Fog Computing Architecture, Application and Resource Allocation: A Review

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Abstract
Fog Computing, may be considered as Edge Computing which expands Cloud Computing model while improving efficiency, and lowers latency. Fog computing is used to keep up day by day growing need of IT related services with the alliance of cloud computing. Having fast development of IT, the fog computing is arising as an appealing solution for retrieval and transformation of the data related to IoT applications. This paper discusses the concept, architecture of fog computing and its implementation with the existing and new applications. Fog devices are very complex and heterogeneous. The resource allocation problem is one of the core challenges in running the IoT application in the Fog area. The goal of this paper is to examine recent work on the allocation of resources in the fog area. The rationale of this survey is to realize the application of fog computing and make some improvements in the existing technology. This study will help researchers to understand and utilize technology better.

Keywords 1
Fog Computing, Cloud Computing, Resource Allocation

1. Introduction

Nowadays, a large number of device objects are attached to the Internet to capture and exchange data from the real world, which brings the new idea of the Internet of Things (IoT). As stated by Gartner, around fifty percent of the Internet of Things (IoT) study that is related with industry will be carried out at the edge by 2022. [1]. According to an estimation that about 50 billion appliances may get linked to the IoT network by 2022[2][3]. This gives an idea that future computation will require a new and savvy edge computing foundation. Earlier, Mobile cloud computing (MCC) was broadly utilized to deal with tasks that require high efficiency, due to its large computation and storage assets to appease the fast increasing and changing need from distant cloud data centers [4]. Nevertheless, it is not easy to deliver relying efficiency for IoT devices which are delay sensitive at the end of the network because of the considerable interval between arbitrarily scattered terminal devices and distant cloud data centers. As a response, the concerns of energy consumption, heavy load, delay, congestion, and unreliable wireless connections may be unavoidable, which would restrict cloud computing growth [5]. Edge computing, therefore came into the existence to control the limitations of cloud computing. In contrast to conventional cloud computing an Edge computing offers data offloading services which is distributed and its near-to-terminal, which may enhance the accuracy of service and decrease the latent period. It has recently come out as a feasible solution to coordinate the network architecture which is currently existing and new network Architecture using large amounts of pliable fog deployed Nodes (FNs) for mutual offloading of tasks from the IoT systems nearby.

WCNC-2021: Workshop on Computer Networks & Communications, May 01, 2021, Chennai, India.
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The goal of fog computing in IOT is, boosting its abilities and performance while decreasing the scale of data transmitted for collection, storage and analysis too. The data obtained by the sensors is transmitted to the edge appliances instead of being sent to the server, thereby reducing network traffic and latency. A new framework for services is provided via Fog computing incorporation with the IOT, This is classified as Fog as a Service (FaaS), in which supplier of the service creates the fog nodes array around its geographical footprint and functions as a distributor for many who require different services.

Each node of the fog hosts capabilities for local computation, networking and storage. All the fog computing resources are referred to as the entangled fog nodes through the Internet to the edge network.

2. Contribution of this paper

In this research analysis, we tend to examine different resource allocation techniques and its infrastructure that powers the components and server's devices. The remaining part of the paper is outlined as follows: In Section 2 it defines the related work done in the resource allocation technique. Section 3 provides the background and definition of key terms used, it explains the key difference in both the technologies that is Fog and Cloud Computing while discussing characteristics of Fog Computing and its architecture and deployment models. It also presents taxonomy of Fog Computing. Section 4 discusses related computing model and their differences. Section 5 discusses application of Fog Computing. Finally, section 6 discusses different resource allocation techniques used by researchers and presents their comparison.

2.1. Related Work

The instruments of cloud computing / Fog computing and resources of it may be either tangible resources or virtual resources. The issue of resource allocation is a complex task in a Fog environment. It determines the right task distribution, given in to be done on the fog junctions or nodes to satisfy the QoS, at the side or edge of the network. Some criteria, such as latency, performance, energy use reduction, cost allocation minimization and response time, must be viewed as the product of any optimal resource allocation strategy. There are several experiments and studies of cloud/fog computing on resource distribution [6] suggest a presumptive resource allocation model in which jobs come in accordance with a stochastic process and call a number of virtual machines. To guarantee the user's experience with the resource request, after a resource request has been sent by the user, a decision on the allocation of the resource must be taken in due time to position the VM on the server responding to this request, that involves making VM placement decisions without any potential information upon the delivery of the resource request. To take better advantage of a server's multi-resource capability and reduce the total number of active servers, VM placement should be developed. Some approaches proposes the idea of offline VM placement problem. Stillwell et al [7] introduced algorithms to delegate different types of resources for engaging services Working with virtual machines on distributed, diverse systems. The key result of their input is, what he proposed as vector packing methods in a homogenous case can be generalized to deliver valued solutions in a diversified case and merged to support a single, effective algorithm. The online VM placement issue is taken into account by a few other strategies. Tang et al. [8]used heuristic algorithm to achieve high resource utilization. But this couldn't achieve optimal resource utilization. Authors in [9] established an algorithm which is based on a predictive control model for resource allocation. This model establishes the future workload depending on a restricted horizon and addresses the problems of autoscaling in the cloud. Chandra et al. [10] suggested a system architecture that integrates the properties of the workload and the current state of the system with estimation and resource allocation techniques. The strategies for dynamic allocation of resources on public web servers were discussed. The key objective of their strategies is to respond to temporary system overburden by integrating online system frameworks.

In [11] authors used non-pre-emptive technique for load balance to schedule VM configurations. Offloading decision making and Resource allocation for energy conservation.

2.2. Background and Definition

Fog Computing [12], can also be identified as Edge Computing which expands the Cloud Computing model while improving efficiency, and lowers latency. It also improves location consciousness and assures better support for portability. As a result of this, business capabilities increases. The word first used by Cisco, It means that, instead of working on a centralized Cloud environment, it works at the end of the network. This is done by adding some intelligence, processes, and resources at the boundary of the Cloud, instead of initiating channels for Cloud storage and utilization. Fog computing technology disseminates the assets and services attached to the communication storage near to gadgets or close to the users. A fog computing paradigm analyses and runs applications on anything from the network center to the edge -wherever it is required. It is a process of extending computation and storage services almost immediately and near to the physical devices of an organization or at the boundary of the Cloud network. It is also a technique through internet can be bypassed, whose speeds are more often depends on bandwidth and carriers [13]. Because of the highly variable and unpredictable fog environment, resource management is the difficult problems in the fog landscape that need to be taken into account.

3. Dissimilarities of Cloud Computing and Fog Computing

The amount of information is on the rise in overall networking. To deal with this, services such as cloud storage and cloud computing are used to handle and distribute data easily to end users. However, fog computing is a more feasible option for handling high levels of security updates and reducing bandwidth issues. Table1 shows the dissimilarities between the two technologies.

Table 1: Differences between Cloud Computing and Fog Computing

FEATURE	CLOUD COMPUTING	FOG COMPUTING
Delay time	It is of enhanced latency	It is of less latency
Geographic Distribution	It's centralized.	It's distributed and decentralized.
Awareness of Location	Moderately Supported	completely Supported
Number of Server Nodes	Less server nodes.	High number of server nodes attached
Security	It's less secured than Fog Computing	Fog computing is of high security
Mobility	limited mobility	Mobility is provided by fog computing.
Speed	Access speed is fast and it depends on the VM connectivity.	Higher than Cloud Computing.
Power source	Power source Battery as well as direct power	Power source Battery/Direct power/Green
Failure management	Failure management Strong (VMs can be easily migrated from one node to other) Rescheduling of failed tasks	Failure management Strong (Solid (VMs can be quickly migrated from one node to another) Rescheduling of failed tasks

4. Taxonomy of Fog Computing

Qureshi et al. [40] has given the taxonomy of Fog Computing focused on platform specifications application, technology.

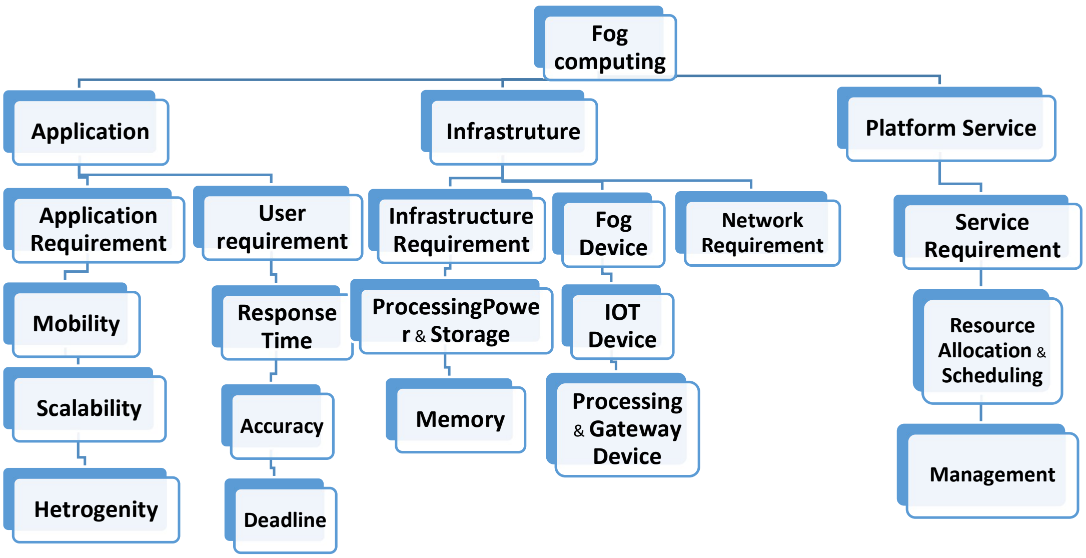

Figure 1: Taxonomy of Fog Computing [40]

4.1. Characterization of Fog Computing

It's basically an augmentation of the cloud, but similar to the stuff which functions with IoT Data. As seen in Figure 1 above, fog computing serves as mediator linking cloud and end devices, bringing storage and networking resources and processing closer to the end devices respectively. It provides less latency and location awareness due to the localization of fog nodes. It provides a dynamically virtualized interface services for storage, computing and networking between end computers and typical data centers for Cloud Computing. It has following characteristics [14]

- Low latency- fog nodes are near to the devices attached that makes response time very less and data processing faster. It supports awareness of locations in which fog In various locations, nodes can be installed.
- Mobility- Because of the state forward communication between fog and devices it provides better mobility
- Real-time Interaction - Because of the closeness of devices and fog nodes interactions may occur in real time not like batch processing in case of cloud computing.
- Geographical distribution- For computing works in a distributed environment so it is quick in delivering high quality streaming services. The essence of fog computing is because of lack of aid with Quality Services at the end of network [15]
- Protection and Privacy-Because the data contains subtle information, IoT has a critical role in defense Of that kind of detailsTo ensure defense from cyber hackers. It hase its own security implementation. [16]

Content caching-content caching in fog platform is a technique to reduce network traffic and improve response time by caching

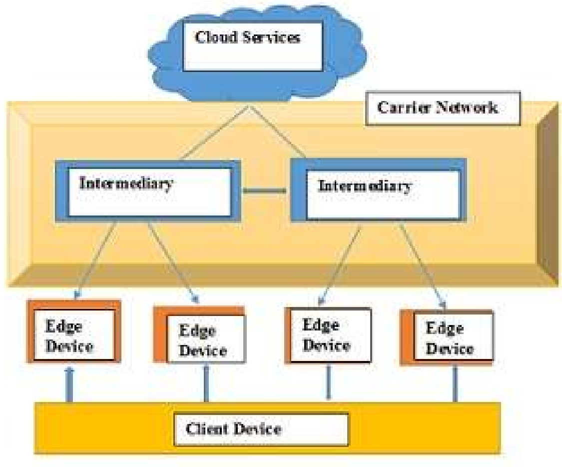

Figure 2: Fog Computing is an extention to cloud

4.2. Architecture of Fog Computing

It is a connection between edge devices and the cloud. It's a combination of devices connected at edge and cloud. Three-layered architecture is very common architecture. The layers are discussed below

Layer 1: This is lowermost level which consists of all IoT devices they are capable of storing and transmitting raw data to its upper layer
Layer 2: The middle layer consists of different network devices like routers, switches which can process and temporarily store information. These devices are linked to the cloud network and keep sending data to the cloud at the regular intervals.
Layer 3: The uppermost layer has many servers and data centers. which are capable of storing a high amount of data and have capacity to process it too.

Layered Architecture for Fog Computing

As per Mukherjee et al. [17], The architecture is made up of six layers. — Virtualization and physical, control etc. Temporary storage, defense and transport layers—as seen in Figure 3.

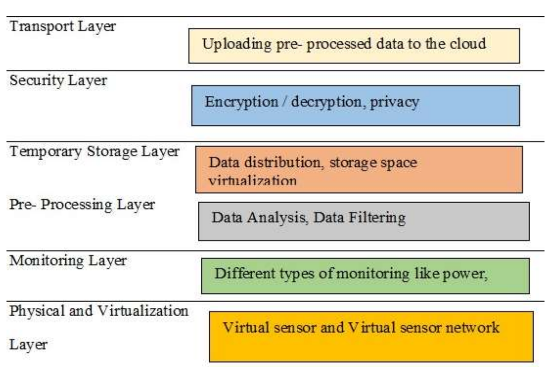

Figure 3: Architecture of Fog Computing

The very first layer which is physical and virtualization includes multipule catogries of nodes, like physical nodes and virtual nodes. Various kinds of sensors are categorized to moniter the environment and transfer the acquired data to the higher layers through gateways for more preparation and refining. Monitoring layer controls the task which is requested and keep tracks of energy usage concerns of the fundamental physical devices. Preprocessing layer controls task related with the Data management like filtering and trimming. The temporary storage layer holds the Data for a short duration only. The security layer is concerned with the encryption/decryption of data. Additionaly, data integrity steps are also implemented to defend them from tampering. At the end, in the transport layer, previously-processed data is submitted to the cloud to make the cloud able to retrieve and generate more valuable data [17].

4.3. Fog Deployment Models

We may distinguish fog models based on the ownership of the fog infrastructure and underlying properties. We have four different types of fog models.

- Private fog: A private fog is developed, purchased, maintained and controlled by an entity, a third entity or a variation thereof. It can be installed on or off-site. Private fog services are sold for absolute use by a single company.
- Public fog: A public fog is owned, developed, and managed by, or a combination of, a corporation, academic institution or government organization. It is deployed on the premises of the fog suppliers. Public fog services are provided for open access by the common or general public.
- Community fog: Community fog is developed, maintained and controlled by different community organizations, which may include a third party too, or a consolidation of them. It can be installed on or off-premises and services are provided for exclusive use, typically by customers in a particular group of organizations with common interests.
- Hybrid fog: Hybrid fog is a type of cloud computing that incorporates the use of public/private/community fog with public/private cloud computing (i.e., hybrid cloud). It may be helpful due to the disadvantages of the physical resources in the fog. As a result, the platform is applied to the hybrid cloud to scale performance. The hybrid cloud is flexible, modular, and services are accessible on demand.

4.4. Disadvantages of Fog Computing

- Complexity: Different modules from both the edge and the central network can make use of a possible Fog computing framework. Usually, these modules are Equipped with different types of processors but not us ed for general purpose computation. Owing to its ambiguity, it can be difficult to grasp the principle of Fog computing. There are several computers placed at various locations that store and evaluate their own data collection. This could bring more complexity to the network. In addition, more advanced fog nodes exist in the fog infrastructure.
- Security: Authentic entry to services and privacy in Fog computing are difficult to ensure. There are various devices and different fog nodes in the fog computing environment. These fog nodes are likely to be in a less secure environment. Hackers can conveniently use bogus IP addresses to obtain access to the corresponding fog node.
- Power Consumption: There are many fog nodes available in the fog environment that is directly proportional to their energy consumption. That implies that these fog nodes need a high volume of energy to work. If the fog infrastructure requires more fog nodes, there is even more power usage.
- Authentication: The service delivered by fog computing is on a wide scale. Fog networking is made up of end-users, Internet service providers, and cloud providers. This will also pose concerns about trust and authentication in the fog.

5. Related Computing Models

There are many similar computing models similar to Fog computing exist such as Edge computing, Dew computing, Mobile Edge Computing (MEC), Mobile Cloud Computing (MCC). In Cloud computing, there are many IoT appliances or devices attached face to face to the cloud and computing relies entirely on the cloud.

- **Mobile Cloud Computing**: Mobile cloud computing makes use of cloud computing to provide services or required applications to mobile devices. This mobile application can be implemented far away using pace, mobility and development software. MCC Overcomes computing, energy, and storage capacity Restriction on smart mobile devices. At the edge of the network, Cloudlet is used to solve these problems [19]. It increases the durability and reliability of cloud-backed and stored content.
- **Mobile Edge Computing**: It enlarges the effectiveness of cloud computing by taking it to the edge of the network. Whereas conventional cloud computing takes place on remote servers located far from users and computers, MEC allows processes to take place at base stations, central offices and other aggregation points on the network. MEC supports the co-location of storage and computation Resources at cellular network base stations. According to Klas [18], The development of mobile base stations is the MEC. Various services could be offered by this technique, including IoT, caching, location services, video analytics, and local Distribution of material.
- **Edge Computing**: It is a recent development in computing model that carry out transformation of data at the "edge" of the network [19]. It's a computing that is done at or near the data source, instead of depending on the cloud at one of a dozen data centers to do all the work. All devices attached with sensors will contain data sources, but the edges are different altogether. A cloudlet, for example the edge of the mobile application is a micro data center. Likewise, if a smart phone is running a cloud application, then the smartphone will be considered as edge [24]. Its core principle is, it can be performed closer to the origins of data.
- **Dew Computing**: Dew Computing is a model which makes use of programming that enables the plug-in to be omnipresent, ubiquitous and simple, ready-to-go. It facilitates a single Super-Hybrid-Peer P2P interaction link for personal networks. Its key objective is to access the raw data pool that can be fitted with meta-data. Skala et al. [19] discussed that DC is largely effective in daily life than Fog computing. IoT-based apps are sponsored by Fog, although DC is a microservice idea and that's why it doesn't rely on any compact or centralized device, server or cloud, it requires low waiting time, real-time capacity and active network configuration.

In summary, IoT devices are linked to the cloud via Fog devices in the Fog computing paradigm. Fog devices are linked via the core network to the cloud. These similar paradigms vary on the basis of Internet and cloud access. Table 2 displays the features of the similar computing discussed above.

Table 2: Different Computing Models

	MCC	MEC	EC	DC	Fog
The Cloud Link	√	Both	Both	x	√
variety of Users	Ambulant	Ambulant	Ambulant/ Stationary	Uses devices which is attached with sensors	Ambulant/ Stationary
Technology used	It uses hypervisor / Container	It uses Hypervisor / Container	Hypervisor or Container	Container	Hypervisor / Container
key component engaged in computation	Iis connected with the base station server	MEC	Small Data Center	Mobile phone	devices which can compute, store and has network adapter

6. Applications of Fog Computing

It is useful in various IoT applications. A large range of sensors can be mounted in the sea, airline fleets or a car, so it's difficult to dispatch and reserve all data produced instantaneous in the cloud. A few interim computing, analysis and processing will be provided by Fog Computing appliances.

- **Connected Vehicle**: There are several useful qualities that rely on fog and Internet access which is applied to vehicles, like automatic transmission and "hands-free" operation or vehicle that is capable of parking itself, which means, no requirement for a human being to park a vehicle [8]. As part of the Intelligent Transport System, vehicle communication has been designed to achieve protection and efficiency through intelligent transportation by incorporating a variety of information. Connections in an intelligent transport system are accomplished by different communications variations which is vehicle-to-vehicle (V2V) and many a times vehicle-to-infrastructure (V2I). Fog computing is the highly capable approach for all Internet connections. Vehicles, as they have a high degree of real-time interaction., it will encourage vehicles, traffic lights and access points to exchange communication with each other in order to provide a reliable service to users [24].
- **Smart Traffic Lights**: Fog computing enables road signals to be opened based on the sensing of blinking lights. It detects the appearance of bikes and pedestrians and monitors the speed and distance between vehicles in the vicinity. Sensor lighting is turned on as it detects motions and vice versa Fog computing enables traffic signals to clear roads based on the sensing of blinking lights.
- **Augmented Reality**: Augmented - reality technologies are highly delay sensitive; a minor delay will result in significant errors in user interface. Therefore, Fog computing-based technologies will have tremendous potential in this area [25]. Zao et al. [26] proposed an improved interaction game for brain computers using Fog and cloud infrastructure.
- **Smart HealthCare:** Because of pollution our surroundings have various kinds of bacteria and viruses which causes various diseases. Smart healthcare includes smart IoT, which is capable of tracking the activities of patients and keeps track of various parameters of their body and uploads the data on the fog nodes, and these are being noticed by the medical staffs and then appropriate measures are suggested by the doctors to the patients [27]
- **Waste management:** The earth is getting polluted every day. To save the earth, we need to focus on natural resources. Rising waste and water loss from the ground needs significant consideration. Smart garbage management may be considered as one of the solutions for the improvement of the environment [25].

7. Resource Allocation

From a consumer's viewpoint, the distribution of resources relates to how the dissemination of products and services among users is done. The resource allocation problem is a major issues in the management of IoT applications in the fog scenario. To decrease time delay in mobile and time sensitive applications which works in real time, service allocation is crucial. Simultaneously, in order to control the set of large numbers of nodes scattered globally, the computational and storage resources of the fog layer should be used effectively. Fog computing must, in particular, manage resource allocations very effectively by taking into account the quality of service (QoS)which has been requested. Assignment of resources is generally carried out by choosing devices to provide the resources needed for the application services, taking into account certain constraints. According to Ni et al. [28], He suggested a Fog computing resource allocation policy based on priced Petri timed networks (PTPNs) that will encourage users to select required resources individually from a category of pre-assigned resources. The proposed solution regarded the time cost and factors to finish a task of creating the Petri nets task model. Alsaffar et al [29] designed an algorithm which implements decision tree learning technique that depends on the scale of resources, completion time, and power metrics of VMs to handle and assigns user resource allocation requests in the fog environment. Quang et al.[30] suggested First Fit placement algorithm to dispense IoT application modules in the Fog computing model. The algorithm allocates several modules, which depends on the configuration of the module. Each device, taking into account its processing capacity, bandwidth Capacity and RAM. Another method proposed in [31] suggests a heuristic resource allocation algorithm for Fog Data Centers (FDC). The algorithm is designed to decrease the energy consumption and the price evolved of connectivity on these devices. Optimization-based resource allocation approaches provide an effective cost-effective estimation domain for different cases, like, time-sensitive applications, real-time applications, vehicle network applications, etc. Table 3 shows the comparison between different resource allocation approaches.

Table 3: Comparison between different Resource allocation approaches

Utilized Technique	Author	Performance Metrics	Goals Achieved	Simulation environment
Priced Timed Petri net	Ni et al.[28]	Cost, Number of completing task	Efficient and realistic resource allocation	
Heuristic-based	Alsaffar, Pham, Hong, Huh and Aazam[29]	Number of VM, Processing time	Effective distribution of services on the basis of fog-cloud computing partnership	CloudSim
heuristic algorithms: MBFD and MDC (Maximum Density Consolidation)	Zahra Pooranian et al[31]	heuristic algorithm, MBFD and MDC	Resource enhancement, number of chosen servers, electricity usage, and response time on various FN scales	iFogSim
Optimization (MINLP)	J. Du et. Al[33]	Offloading and Resource Allocation	Performance increased	Matlab
Optimization (F-RAN)	2016, Peng and Zhang [34]	Edge cache-based study of performance and distribution of radio services	essential in solving partnership improvement in different caching	
Lyapunov optimization	A. Abouaomar et. Al[35]	System Performance	Minimizing delay and enhancing system performance	Docker containers
Auction-based resource allocation strategy	Xu et.al[36]	Resource Allocation	Minimizing latency and enhancing performance	iFogSim
knapsack-based scheduling	Rahbari et al.[37]	Energy consumption , network usages	improvements in the energy consumption by18%, network usage by 1.17%	iFogSim
Integer Non-linear Programming	Zahaf et al.[38]	Energy efficiency ,Response time	Increased energy efficiency and reduced response time	Matlab
Fog Torch Tool	Brogi et al.[39]	Latency , bandwidth and Resource Allocation	Decreased latency , efficient resource allocation	Monte Carlo

The fog computing resource scheduling problem decides the best allocation of the various tasks given in to be executed on the network edge fog nodes concerning to meet the QoS requirements signed with the owner of the IoT system thereby decreasing the implementation time for the specified task [32]. First, as users send tasks, that can be split into a number of smaller sub-tasks. These secondary operations are then sent to the task scheduler where the task scheduling strategy and the QoS request play an important role in the task scheduler. The job scheduler collects user scheduling data, resource monitors and cloud gateways and assigns the corresponding fog resource to each mission. J. Du *et al* [33] investigated cost conservation problem using min-max fairness while using the decision-making method, to reduce system costs. Authors devised an algorithm and named it computation offloading and resource allocation algorithm (CORA) which solves the articulated NP-hard optimization problem. In [30] M. Peng *et.Al* analyzed latest events in performance measurement and radio resource allocation for socially conscious mobile networking in fog radio access networks (F-RANs).Authors in [35] used Lyapunov optimization problem to minimize the system latency. They also used containers as a lightweight virtualization mechanism to simulate our proposed method. Xu et.al[36] implemented a decoupled resource allocation technique called Zenith to handle the allocation of fog infrastructure computing resources. Besides this, an auction-based resource allocation approach was designed to ensure the service providers' truthfulness and utility maximization. Rahbari *et al.*[37] proposed a knapsack-based schedule designed for symbiotic search.The contribution of their paper is reduction of delay and energy consumption with the increase in network usages. Zahaf *et al*[38] presented the efficiency and energy utilization model of a parallel real-time task conducted on the ARM bigLITTLE architecture. In the second part of the paper, authors used this model, where they first describe the optimization problem and then suggest heuristics for an efficient solution.In [39] Brogi et al. discussed the impact of the Monte Carlo simulations in the FogTorch tool while keeping time delay, bandwidth and resource usage in mind.

8. Discussion and Conclusion

Fog computing is a distributed processing system where computing, storage and software are placed somewhere between the data source and the cloud. The resource allocation problem is a challenging task in running the IoT application in the Fog scenario. The level Quality of service (QoS) efficiency in cloud computing is primarily controlled by the resource allocation approach implemented. In this paper we review several aspects of the resource allocation technique used in Fog computing area. A comparison is done among different resource allocation techniques used by their performance matrix and goals achieved. Besides reviewing different resource allocation techniques the architecture and features of Fog computing is also discussed. The difference between Fog and cloud computing is explained too. This work will give a chance to all nascent researchers.

9. Acknowledgements

The authors are thankful to the Lovely Professional University, Jalandhar for providing library and all necessary supports for the research.

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