivery for multiple IoT clients by allowing the administrationof services and resource provisioning outside of CC, nearer to devices, or at specific locations for Service Level Agreements (SLAs).

It's important to note that Fog Computing is not intended to replace CC, but rather to complement itas a critical component. In this paper, we explore various computing paradigms, examine the features and architecture of Fog Computing, analyze its relationship with IoT, and assess differentalgorithms used in Fog Computing systems. Furthermore, we tackle the distinctive challenges that emerge with Fog Computing as an intermediate layer between IoT sensors/devices and data centers.

*Keywords: Fog Computing, Internet of Things(IOT), Cloud Computing (CC).*

## Introduction

The 1970s saw the emergence of distributed systems, which consist of multiple autonomous computers that operate as a single entity, and were made possible by the advent of computer networks. This coordinated aggregation of distributed computers allows access to a large amount of computing power, making it an attractive option for high-performance computing tasks.

While peer-to-peer (P2P) networks emerged as one of the primary distributed systems, the use ofdistributed computing systems for high- performance computing has become popular over time. Despite the hype surrounding cloud computing in recent years, it has passed its peak of inflated expectations according to the Gartner Hype Cycle for Emerging Technologies 2013, and the trend in distributed systems is shifting towards newer computing paradigms.

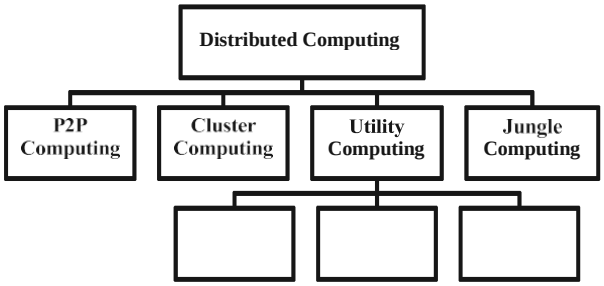


***Figure 1.*** *Distributed Computing Classification System*

As industries increasingly rely on intelligent devices and desktops to handle day-to-day tasks, large volumes of information are being generatedand stored consistently, leading to a growing interest in big data analytics. Variousorganizations are analyzing this data to extract meaningful insights and make crucial decisions.

Industries nowadays require a robust cloud-based infrastructure that provides pay-per-use, scalability, and accessibility. As everything is being migrated to the cloud, CC offersInfrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).However, the massive amount of data generated by millions of sensors, also known as Big Data, cannot be entirely processed and moved to the cloud due to latency issues. Additionally, some IoT applications require faster processing than what CC can provide.

To address this issue, Fog Computing ties together smart devices' processing power, located near the client, to facilitate networking, processing, and storage at the edge. The integration of fog computing with IoT helps reduce information transfer to CC for storage, analysis, processing, efficiency, and performance improvement. This way, sensor devices transmit the gathered information to network devices such as edge for temporary storage and processing, reducing latency and network traffic.

The convergence of IoT and Fog Computing presents a novel opportunity for creating services called Fog as a Service (FaaS). FaaS involves the deployment of multiple fog nodes by a service provider in different geographical locations. These nodes serve as hosts to various users from diverse verticals, with each node managing storage, computation, and networking resources.

Unlike CC, which relies on an integrated component, Fog is a completely distributedcomputing approach. By leveraging unused resources on devices located near the client, Fog can address the latency issue experienced in CC. However, it still relies on CC to perform critical tasks.

Fog Computing is a distributed computing approach that utilizes the computing capabilities of devices near clients, such as network device management, switches, base stations, routers, and smartphones. These devices have good computing capacity with several cores, albeit with less- features. They are installed with storage and computing power to act as fog computing devices.Due to the diverse organization and global connectivity, various research problems related to fog computing have emerged. The deployable environment and its requirements are critical issues in the fog computing principle, which has led to diverse computing schemes within the domain.

The main question that arises is how fog computing can handle novel challenges related tofailure handling and resource management in diverse domains. Therefore, it is crucial to examine the precise requirements of all interconnected features like services, simulations, fault tolerance, hosting issues, and resource administration to effectively address thesechallenges.

To guide our discussion in this research paper, wewill be presenting a brief overview of the focus and literature domains within the realm of Fog Computing, drawing from existing research conducted on this topic.

## Fog Computing

### Overview

Fog computing is a cutting-edge technology that expands the potential of cloud computing to the network's periphery. The fog computing environment is highly virtualized, providing networking, storage, and compute resources between outdated CC information centers, typically located at the network edge.

It consists of various edge nodes that have limited processing power and storage capacity, also known as "fog nodes. These fog nodes operate in conjunction with cloudlets, which are a combination of edge devices and servers designed

to participate in the shared computing environment within the network.

The main objective of fog computing is to reduce latency and improve application performance by allowing data to be processed at the point of collection rather than being transmitted to remotedata centers for processing.

This approach provides faster response times and

reduces bandwidth consumption. By using fog computing devices, clients can obtain real-time responses for latency-sensitive applications.

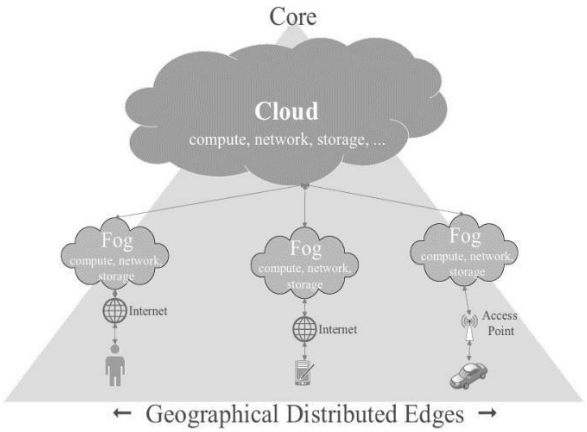


***Figure 2.*** *Fog Computing Diagram*

Although Cisco initially coined the term "fog computing," many researchers and industries defined it from various perspectives.

One definition describes fog computing as a geographically shared computing framework consisting of a pool of requirements that includes different universally linked heterogeneouscomputing devices at the network edge. This framework is not entirely supported by cloud services but collectively offers transmission,storage, and elastic computation in remote surroundings to an enormous scale of users in proximity.

Another definition of fog computing provides a system-level flat framework that separates storage, resources, computing services, and networking from every place along the range fromCloud to Things.

This spectrum of Fog Computing allows for the deployment of IoT (Internet of Things) devices,where a vast number of connected devices can generate a massive amount of data that needs tobe processed in real-time.

**Fog Computing Architecture**

Fog computing is a relatively new architectural approach that seeks to bring certain data center operations closer to the network edge. By doingso, it provides shared access to less storage, processing power, and service networks between end devices and cloud computing datacenters. The primary objective of fog computing is to offer reduced and predictable latency for Internet of Things (IoT) functions that are time-sensitive.

Over the years, various reference architectures have been developed by researchers in an attempt to understand the workings of fog computing better. These architectures are typically designed based on different topologies specific to user applications and services.

Several researchers, including Ranesh et al.,Aazam and Huh et al., Muntjir et al., and Mukherjee et al., have proposed a reference framework for fog computing. This framework comprises seven levels, namely virtualized andphysical, fog devices, servers, and gateway, monitoring, preprocessing and post-processing,storage and resource management, security, andapplication. Fig. 3 shows a layered architectureof fog comprising of these seven levels.

Each level in the fog framework is classified based on different applications, and theirimportance and usage in various applications areexplained. These levels work together to executetasks from IoT devices to fog nodes and then tothe cloud.

They focus on carrying out various tasks such as information management, data analysis, processing of data, categorizing of informationto cloud servers and fog servers, and other tasksbased on the services of the fog and cloud, andthe demands of applications from users.

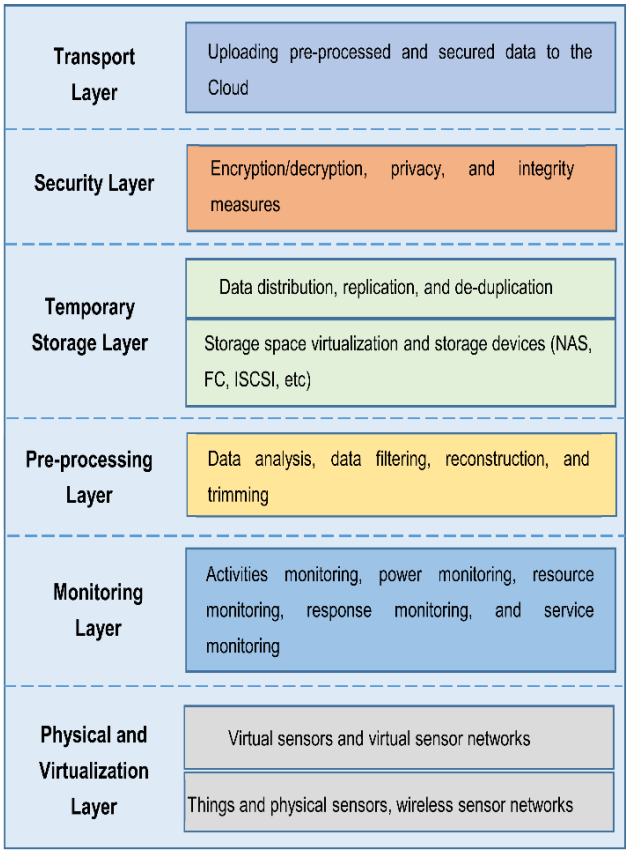


***Figure 3.*** *Fog Computing Architecture*

***Level 1: Physical and virtual sensors***

Sensors play a central role in generating data that supports Fog Computing. These sensors are foundin various devices, including intelligent homes and appliances, surveillance systems like CCTV and traffic monitoring, automated driving vehicles, humidity and temperature sensors, and more.

For instance, in an intelligent traffic surveillance system, continuous updates on traffic status must be obtained from various sensors and devices located along different routes, as well as roadside CCTV monitoring, to help manage traffic signals effectively. Gathering information from diverse GPS sensors is crucial to predicting future traffic requirements.

In the event of an incident such as a road accident, relying on one sensor alone may not provide enough information to determine whether it isnecessary to block the road or allow traffic to continue. Multiple lanes in a path could be affected by the incident while alternate paths could permit traffic movement to go on. This situation can reduce the ability of traffic management. However virtual sensors can provide instant resolutions for rerouting traffic, multiplexing, and road environments.

***Level 2: Fog device, server and gateway***

The use of a fog server, fog device, or gateway is common in both IoT and independent devices. However, it is important to note that the configuration of the fog server must be superior to that of the fog gateway and devices since it controls multiple fog devices. The successful functioning of a fog server involves various factors such as hardware configuration, network connectivity, and control over connected devices.

The role of the fog server is determined by its association with IoT components including a cluster of virtual and physical sensors linked to fog devices, which are further connected to the fog server. The fog server should possess advanced computation and storage capabilities compared to the fog device. A specific group of fog devices linked to the same server can communicate with each other when required. In some intelligent transport applications, computation may need to be performed on multiple servers and fog devices to generate accurate results.

At the device level, the fog server and fog devicesare responsible for controlling and maintaining software and hardware configuration, server and device network connectivity, and processing demands for various applications. The processing needs depend on the total number of devices linked to the IoT and fog devices, which are further connected to the fog servers. Communication between different fog servers is also managed at this level. For example, Cisco routers can be used as fog devices, and the Cisco information service of fog devices can function asthe fog edge server, handling the minimum amount of data storage.

In order to optimize data usage, frequently used ata is sent to the fog servers while rarely used data is stored in the cloud. In an application such as smart transportation, data is generated from multiple sensors, but storing all of it might not be practical. Depending on the requirements of the application,

data can be trimmed or the number of readings can be reduced without compromising accuracy. The data reconstructioncomponent ensures that incomplete or faulty data is reformed based on the available information pattern, preventing application failure and interruptions caused by sensorfailure.

***Level 3: Monitoring***

The monitoring level of a system keeps track ofits performance, resources, utility and feedback.When it comes to operating systems, monitoringfacilitates are chosen as relevant resources to ensure smooth operations, especially in scenarios where smart transportation is involved.

In such scenarios, resources availability may be negated for calculations or storage on fog devices or servers. To handle these situations, the devices and servers on the fog side access help from different peers, which are efficiently decided by the components of the system monitoring. The resource demand component audits present resources and predicts future onesbased on user activities and usage. This method ensures that any risky situation where failure could occur is handled properly.

Based on network load and resource availability,the prediction monitors signal the performance of the fog system, which is required to maintainthe required QoS attributes in SLAs. ConsistentSLA violations lead to increased system costs due to penalties, which can be minimized by performance prediction forecasting the usage and structure performance.

***Level 4: Pre and Post processing***

This stage focuses on analyzing both basic and advanced data, consisting of multiple components. Its primary function is to obtain data by using techniques such as analysis, filtering, trimming, and reconstruction.

Once the data is processed, the data flow component decides where it should be stored - either locally at the fog or in the cloud for extended periods. With fog computing, thechallenge lies in processing information at the edge while minimizing storage requirements. Thekey concept is to send frequently used data to fogservers and rarely used data to the cloud. In smarttransportation applications, sensor data generatesa large volume of information, which may not always be useful.

Depending on the application requirements, the average value of the data within a minute or houris often stored rather than the raw sensor data. Similarly, if the information values do not vary over a fixed period, the number of readings takenmay be reduced without affecting performance. Although this may affect accuracy slightly, it fulfills the application's requirements. Another component in this level involves data reconstruction, which addresses incomplete or faulty sensor-generated data. This component also reformats the information based on the pattern of information if sensors fail, preventing application failure and other disruptions.

***Level 5: Storage & Resource Management***

The storage module is responsible for utilizing storage virtualization to store data, while the data backup component ensures data availability and protects against data loss. Storage virtualization involves a network of devices acting as an individual storage device, which simplifies management and reduces storage complexity. This approach also reduces hardware and storagecosts, providing better enterprise functionality. Inthe event of storage failure, the data backup module customizes backup schemes periodically.

Resource management components allocate and schedule resources while addressing energy- saving issues. The reliability component maintains scheduling and resource allocation reliability, even during peak demand when calability is critical. Horizontal scalability is achieved on cloud platforms while fogenvironments aim to achieve both vertical and horizontal scalability. Resource allocation component performs necessary resourceallocation, de-allocation, and reallocation tasks in distributed resource scenarios.

Application scheduling components managemultiple applications running simultaneously in fog environments, prioritizing various objectivessuch as

energy efficiency and performance, managing resources efficiently to minimize operational costs. Finally, the reliability component focuses on maintaining measurement and metrics of reliability, including redundancy of data centers and fog nodes, mean time between fog node failures, andmeantime of critical failures of IoT applications. Fog computing systems are complex architectures that maintain IoT devices, fog nodes, fog servers, and clouds.

***Level 6: Security***

The level of security is responsible for all matters related to security, including communication encryption and secure information storage. It also safeguards the information of fog users. The proposal is for thefog environment to be installed as a utility system, similar to a cloud environment.

Unlike the cloud environment, where clients connect to the cloud for all services, in the fog environment, clients connect to the fog system for all services while the middleware in the fog manages and maintains all communications with the cloud. Therefore, authorization is required for users who want to associate with a service.

The validation component is responsible for providing authentication requests to all users in the fog to prevent intrusion by malicious users. Encryption between different communications is crucial to maintaining security and privacy, especially since most of the fog components areconnected wirelessly. User data should not be disclosed in the fog environment to maintain itsprivacy. Some smart city and smart house services have user-related data in their systems that should not be disclosed. However, in currentscenarios, users tend to accept most security policies without thoroughly reading them.

Therefore, it is essential to consider these types of services where the involvement of the privacy of the user is critical.

***Level 7: Application***

When fog was initially introduced for IoT applications, it gained considerable support from Wireless Sensor Network (WSN)-based applications. A significant number of applicationsthat were plagued by latency issues began toleverage the advantages of the fog environment.

These included various utility services that could integrate with fog to improve their service delivery and minimize costs. By adopting foginfrastructure, Augmented Reality-based systems can change the present world by catering to real- time processing requirements, thus leading to a prolonged improvement in the different services related to augmented reality.

**Fog Computing with IOT**

The current integrated CC framework is encountering various problems when it comes to Internet of Things (IoT) applications. For instance, time-sensitive requests like augmented reality, audiovisual streaming, and gaming cannot be catered to. Additionally, the framework lacks position responsiveness due to its integrated model. To address these issues, Fog Computing comes into play. Acting as a bridge between IoT,storage devices, and CC, fog computing can be seen as a part of the CC model that brings cloud computing closer to the network edge. It offers a highly virtualized prototype of processing, storage, and resource networking between cloud servers and end devices. In order to increase the efficiency of IoT requests, most of the data generated by these IoT devices must be transformed and analyzed in real-time. Fog Computing brings the processing, storage capacity, and cloud network to the network edgeto effectively tackle the real-time issue of IoT devices and deliver secure and efficient IoT requests. Notably, Fog Computing provides numerous applications and services with widely dispersed positioning. According to Cisco, Fog Computing offers a solution for theshortcomings faced by the integrated CC framework for IoT applications.

Fog Computing is a highly beneficial option forIoT applications that require instantaneous transmission, such as those involving linked vehicles. This innovative technology offers advantages to various other IoT requests, particularly those with less waiting time, like augmented reality, audiovisual streaming, and gaming. Fog Computing facilitates faster communication between IoT devices, reducing waiting times and enhancing the overall performance of time-sensitive requests.

Additionally, one of the key benefits of fog computing is its ability to support large-scale sensor networks. As depicted in Fig. 4, Fog Computing provides numerous advantages to different IoT applications, and several research articles have discussed the merging of IoT and Fog Computing in various applications. These studies cover various characteristics of fog computing, including a survey on CC and Fog Computing presented by Saharan et al., where they addressed the motivation and features of IoT applications for Fog Computing.

Similarly, S. Yi et al. presented a study on Fog Computing by discussing several application scenarios and potential concerns during implementation. S. Yi et al. examined the critical features of Fog Computing in healthcare schemes.

In N. Peter's article, Fog Computing and its capabilities in handling data generated by IoT devices are presented. The article highlights the issues of waiting time and congestion that can be efficiently managed by fog computing.

It also emphasizes that Fog Computing can help create a smart platform to control the decentralized and rapidly developing IoT setups, leading to the establishment of different business prototypes and prospects for network organizers at the edge network. M. Chiang et al. discuss the integration of IoT with fog, outlining the problems encountered while developing systems of IoT and how they can be addressed through a novel structure of networking, processing, and storage.

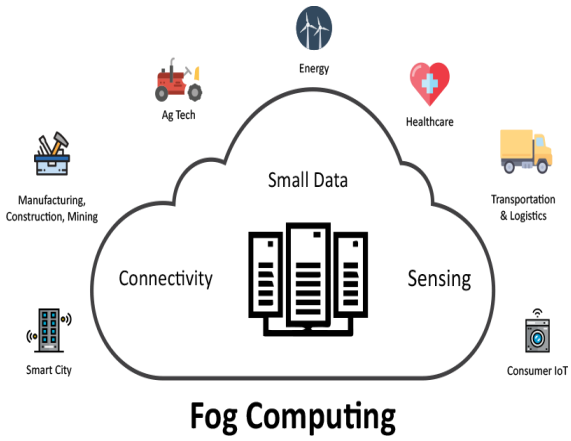


***Figure 4.*** *Implementing Fog Computing with IOT*

They also explore the features of Fog Computing,its merits, and potential solutions to various IoT issues. C. Puliafito et al. examine the problem of mobility backup in Fog Computing surroundingsin a cellular IoT scheme, defining three situationswhere flexibility support is vital. Dastjerdi et al. surveyed a reference framework prototype forFog Computing, emphasizing localization insteadof engaging the cloud. F. Bonomi et al. studied the integration of Fog with IoT, where they discussed vital features of fog and how it complements CC through the fog, delivering an application scenario for a wind farm with an

intelligent traffic light system. Aazam et al. provided a method for resource management utilizing Fog Computing, which uses the allocation and prediction of resources to control resources vividly and realistically. Finally, O. Skarlat et al. present the architecture of fog delivery resources, which formalizes an optimization problem to provide stalled responsiveness operation of available fog-based processing resources, leading to a reduction in latency compared to existing methods.

Researchers have conducted various studies on the proposed model of Fog Computing and its applicability to IoT devices. Bonomi et al. suggested that their prototype is an efficient method to support IoT devices with resource limitations, presenting three use cases to demonstrate its applicability.

Hong et al. surveyed Fog Mobile, which can allocate IoT applications through multiple devices in an ordered structure framework fromthe edge network to CC. Yousefpour et al. proposed a latency-reducing

method for fog nodes to model service latency, establishing a fog-to-fog transmission to minimize service latency by distributing the load. Gazis et al. identified the critical assisting technologies applicable to the fog paradigm, proposing an adaptive platform for operations for Fog Computing.

Alrawais et al. discussed safety and privacy issues in IoT surroundings and proposed a method for safety improvement that deploys the fog to enhance the delivery of certificate reversaldata amid IoT devices. Lee et al. examined the security threats associated with combining IoT and fog computing. Sookhak et al. surveyed fogvehicles to use the unexploited means of automobiles to influence Fog Computing.

Khan et al. recognized the safety problems of existing prototypes of fog computing. Stojmenovic et al. discussed the state-of-the-art of fog computing, focusing on the privacy and safety concerns of the present Fog Computing model.

Mahmud et al. argued a taxonomy of Fog Computing according to its characteristics and issues, examining the structure of the fog node, several parameters of fog computing, and networking devices of fog while highlighting thedifferences among mobile CC, edge computing, and fog computing.

**Features of Fog Computing**

Fog computing is an advancement of cloud computing that prioritizes the processing of data from Internet of Things (IoT) devices. It acts as amiddleman between the cloud and end devices, bringing computation, networking, and storage services closer to edge devices, also known as fognodes. These fog nodes are positioned wherever they can connect to a network and can be any device with computing, network connection, storage, and computing capabilities, such as routers, servers, switches, or surveillance cameras.

In essence, Fog computing is built on the fundamental blocks of cloud computing. The main characteristics of Fog Computing have beenidentified as follows:

- **Synchronous communication:** Fog computing requests for real-time communications that enable concurrent communication among fog nodes compared to the batch analysis employed in cloud computing.
- **Low-latency and Location-based:** Fog computing has the advantage of being closer to edge devices, resulting in reduced latency when computing the data of these devices. Furthermore, it enables position awareness, allowing fog nodes to be hosted in various locations for improved responsiveness.
- **Web-Enabled Analytics and Cloud Integration:** Fog computing is strategically placed between edge devices and the cloud to play a crucial role in capturing and computing data near the edge devices. It also provides web-based analytics capabilities and seamless integration with cloud services.
- **Heterogeneity:** Edge devices or fog nodes are created by multiple manufacturers, resulting in diverse configurations that require hosting based on their location. As aresult, Fog computing can be customized to operate on different platforms due to its adaptability.
- **Compatibility:** Fog modules have the ability to adjust and collaborate with various platforms provided by numerous service providers, enabling compatibility.
- **Physical distribution:** Unlike the centralized cloud, Fog computing offers decentralized applications and services that can be hosted in any physical location.
- **Adaptability:** Fog computing provides storage resources and distributed computing that can work with various extensive end devices, such as network sensors that monitor the local environment.

**Algorithms used in Fog System**

Fog systems algorithms refer to the various computational techniques used by fog computing systems to efficiently process and manage data atthe edge of the network. They are as follows:

***Data Compression Algorithm:***

Data compression algorithms are computational techniques that enable the compression of large amounts of data generated by IoT devices at the edge of the network. These algorithms work by removing redundant or unnecessary information from the data, resulting in a smaller and more compact file size.

Implementing these algorithms allows the transmission of compressed data over limited bandwidth networks, reducing the time and resources required for data transfer.Additionally, compressing data can be significantly reduce storage requirements, making it easier to store data on edge devices with limited storage capacity.

Various data compression algorithms have been developed, including lossless and lossy algorithms. Lossless algorithms are used when maintaining the original data quality is crucial while lossy algorithms are employed in caseswhere some loss of data quality is acceptable.

***Edge Analytics Algorithm:***

Edge analytics algorithms are a set of computational methods that empower fog computing nodes to conduct real-time analysis oflive data streaming from IoT devices. These algorithms are designed to operate at the edge of the network, where they can process data swiftly without requiring expensive cloud resources.

These algorithms can be utilized for various purposes, including predictive maintenance and anomaly detection. Predictive maintenance is a use case where these algorithms identify potential equipment failure before it happens, allowing for timely repairs or replacements. On the other hand, anomaly detection involves identifying patterns in the data that do not conform to expected norms, indicating potential security breaches or system malfunctions. The flexibility of this algorithmmakes them useful for a variety of scenarios, allowing businesses to make informed decisions based on real-time data insights.

***Load Balancing Algorithm:***

Load balancing algorithms play a vital role in optimizing the performance of fog computingsystems, these algorithms are designed to distribute workloads effectively across multiple fog nodes, ensuring the optimal utilization of resources and minimal latency. The main aim ofthis algorithm is to ensure that no single node is overloaded while others are underutilized. This approach enables fog nodes to handle more workloads efficiently, resulting in increased overall system performance.

There are various types of load-balancingalgorithms that can be employed in fog computing systems. Round-robin, Weighted Round Robin, Least Connections, and IP Hashing algorithms are some of the most commonly used ones.

**Research Challenges**

The domain of Fog computing has emerged as a viable and cost-effective alternative to Cloud Computing for supplying computational resourcesto customers. This is in response to the emerging trend of IoT devices such as sensors and smartphones, which have become increasingly affordable in terms of hardware costs. By performing computations at the edge of the network, it is possible to reduce computation requirements and data transfer expenses to the cloud, while simultaneously enhancing data security and privacy.

However, the practice of computing at the edge poses various difficulties related to networking, security, device compatibility, and the integrationof fog with IoT, all of which are currently under investigation. Fog computing operates in a distributed setting that takes into account a varietyof challenges.
This section provides a brief summary of the obstacles encountered while developing fog solutions.

***Challenge in managing request provisioning:***

The Fog paradigm is responsible for managing a vast number of IoT devices that have applicationsthat are periodically responsive or unresponsive. Due to the varying levels and nature of service availability within the Fog domain ensuring consistent service availability is a unique challenge.Further investigation is necessary to determine thefeasibility of implementing Fog based solutions.

***Challenge in managing request provisioning:***

The Fog paradigm is responsible for managing a vast number of IoT devices that have applicationsthat are periodically responsive or unresponsive. Due to the varying levels and nature of service availability within

the Fog domain, ensuring consistent service availability is a unique challenge.Further investigation is necessary to determine thefeasibility of implementing Fog-based solutions.

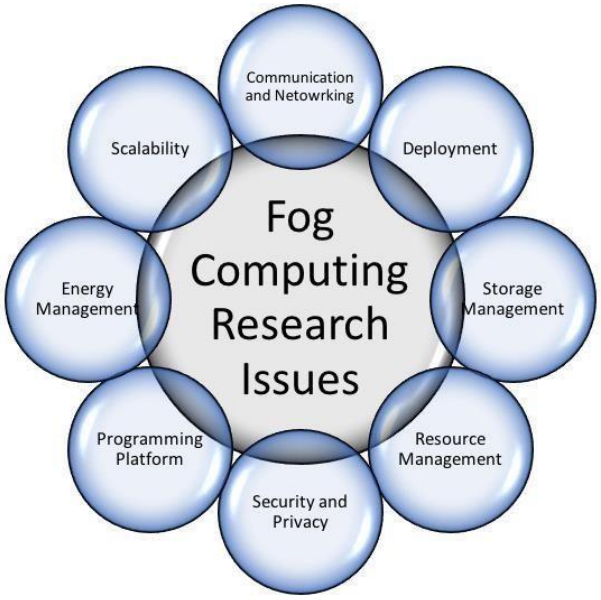


***Figure 4.*** *Research Challenges in Fog Computing*

***Challenge related to complexity:***

In the realm of Fog computing, there are a multitudeof sensors and IoT devices developed by various companies. Selecting the optimal mechanism has become increasingly challenging due to variations in hardware structure, software configuration, and individual requirements. Additionally, certain security applications require specific protocols and devices, which further complicates the process.

***Challenge related to security:***

The Fog Architecture is comprised of diverse devices that have varying susceptibilities to attacks. In the Fog environment, two primary concerns are data and network security, which can be influenced by factors outside the Fog andat cloud data centers. As the Fog's devices are deployed in an environment with lower levels ofsecurity, they are more susceptible to physical or vulnerable attacks. It is therefore imperative to ensure secure operation of devices at the edge ofthe Fog.

***Challenges involved in managing systems:***

Numerous system-level challenges pertaining toFog computing are discussed below, including service-oriented computing, resource management, and integration between Fog and cloud nodes.

***Computing based on services***

In the architecture of Fog computing, client services are divided into numerous small services that are spread across cloud and edge devices. This particular distribution of facilities over the Fog devices is a form of service- oriented computation via edge devices. However, conducting small services through Fog nodes has its own set of challenges. The primary challenge in the Fog computing field isorganizing the framework to acquire the appropriate services. There are several issues regarding small service management, such as implementation stages, service combination andplacement, and more. An appropriate composition structure is necessary to ensure swift delivery of these services to clients via the Fog architecture.

***Resource Management***

Fog computing is intended to be flexible and versatile, capable of handling various issues like resource scarcity and temporary failures.

A failure of a Fog node can lead to systemdowntime, making the resources from that node unavailable. However, in the Fog environment, these resources are virtualized. Properly managing challenges associated with resource virtualization such as migration, latency, initialization, etc., is critical to ensure that resources remain accessible during downtimes.

***Incorporation of Fog and cloud nodes:***

Another significant aspect is to offer end-to-end services from Fog nodes to the cloud, while providing Quality of Service (QoS) attributes tailored to different users based on their services. The Fog framework involves both cloud and edge devices. Orchestration of these heterogeneous edge devices, as well as management of the cloud architecture for

performing computation and storage in a distributed environment, must be addressed. Therefore, it is necessary to dynamically allocate resources for end-to-end integration between Fog devices and cloud servers.

- **Cloud Computing**

The Cloud is a widely distributed and parallel system that encompasses a communal pool of virtualized resources including servers, storage, applications, services, and networks hosted invast data centers.

*Figure 5. Cloud computing architecture*

These resources are easily provisioned and reconfigured through a pay-per-use economic model where the consumer is charged for the number of cloud services used, and the provider ensures Service Level Agreements (SLAs) via negotiations with consumers. Moreover, minimum management effort or service providerinteraction is required to lease or releaseresources rapidly. The user is abstracted from hardware management, and the infrastructurecapacity is highly scalable.

An overview of the Cloud computing architecture is presented in Figure 5. Its primary objective is to centralize computation and storage in data centers, where high-performancemachines are interconnected by high-bandwidthconnections, and all resources are efficiently managed. End-users initiate computations by making requests and receiving results.

- **Delivery Models**

Fog computing follows a decentralized model of computing that operates across various levels of network topology, similar to traditional cloud computing. The NIST Special Publication (SP) 800-145 specifies different service models for cloud computing that can also be utilized in fog computing.

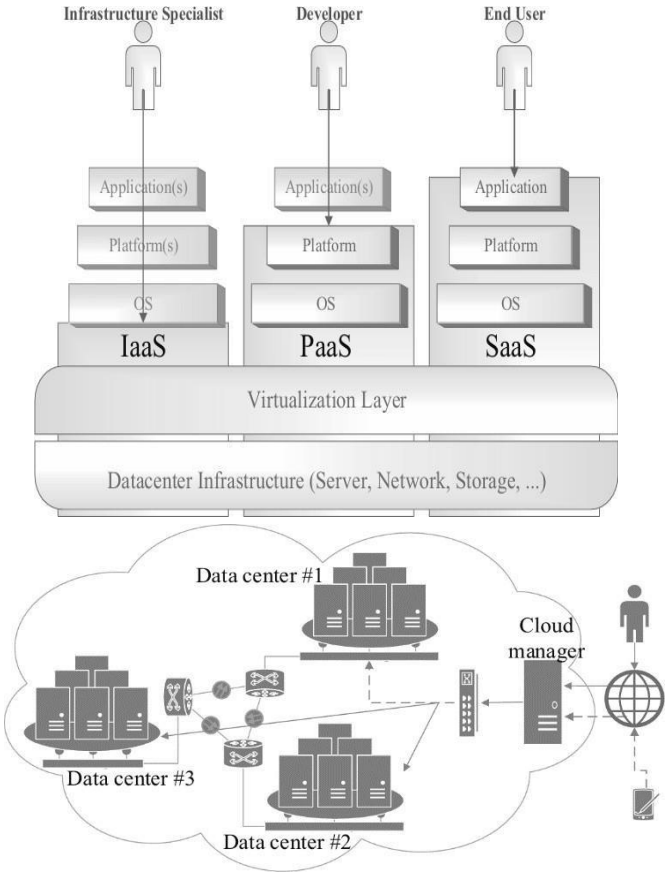


*Figure 6. Various Delivery Models*

### *4.1. Software as a Service (SaaS)*

Fog service customers are granted access to a cluster of federated fog nodes managed by the provider, which enables them to use the provider's applications. This type of service is comparable to Software as a Service (SaaS) in cloud computing and involves smart devices or end-devices accessing fog node applications via a program interface or thin client interface. The user is not responsible for managing or controlling the underlying infrastructure of the fog node, including storage, operating systems, servers, network, or individual application capabilities. However, the user may have limited control over specific application configurationsettings.

***Platform as a Service (PaaS)***

Fog service customers are granted a capability similar to Platform as a Service (PaaS) in cloud computing, allowing them to deploy their own custom or acquired applications using programming languages, libraries,

services, and tools supported by the fog service provider onto federated fog nodes forming a cluster.

Although the end-user has control over deployed applications and may configure application-hosting environments, they do not manage orcontrol the fog platform(s) and underlying infrastructure, including network, servers, operating systems, or storage.

***Infrastructure as a Service (IaaS)***

Fog service customers are provided with the ability to leverage federated fog nodes' infrastructure to provision vital computing resources like storage, networks, and processing power.

This feature is similar to IaaS services in cloud computing and enables customers to deploy and run any software, including operating systems and applications.

However, the end-user does not manage or control the underlying infrastructure of the fog node cluster but retains control over deployed applications, storage, and operating systems while having limited control over selectnetworking components like host firewalls.

5. Fog vs Cloud Computing

We focused on the comparison of fog computing and cloud computing, discovering a number ofscenarios where fog computing outperforms itscounterpart. The main advantage of fog computing lies in its capability to process real- time data promptly and accurately. In situations where speed and accuracy are crucial such as in autonomous vehicles or medical monitoring systems, fog computing can be an absolute game-changer.

“For example, imagine a self-driving car that relies on cloud computing to analyze sensor data and make decisions. Due to the latency intransmitting data to and from the cloud, the vehicle might not be able to make split-second decisions when encountering unexpected road hazards. However, with fog computing, the vehicle could process data locally and respond immediately, significantly reducing the risk of accidents.”

Another significant advantage of fog computing isits low-latency communication abilities. In industrial automation, it's vital that communication between machines happens quickly and reliably. With fog computing, devices can communicate directly with each other, reducing the need for centralized data centers and minimizing potential latency issues.

“For instance, consider a manufacturing plant that relies on cloud computing to monitor its machinery. If there were delays in transmittingdata to the cloud and back, it could negatively impact the efficiency of the plant. However, if the plant utilized fog computing, the machines could communicate directly with each other, allowingfor faster and more efficient decision-making.”

It is critical to acknowledge that while cloud computing remains vital for data storage and accessibility, fog computing provides a superior solution in specific use cases. Understanding the strengths and weaknesses of both technologies will allow organizations to make informed decisions about which option best suits their needs.

| LETTER | COMMENT |
|---|---|
| T | Multi-tiered access organization. |
| H | Cloud-enabled hierarchical management. |
| E | Expanded mobility model |
| G | Locality-focused geo-distributed computing |
| R | Real-time tiered analytics |
| O | Multi-tier orchestration. |
| U | Consolidated virtual resource exposure. |
| N | Negligible latency |
| D | Distributed multi-tier policy management. |

***Figure 7. Fog Computing vs Cloud Computing***

**Acknowledgments**

The authors would like to express their gratitude to the various publishers whose research papers have been Instrumental in shaping this work.

- Naha, R. K., Garg, S., & Chan, A. (2018). Fog Computing Architecture: Survey and Challenges. https://doi.org/10.1049/PBPC025E_ch10
- Iorga, M., Feldman, L., Barton, R., Martin, M. J., Goren, N., & Mahmoudi, C. (2018). Fog computing conceptual model.
- Sabireen, H., & Neelanarayanan, V. (2021). A Review on Fog Computing: Architecture, Fog with IoT, Algorithms and Research Challenges. *ICT Express*, *7*(2), 162–176. https://doi.org/10.1016/j.icte.2021.05.004
- G. R. ANDREWS, Foundations of Multithreaded, Parallel, and Distributed Programming. Addison Wesley, 1999
- M.ARMBRUST,A.FOX,R.GRIFFIT H,A.D.JOSEPH, R. H. KATZ,A.KONWINSKI,M.ZAHARIA, Above the Clouds: A Berkeley View of Cloud Comput ing. EECS Department, University of California, Berkeley, 2009.
- A, Security Guidancefor Critical Areas of Focus in CloudComputingV2.1..CloudSecurityAlliance, 2009**.**
- FORREST,ClearingtheAironCloud Computing. McKinsey & Company,2009.
- P. MELL,T.GRANCE, The NISTDefinition of Cloud Computing. Information Technology Laboratory: National
- R. V. NIEUWPOORT,T.KIELMANN,H.E.BAL,User friendly and reliable grid computing based on im perfect middleware. Proceedings of the ACM/IEEE Conference on Supercomputing, (2007) Reno, Nevada, USA.