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FOG COMPUTING AND SIMILAR DISTRIBUTED COMPUTING PARADIGMS: A REVIEW

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ABSTRACT

Nowadays, Users are increasingly adopting Internet of Things-based gadgets, resulting in significant data creation. All IoT devices, whether they are appliances, sensors, actuators, or other gadgets, continuously generate data that is processed in the cloud. The ever-increasing volume of data can cause a variety of cloud-based bottlenecks, such as latency and bandwidth concerns. Cloud being a central computing unit suffer from bandwidth issues due an expanding number of IoT (Internet of Things) devices. Fog computing is a novel paradigm to address these challenges. It provides the storage, networking and computation facility near the data sources and helps in spanning the aperture between cloud and the end devices. This paper provides an overview of cloud computing and fog computing paradigms, some basic differences between them, technologies similar to them and a basic idea about different applications and tools used for fog assisted cloud architecture. In the end of this paper, by finding research gaps from the literature of Fog assisted cloud architecture, we will address some ongoing research issues and challenges in this field.
Keywords: *Cloud Computing, Internet of Things, Edge computing, Fog Computing, Research Challenges*

1. INTRODUCTION

Cloud Computing is the most widely used computing solution which has now replaced the computing paradigms such as cluster computing and grid computing. Nowadays, SMART is the commonly used prefix before any device we use from smart house, smart lights, smart meters, smart health monitoring devices to smart cars etc. Cloud Computing is a landmark development in technology that has made it possible to develop, deploy and execute various IoT solutions that can be used to shift the computing capabilities, controls, or store big amounts of data in a medium that has unlimited resources. This paradigm remains the leading solution to deploy applications that have high computational requirements and application mainly focused on the processing of huge volumes of data produced by the IoT devices such as meters, sensors, health monitoring devices, smartwatches, cameras, and smart vehicles. However, today due to the proliferation of IoT devices huge amounts of structured and unstructured data is being produced which cannot be harnessed by traditional databases [1] therefore, “Big Data Analytics” came into the picture. According to a Survey performed by “Transforma insights” number of Connected devices are increasing exponentially as shown in Figure 1.

This paradigm facilitates the storage and processing of this data but it fails to efficiently manage bandwidth issue and the requirements of those IoT applications which are either time-sensitive or generating Big Data. This data generated has to be moved to the cloud for processing. The results are then communicated back to the respective devices. Given these facts, the need for an additional layer of computation was required. Therefore, different intermediate computation models were suggested by researcher from academia and industry. Some of these models are Mobile cloud computing, fog computing, edge computing, cloudlets and dew computing etc. Among all these computing models, fog computing is the most reliable and feasible solution. Fog Computing was introduced to do localized computing to decrease latency and bandwidth usage. Fog computing architecture is distributed in nature which doesn’t only depend upon the central computing components but brings the computation, networking and storage capabilities near to the edge of the network. Specially, for applications which requires real time response, this paradigm has many advantages over cloud computing. We cannot deny the fact that cloud computing is the backbone of “fog assisted cloud architecture” because all the complex jobs are carried out at the cloud. Also, Fog layer may find

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itself resource deprived for some applications. This layer doesn't have as much resources as the cloud has for storage and computation. Fog layer can only assist the cloud layer to process data for applications which are either time sensitive or situated at distant geographical locations where cloud data centers cannot be accessed. It is safer to state that instead of replacing cloud computing, fog computing complements or assists it.

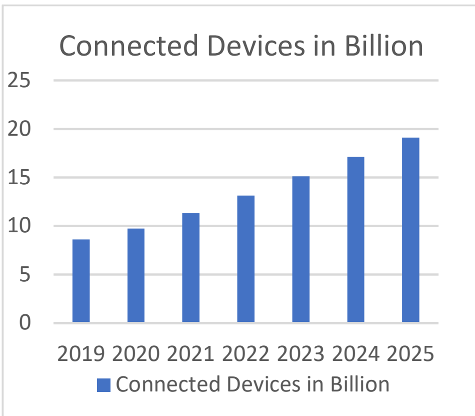

Figure 1: Number Of Connected Devices In Billions

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Currently, the Fog computing model is in its infancy phase, so a lot more research is required to be done. Many research challenges are spawning due to omnipresent connectivity and diverse nature of organizations. Fog Computing model still has many queries to answer about resource management and service management in it. Research in the domain of fog assisted cloud architecture is carried out by deploying virtual and physical components as a research outcome. For Virtual components, proof-of- concept is performed by using simulators like iFogSim Toolkit, CloudSim (Open-source simulation and modelling tools) etc. On the other hand, physical components are deployed and tested by using physical hardware like prototype models and testbeds [1].

This paper is arranged as follows: Section II provides the review of Cloud and Fog model definitions, characteristics and architecture. In Section III, we gave the overview of similar technologies and paradigms [2]. Section IV outlines the open issues and research gaps present in current literature. Finally, Section V concludes our survey and then references given in this paper are mentioned.

2 OVERVIEWS OF CLOUD AND FOG COMPUTING

This section gives an idea about Cloud and Fog Computing models

A. Cloud Computing

Cloud is a glue that keeps technology, procedures, and personnel together while they create and innovate for delivering digital experiences to the clients. Cloud Computing is an advancement of information technology through which individuals, different small and large organizations can get on-demand IT resources for storage, application development, networking and computations. In cloud computing every user is not a custodian of the whole computing network, but draws service according to their demands just like electricity power grids. IaaS (Infrastructure as a Service), SaaS (Software as a Service), and PaaS (Platform as a Service) are the three core services offered by cloud computing (platform as a Service). Cloud computing was introduced around 2007 and since then it has changed the way the IT industry works. Through cloud computing, IT service girding model which was earlier product centric has now changed into a distributed and service centric model globally. Even those organizations who cannot afford money and operational expertise for computation and infrastructure for storage etc. are leveraging the Powerful services provisioned by cloud computing [3].

Leading ITC organizations, like Google, IBM, CISCO, Amazon, Novell, Sun, Dell, Oracle, HP and, Intel, have invested in cloud computing and provide individuals and business organizations different kinds of cloud computing services [4]. According to a survey conducted by Frost & Sullivan in 2019 it was stated that "92% US-based IT decision-makers said that the cloud is the most critical part of our digital transformation strategy." 93% agreed that their cloud strategy is "essential to remaining competitive in our industry." 85% cited "innovation" as a top corporate priority[1]. It's worthy to note that the IT industry is going through significant changes since last decade e.g., Increase in the number of IoT devices which are generating huge amounts of data continuously, have gave rise to the new term which is "Big Data ". Cloud computing has enhanced the working of different domains like Big Data Analytics, internet of things, Artificial intelligence etc. According to the statistics provided by CISCO By 2022, 50 percent of mission-critical applications will rely on public clouds [5]. There are three different types of clouds: Public Cloud, Private Cloud and Hybrid Cloud. In the public cloud the computing services are shared across organizations through the internet as medium. On the other hand, a private cloud is designated for a particular organization. Hybrid clouds have the best resources of both public and private clouds [6]. Cloud computing has been described in a variety of ways by various researchers. Some of the definitions given by researchers are mentioned in Table 1 below:

a) ***Definition of Cloud Computing:***

Table 1: Definition of Cloud Computing

Defined By	Characteristics
CISCO[5]	▪ Convenient models to access infrastructure, platform, and software ▪ pay-as-you-go basis ▪ secure and flexible ▪ Generally used with IoT
IBM[7]	▪ on-demand access, connected via the internet, ▪ offload some or most of the costs and efforts of purchasing, installing, configuring, and managing ▪ provides elasticity ▪ Improve agility and time-to-value
Michele De Donno et al. [8]	▪ On-demand self-service ▪ Broad network access ▪ Resource pooling ▪ Rapid elasticity ▪ Measured service
Mohammed Al Yami et al. [9]	▪ centralized high performance computational platforms ▪ based on pay-as-you-go pricing models
Liang Yu et al. [10]	▪ high resource utilization, ▪ strong computing ability, ▪ high reliability, ▪ rapid elasticity
Proposed definition	▪ a virtualized pool of resources ▪ on demand availability of resources on pay as you go basis ▪ High reliability and elasticity ▪ No direct active management by user

b) ***Architecture of Cloud Computing:*** Architecture of cloud computing is divided into two parts: *front end* and the *back end* [11]. Front end means what the end user can see and back end handles all the processing which takes place in the cloud. Many applications' specific architectures are present in the literature but basic or the conceptual architecture of Cloud computing comprises three layers: The End user layer, Middle layer and the Cloud layer. End user layer contains all the sensors, Smart devices and actuators etc. which constantly generates the data after sensing their surroundings. Middle Layer has all the networking devices which help in connecting end users to cloud. Finally, the cloud layer has virtual desktops, databases, Servers and different application software for processing the data. Figure 2 shows the high-level architecture of cloud computing paradigm. In the last decade, an increase in the number of IoT devices has demanded a Shift of computing from the conventionally used parallel, grid, and cloud computing to Fog assisted cloud computing [12]. Reasons for this paradigm shift are latency, bandwidth and security issues which started to arise due to huge amount of data generation by these IoT devices. Fog computing expands the

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cloud to the edge of the network for resolving all these issues.

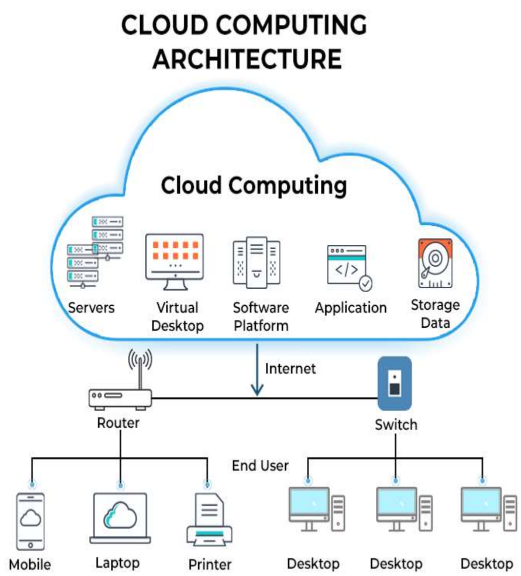

Figure 2: Cloud Computing Architecture

B. Fog Computing:

Fog computing is a distributed computing paradigm introduced by CISCO in 2012 to overcome the bottlenecks present in the cloud computing paradigm. Processing in Fog takes place closer to the network edge by seamless support of cloud computing. It harnesses computing provisions for IoT environments and real time applications. Transfer of data from all the connected devices to the cloud for processing results into two major challenges of storage and bandwidth requirements. Fog computing has come up as a solution for such problems.

Cloud or Fog alone cannot meet the computation requirements of today's world. Fog can only complement cloud for delivering better services. Cloud computing is the backbone of fog assisted cloud architecture. Many definitions of fog computing have been given by different researchers in different ways.

a)Definition of Fog Computing:

- "*It refers to a computing paradigm that uses interface kept close to the devices that acquire data. It introduces the facility of local processing leading to reduction in data size, lower latency, high throughput and thus power efficient systems*" [13].
- *"Fog computing is a network architecture that uses near-end user edge devices to accumulate a large amount of storage, communication, and computing resources that is used to carry out processing, control, configuration, measurement and management tasks"* [14].
- *"Fog Computing refers to a distributed computing paradigm that moves storage and computation usually near the end nodes of the network with the purpose of reducing the network overload and compute the gathered information as soon as possible. So that, the response time and the system performance improve"* [15].

b) ***Architecture of Fog Computing:*** Architecture of fog computing model can vary from application to application. In our paper, we have given an overview of a three-layer traditional architecture of fog computing as shown in figure 3. Bottom layer of the framework is the end user layer which comprises different IoT devices, sensors, actuators, smart devices and smart phones etc. Middle tier of the framework is fog layer where multiple fog nodes are present. Devices like laptops, routers, gateways, Raspberry pi boards, base stations and proxy servers can act as the fog nodes. These fog nodes process the data near end user devices. In case a fog layer is resource deprived to process a particular request, then data is directly transferred to the cloud. Information sent to fog nodes may or may not be critical but a security mechanism needs to be implemented on the fog nodes [16]. There are several applications of fog computing (Especially real time applications) for example, Automated vehicles, augmented reality, fire detection or intrusion detection in smart homes, in smart healthcare, smart agriculture, smart parking systems or smart traffic light systems etc. Therefore, architecture of fog can vary from application to application.

There are some demerits of fog computing e.g., due to wireless connectivity, distributed network and battery-operated device's chance of failure are more in it. Also, Malicious software in fog node devices can go unnoticed by users. Therefore, a good security mechanism needs to be implemented on each fog nodes in order to prevent attacks.

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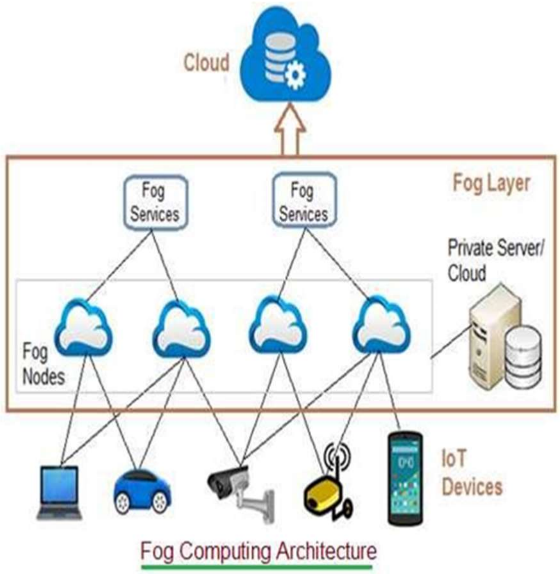


Figure 3: Architecture Of Fog Computing

Cloud computing will retain its job of doing complex computing tasks but when it comes to do small and time sensitive jobs, fog computing comes into the play. Fog cannot replace cloud but when its capabilities are integrated with cloud it can uplift computing services to a next level. There are different parameters to compare the working of cloud and fog [17],[18].

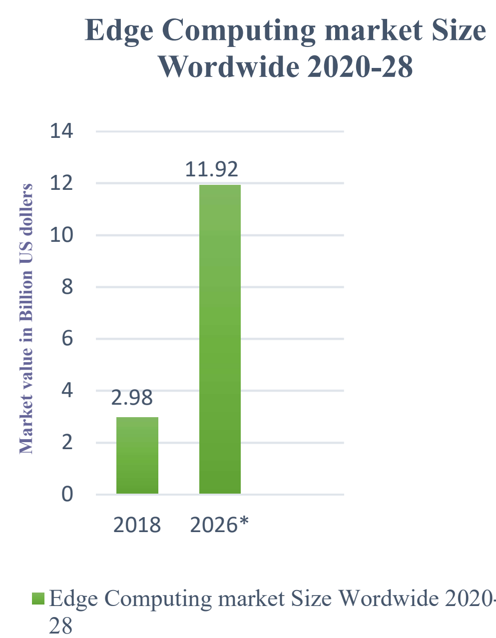
When the number of connecting devices increases, cloud alone cannot handle their requests efficiently. In such scenarios, cloud computing models will suffer from latency and bandwidth issues. However, Fog will come up with extra advantage of low latency and reduced bandwidth by processing these requests closer to the network edge.

3. OVERVIEW OF SIMILAR TECHNOLOGIES

Apart from cloud and fog computing there are many other similar technologies. Some of the computing paradigms which are overviewed in this paper are Edge Computing, Mobile Computing, Mobile Cloud Computing, Mobile ad hoc Cloud Computing, Mobile Edge Computing, Dew computing and Fog Dew Computing. Unlike cloud computing, IoT devices are not directly linked to the cloud for processing of data in the above-mentioned computing models. In these paradigms the end user devices are dependent on some intermediate devices, base stations or proxy servers for data computation [1].

A. Edge Computing:

Edge computing is a new paradigm in which computing is done near the data source and edge devices takes part in the computation. In edge computing edge devices have the ability to distribute requests and to give response to users on the behalf of the cloud. This model has migrated the services of computing, storing, networking and resources to the edge of the network, so that it can fulfil the requirements real time businesses, security and privacy, data optimization of today's IT industry [19]. According to the reports by edge computing market size will increase from 2.98 billion in 2018 to 11.92 billion in 2026 as shown in the chart below.



According to IBM "*The global edge computing market is expected to reach USD 6.72 billion by 2022 at a compound annual growth rate of 35.4%"*. With numerous deployment models, edge computing is becoming more and more popular. The four types discussed below give one the operating area or domain based on the latency requirements. "Internet of things edge" process with minimum latency while "network edge" takes maximum time as shown in figure 4 below.

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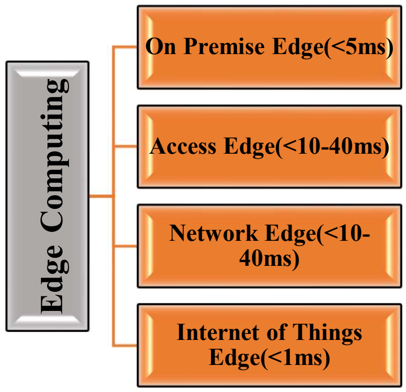

Figure 4: Operation Domains Of Fog Computing

B. Mobile Computing:

Since the 1990s, the fundamental concept of mobile computing has developed. Two-way radios have given way to this present communication technologies. Mobile computing enables users to send and receive data at a faster rate without any physical connections and links. Due to growing requirements of computation and storage mobile computing is no longer a viable solution to the compute and storage intensive applications. Portable computers, personal digital assistant (PDA), laptops, smart phones, wearables, mobile phones and tablet computers are used as the hardware for this distributed computing paradigm. Therefore, in comparison to cloud and fog, mobile computing is resource constraint. It is possible to build this paradigm without or with spotty internet connectivity. Devices are typically connected using Bluetooth, ZigBee, wi-fi, and cellular technologies. Mobility, location awareness and its distributed architecture are the main advantage of this paradigms but it doesn't support real time data analysis and virtualization etc. Along with performance there are security and privacy concerns also which can be resolved by implementing a security mechanism on the mobile devices itself .

A new paradigm called mobile cloud computing was introduced to address the drawbacks of mobile computing, shifting most of the computation to the cloud. Application area of mobile computing can be entertainment, education and Global Positioning System (GPS).

C. Mobile Cloud Computing:

Mobile cloud computing is an integration of services offered by cloud and mobile environments. Number of mobile users is increasing at a fast pace due to its user-friendly interface. But mobiles are resource constrained devices which cannot perform computation and storage on its own. Therefore, the mobile cloud computing paradigm is introduced to meet the requirements of mobile users in which cloud services are availed by communication between cloud and mobile through the internet [20]. In mobile cloud computing, cloud-based applications installed in smartphones leverage the services of different clouds via wireless medium. Applications like Gmail, Dropbox etc. are examples of mobile cloud computing.

D. Mobile Edge Computing:

Mobile edge computing is the outcome of a paradigm shift from mobile cloud computing. Services which were earlier provided by the cloud and now pushed to the network edges (e.g., servers, base stations or access points) so as to facilitate the real time and computation intensive applications on the mobiles [21]. In this paradigm edge nodes can not only communicate but can also help each other in computation. Task offloading at edge nodes can make this paradigm more efficient for time critical applications [22].

E. Mobile ad hoc Cloud Computing:

The most decentralized type of network is an ad hoc mobile network, which is made up of nodes (Mobile devices) that use routing and transport protocols to create a transient, dynamic network which is always capable of removing and joining new nodes to it. Unlike cloud computing there is no centralized cloud. Ad hoc networks of mobile devices itself act as the compute and storage resource. This computing paradigm is different from the cloud computing and mobile computing models because it is resource deficient in comparison to these paradigms as it is using only mobile devices as hardware. Therefore, it cannot handle those applications which require a lot of computation and storage. Unlike fog computing there is no hard and fast requirement of internet connectivity. General applications leveraging this computing model can be group videos live streaming and Automated cars.

F. Mist Computing:

Generally, mist can be understood as fog closer to the ground. Similarly, mist layer in the cloud fog continuum could be placed below fog layer and closed to the end users or sensor devices. All the data is pre-processed on this layer before passing it on the upper layers i.e., fog and cloud. Because processing units in this paradigm can also be other than mobile phones, mist computing can

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be viewed as a superset of the mobile ad hoc cloud computing paradigm. The mist layer, which is the second layer in the computing model for IoT devices, is where data filtering, data aggregation, data mining, and other pre-processing tasks are carried out in accordance with predetermined rules to prevent bandwidth and time wastage by sending only useful data to the upper layers[3]. Applications that need high throughput and are sensitive to latency can use this computing. Smart transportation management and smart medical services can be the two possible mist computing application areas.

G. **Cloud of Things:**

Cloud of things is a concept quite similar to the mist computing model. In mist computing model network of different IoT devices were acting as a cloud to process data by message exchange etc., but there was no concept of resource pooling by the IoT devices. But Contrary to Mist Computing, Cloud of Things model make use of resources pooled by the IoT devices for carrying out processing.

In Cloud of thing model, cloud basically use the sensing ability of sensors as its service.

H. Dew Computing:

According to **Zorislav sojat**[23] "*Dew-Computing is responsible for the layer of devices which are below the Edge of Internet, and which are directly responsible for specific physical aspects of our environment.*" Dew computing enables ground level devices such as sensors, Mobile phones and laptops which are connected to the internet. Fog computing is for time sensitive applications but dew computing is good for day-to-day jobs. Unlike fog computing, it doesn't need cloud or other centralized systems [1].

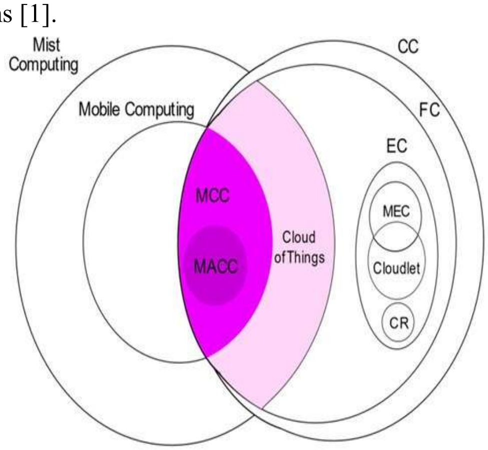

Figure 5: Venn Diagram for Different Computing Paradigms

I. Fog Dew Computing:

Fog-dew computing provides facilities without any internet connection i.e., in offline mode (exceptions are present). For instance, Waze is a navigation application that permits users to navigate in offline mode as well. A few days back, Google map has also incorporated this service in it. This service downloads a map information file of a particular area to the device of the user and permits him to navigate even without internet connection. However, this paradigm doesn't not purely support the offline mode. Once the device is connected to the internet it will sync itself with the internet

4. COMPARISON BETWEEN DIFFERENT COMPUTING PARADIGMS:

Discussion in the last section has stated details about different computing paradigms related to their architecture, advantages, disadvantages and use cases. Each of them has advantages and disadvantages of their own, and different paradigms are appropriate for different use cases. As

demonstrated in the preceding sections of this work, there is no such globally accepted separation between fog computing and related computing paradigms across scholars and industry. Researcher and industries sometimes use names of these paradigms exchange ably. In this review article, we make an effort to state fundamental differences between fog computing and other similar related computing paradigms. Nevertheless, in the present IoT and connected smart device scenario, due to extensive integration with cloud and closeness to the end devices, fog computing is appropriate for a wide range of application. Although it might not be suitable for some of applications which have sparse network topology etc., but for all the data- driven applications which require low latency responses, this computing paradigm is best. In this review article, we make an effort to define the differences between fog computing and other similar computing paradigms. Fig shows overlapping between characteristics of different computing models through Venn diagram. Cloud computing is a superset which is assisted by fog computing mode to enhance its functionalities and overcome disadvantages. Table 2 provides a theoretical comparison of the fog and other similar computing paradigms. After studying all the tables and diagrams it is concluded that fog paradigm is most suitable paradigms to optimize the quality parameters of different applications. Therefore, will

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primarily survey and analyze applications, research trends, and challenges in the literature on fog computing in the next sections of this paper.

Table 2: Theoretical Comparison between Similar Computing Models

	CC	FC	EC	MC	MCC	MACC	Mist Computing
Application Areas	• Big Data Analytics, • PaaS, IaaS, SaaS • Development and Testing	• Software Defined Network • Smart cities, Smart Grids, Smart Transportation etc.,	• Automated vehicles • Content Delivery Networks • Remote monitoring • Caching	• Multimedia Applications • Gaming • Navigation services (GPS) • Mobile utility applications	• Interactive Experience • Commerce • Social media	• Automated video surveillance system • Video live streaming	• Secure and scalable architecture for Smart health etc., • Parallel computation
Application Types	High computation, storage	delay Sensitive and high computation	Low latency and computation	Mobile processing, distributed	High computation	Ample computation but less delay	Distributed computing
Computing Resources	High	Average	Average	low	High	Limited	Limited
Distance from end user	Far	Relatively Close	Close	Very Close	Far	Very Close	Very Close
Architecture	Hierarchical and Centralized	Distributed	Distributed and local	Distributed and local	Centralized for cloud and distributed for mobiles	Distributed	Distributed and local
No. of Server nodes	Few	More	-	-	Few	More	More
Service Area	Within the internet	Within Internet till fog layer	Local network	Local	Within the internet	Local	Local
Real Time Support	Comparatively less	yes	yes	No	No	No	No
Advantages	• High Computation and storage capacity • Scalable	• Low bandwidth, latency. • Distributed processing	• Less transmission time, cost • More secure • Scalable	• Location flexibility • Simple to convey • Distributed computing	• Flexibility • Multiple Platform support • Cost Efficient	• Can operate autonomously with no or small internet access	• Helps in local decision making • Scalable • Cost effective
Disadvantage	• Delayed responses • Higher bandwidth, Power Requirements • No Offline Support	• Security and privacy issues • No offline support • Relative to cloud less resources	• More Infrastructure Cost • Data loss	• Battery issue • Low availability • Small Screen size • Limited bandwidth	• Data Security • Performance Issues	• No real time and virtualization support •	• Performs light weight computation only • Security and privacy issues
Virtualization Support	present	present	Absent	Absent	Absent	Absent	Absent

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Applications of Fog Computing:

Many data-intensive sectors find fog computing to be an appealing solution due to its variety of attributes, including low latency, reduced bandwidth usage, security, increased efficiency and enhanced user experiences as listed in figure 6 below.

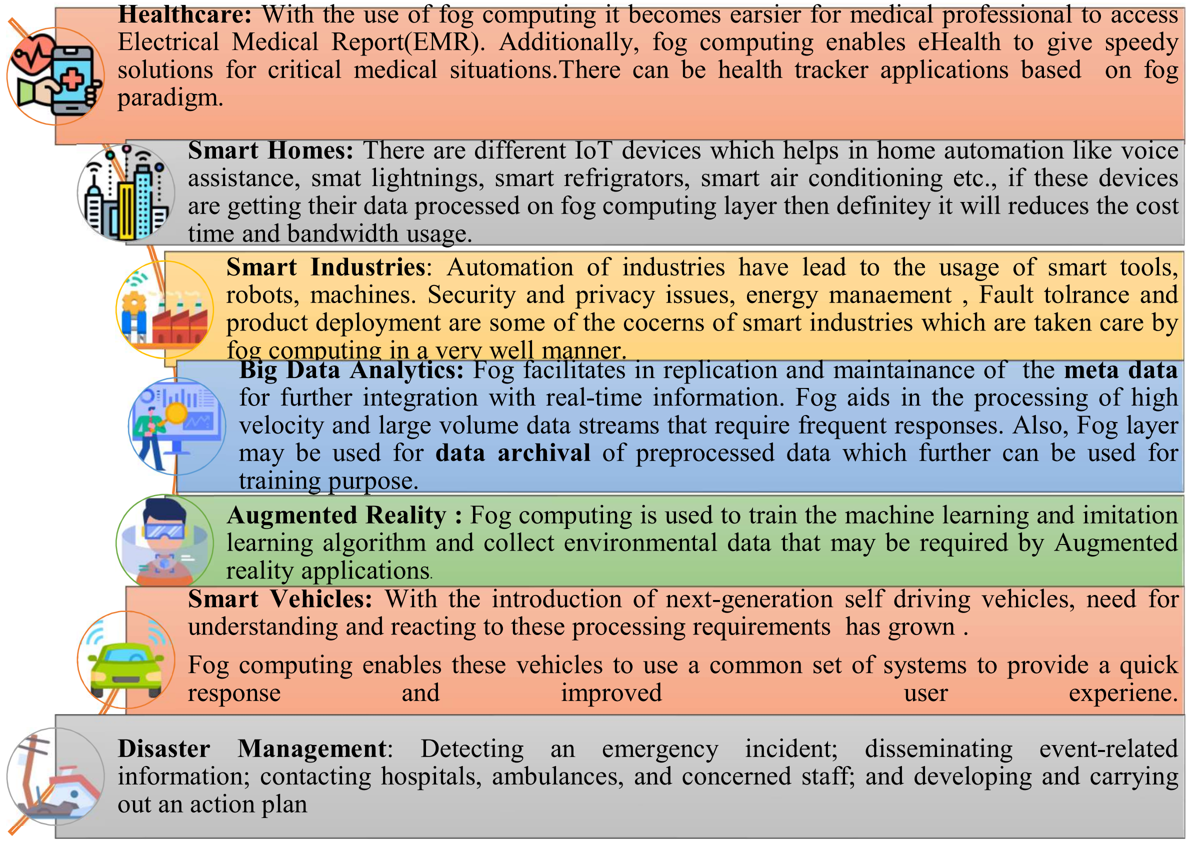

Figure 6: Uses case of Fog Paradigm

5. TOOLS TO SIMULATE RESEARCH SOLUTIONS IN FOG ENVIRONMENT:

Simulation enables you to study 'what if' situations and Challenges without putting the system through testing. There are numerous simulators and emulators to Implement solutions to the problems present in fog cloud environment. These are based on various platforms and programming languages. But, none of them are particularly effective at dealing with diverse challenges. Different simulators are useful in different types of situations. Furthermore, all of the simulators described in the literature have not been updated, and some of them contain obsolete technologies. Simulators can be categorised based on software metrics (language, lines of code, mobility, scalability, energy and cost modelling, infrastructure entities, and so on) or implementation attributes (Core simulator, last update, simulator type etc.). Some of the fundamental simulators include CloudSim, iCanCloud, OMNET++, PiFogBed, and FogTorch, from which further simulators such as FogNetSim++, FogTorchPi, MobFogSim, FogWorkFlowSim, iFogSim , and others are derived .

6. MAJOR RESEARCH CHALLENGES OF FOG ASSISTED CLOUD COMPUTING PARADIGM

In this section, we have listed numerous research difficulties and future directions that are prevalent in the fog computing sector. The table below provides a summary of prevailing research challenge. The advancement of architectural designs, algorithms, or techniques might be considered a research part of the fog aided cloud computing model. In this paper, we looked at the potential for algorithmic research. Using six more categories, including resource scheduling, resource allocation, application placement, load balancing, task offloading, and resource provisioning, we can further categories algorithms. To address these NP-hard issues, academic and industrial researchers employ a variety of heuristic and meta-heuristic optimization strategies, but there is always room for improvement. Details including research gaps about Some of the recent research studies are populated in the table below for a reference for the future researchers.

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Table 3 : Research Gaps in Current Literature of Fog Computing

Sr. No	Reference	Algorithm	QoS metrics	*Simulation*	*Limitations*
1	[23] 2020	schedule fit algorithm	Service response time, service failure probability	CloudSim	Concept of sub tasks are not considered
2	[24] 2020	(I-FASC), (I-FA)	resource utilization, processing time, load balancing	Real implementation (Using Alibaba Cloud Server)	Energy utilization and processing time are not considered.
3	[25] 2021	AHP, TOPSIS algorithm	MIPS, RAM & storage, latency, bandwidth of uplink and downlink, reliability, cost	iFogSim, Also evaluated in real condition as well	Execution and response time can be minimized further
4	[26] 2021	Static, Dynamic Genetic Algorithm .	Reduction in Deadline misses	iFogSim	Module mapping can be done by considering resource utilization metrics.
5	[27] 2022	Mob MBAR	Total Schedule time, make-span, energy consumption	Implementation using Real testbed	Only stationary IoT devices are taken care in this study. As a future work 'mobility' characteristic can also be considered

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6	[28] 2020	NA	Resource utilization, Cost	C programming language.	mean response time increased just marginally
7	[29] 2019	Individual Component Algorithm	Latency reduction	iFogSim	More communication constraints and computing layers can be considered.
8	[30] 2020	CAG task scheduling algorithm	Cost, network congestion and delay	iFogSim	Bag of task workload model is assumed in this study. As a future work dependent tasks can be there in workload.
9	[31] 2021	CASSIA-INT Algorithm and CASSIA-RR Algorithm	Make-span of schedule	Java programming,	CASSIA-RR gives approximate results and not the exact one. More number of resources can be required because different services are using fog layers to get processed.
10	[32] 2019	Linguistic and Fuzzy logic method	Processing time and energy usage	MATLAB is used for performing Numerical simulation	As a future work distributed scheduling of services can be achieved
11	[33]2021	AEOSSA algorithm based on Salp Swarm Optimization	Make span duration and throughput	MATLAB R2018b.	multi-objective optimization variant of AEOSSA can be developed in which monetary costs and energy parameters can also be assumed.
12	[34] 2020	Real time randomized algorithm using power of two choices	Computation cost, deadline violation cost	MATLAB	Concept of dependencies between task is not assumed. Also, energy usage and other costs like communication cost can be considered as a future research work.
13	[35] 2021	PMTSF	Power consumption and total delay	Problem is implemented in java programming language.	More performance parameters can be taken in account.
14	[36] 2020	EoMS algorithm	Energy consumption and makespan	Fog-WorkflowSim	User preferences can also be incorporated while reducing energy, cost and makespan
15	[37] 2020	Task Scheduling Algorithm	Makespan, resource utilization	Java programming Language	More QoS parameters can be taken care while designing algorithm
16	[38] 2021	MHMPA	Flow time, carbon emission rate, Power, makespan	iFogSim	As a future research work Marine predator Algorithm for other challenges like DNA assembly problem can be used.

On the basis of literature following are some of the major research issues in fog computing:

- ***Caching**:* Caching is the technique of keeping frequently used data in the proximity of the processor. Similarly, in case of fog assisted cloud computing to avoid the condition of backhaul congestion, intelligent caching techniques are required.
- ***Fault tolerance***: Architecture of fog nodes is distributed in nature and it uses wireless connections. So, chances of node failure are more [39].
- ***Security and privacy**:* Security and privacy is a major concern for this architecture. Data passes through a large number of hops while transferred from the IoT layer to the cloud which can be risky for the sensitive information. On the other hand, fog layer has multiple participant nodes which need a good authentication system [40].
- ***Data management**:* Data is generated from different kinds of devices and sensors and this data can be structured, unstructured or semi structured. So, it needs efficient algorithms and protocols to handle this data. Also, Segregation of data on the basis of allocation to fog or cloud nodes for processing is also an area of research.

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- ***Communication and collaboration***: Different algorithms for Communication and collaboration between fog-to-fog nodes and other end user devices have been provided by researchers but still the issue is unresolved. Optimum and efficient algorithms are still needed.
- ***Placement of application:*** Application placement algorithms, which assign microservices to fog nodes, are core aspects in fog computing as they affect the overall efficiency of the system in terms of energy consumption, communication costs, load management, and other variables [41]. Availability of resources, Interdependencies between different application modules, Response time for latency sensitive applications, Single or multiple task placements etc., are the main areas of concern while placing an application on fog node.
- ***Resource management***: Resource allocation, sharing and scheduling in fog nodes is also an area which always have a scope of improvement. There are different kinds of resources which includes Communication, Computation and storage resources [42]. Various academics have suggested algorithms to manage resources in fog while taking into account various quality of service characteristics. However, very few studies have taken into account all of the variables at the same time.
- ***Device Authentication***: A number of devices requests to connect to the cloud or fog nodes. In order to prevent security threats, devices need to be authenticated.
- ***Heterogeneity:*** The heterogeneity issue arises due to the IoT layer in fog computing model consisting of multiple end devices such as a smart tv, smartphone, surveillance cameras, different kinds of sensor node, smart objects like automated vehicles, and smart home gadgets. Also, each fog layer is made up of routers, switches, gateways, and other devices with varying computing and communication capabilities. As a result, heterogeneity becomes a significant design consideration in fog computing architecture [43].

- ***Task offloading:*** For balancing the load among different fog nodes efficient task offloading algorithms can be a future research area. While offloading any task, it is critical to identify the criteria that influence efficacy of offloading. In fog computing, real-time data analysis is crucial for application offloading [44][45]. Therefore, dynamic Task offloading algorithms can help better in determining the frequency and efficiency of Application offloading.

9. CONCLUSION:

Cloud computing and other similar computing paradigms have accelerated the pace of advancement in digital transformations. Different sectors including industries, smart cities, healthcare, education, manufacturing, and government are leveraging from this technology. Researchers have proposed various computing paradigms. Two most prominent computing paradigms that are Cloud and Fog computing are overviewed in this paper. However, a brief discussion about edge computing, dew computing, Mobile cloud computing and Mobile edge computing has also been given. From the perspective of different use cases, fog assisted cloud computing provides a richer platform and feasible computing solution. Edge computing differs from fog computing due to the location of nodes placement in the network. Research in the domain of Fog assisted cloud computing is still immature. Therefore, lots of research under this domain is required. Different issues and challenges which still persist in Fog assisted cloud computing are mentioned in this research paper. We believe that this paper will help in understanding the concept of computing

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