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A Review on Fog Computing: Architecture, Fog with IoT, Algorithms and Research Challenges

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Abstract

With the increasing advancement in the applications of the Internet of Things (IoT), the integrated Cloud Computing (CC) faces numerous threats such as performance, security, latency, and network breakdown. With the discovery of Fog Computing these issues are addressed by taking CC nearer to the Internet of Things (IoT). The key functionality of the fog is to provide the data generated by the IoT devices near the edge. Processing of the data and data storage is done locally at the fog node rather than moving the information to the cloud server. In comparison with the cloud, Fog Computing delivers services with high quality and quick response time. Hence, Fog Computing might be the optimal option to allow the Internet of Things to deliver an efficient and highly secured service to numerous IoT clients. It allows the administration of the services and resource provisioning outside CC, nearer to devices, at the network edge, or ultimately at places specified by Service Level Agreements (SLA's). Fog Computing is not a replacement to CC, but a prevailing component. It allows the processing of the information at the edge though still delivering the option to connect with the data center of the cloud. In this paper, we put forward various computing paradigms, features of fog computing, an in-depth reference architecture of fog with its various levels, a detailed analysis of fog with IoT, various fog system algorithms and also systematically examine the challenges in Fog Computing which acts as a middle layer between IoT sensors or devices and data centers of the cloud.

Keywords: Fog computing; Cloud computing; Edge computing; Internet of Things; IoT devices

1. Introduction

Many industries and individuals are gradually becoming reliant on intelligent devices and desktops to deal with the day-to-day task. These intelligent systems generate information through different applications and sensors. As an outcome, industries are producing and storing large volumes of information consistently [1]. The information generated from different types of sensors is on the rise after the evolution of IoT. With this rapid rise in the size of the information being generated and lack of ability of predictable databases to handle different forms of organized and unorganized information, big data analytics has got inordinate consideration at present. The data collected from different devices are being analyzed by various organizations to extract suitable understanding to take crucial decisions [2]. At present, various industries need a powerful cloud-based infrastructure because everything is getting migrated to the cloud as it has different features offering pay-per-use, scalability, and accessibility. The prevailing cloud service offered by CC is Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). All these cloud services are heading in the direction of Everything as a Service (XaaS) [3]. Nonetheless, information produced from these millions of sensors, specified as Big Data cannot be processed and moved to cloud completely as this may majorly result in latency Furthermore, few applications of IoT require quick processing than CC present capacity. This issue can be resolved with Fog Computing which ties together the smart devices processing power situated close to the client to assist the usage of networking, processing, and storage near the edge [4]. The functionality of fog with IoT is to cut down the information transfer to CC for storage, analysis, processing, efficiency, and to improve the performance. Thus, the information gathered by the sensor devices is transmitted

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to network devices such as edge for temporary storage and processing rather than transmitting them to the cloud, thus decreasing the latency and network traffic [5]. The unification of IoT with Fog Computing generates a unique prospect for services, named as Fog as a Service (FaaS), where multiple fog nodes are built by the service provider across various geographic locations and operate as an owner to various inhabitants from different vertical places. Every node in the fog manages storage, computation, and networking capabilities [6]. Fog is completely a distributed computing approach, it does not entirely depend on any integrated component like CC [7,8]. The latency issue of CC can be overcome using fog by utilizing the unused resources of different devices near the client. Nevertheless, it depends on CC to do major tasks.

Unlike CC, fog is a distributed computing approach where different devices near the clients use computing capabilities that have less-features but a good computing capacity with several cores. Therefore, several smart devices like network device management, switches, base stations, routers, smartphones, etc. are installed with storage and computing power which can perform as fog computing devices. Because of diverse organization and global connectivity, various research problems linked to Fog Computing are evolved. The deployable environment of Fog Computing and its requirements are the key issues in the Fog Computing principle. This is the reason, the computing schemes that are present in the Fog Computing domain are diverse. Hence, the query that comes in is: In which way Fog Computing will grab hold of novel challenges of failure handling and resource management in a diverse domain? Therefore, it is essential to examine the precise requirements of all the other interconnected features such as services, simulations, fault tolerance, hosting issues, and resource administration. Various researches on Fog Computing [9–15] have been carried out. Here, we put forward the focus and literature domains of these research efforts in brief.

Various descriptions, applications, and problems are described by Yi et al. [9] related to models of Fog Computing. Baccarelli et al. [10] reviewed the Internet of Everything and Fog domain with a unified view of the Internet of Everything and Fog computing. Perera et al. [11] presented a Fog Computing environment from the display place viewpoints of clients and developers for applications in the smart city towards constructing a viable sensing infrastructure. A categorized framework of Fog Computing and cutting-edge technologies like storage, data processing, security, transmission, privacy protection, and resource governance was surveyed by Hu et al. [12]. Fog, edge, and CC ecosystems concerning many dimensions of platform abstractions, application features, and system framework were presented by Varshney et al. [13]. Fog frameworks and algorithms established on six diverse assessment principles namely flexibility, interoperability, diversification, federation, Quality of Service (QoS) administration, and adaptability are presented by Mouradian et al. [14]. A classification of Fog Computing conferring to the recognized challenges and its important aspects is presented by Mahmud et al. [15].

This paper focusses on a detailed survey on different computing paradigms along with a comprehensive discussion on the framework of fog with a detailed discussion on different levels of fog. This paper also gives a brief overview of the different research works carried out of Fog with IoT and various algorithms used. The survey paper is organized as follows: Section 2 discusses various paradigms of computing and the evolvement of fog. Section 3 gives an overview of the definition, features, and reference architecture of Fog Computing. Section 4 highlights Fog Computing with IoT. Section 5 focusses on different fog system algorithms. Section 6 gives a detailed explanation of the open challenges of Fog Computing.

2. Computing paradigms

Numerous service providers namely Google, IBM, Amazon, Microsoft, etc. are utilizing the services of the cloud. With the evolution of Cloud Computing, the technology has evolved into a new generation with different cloud services like Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS), etc. to have various issues simultaneously related to enterprise, software, and education. Mostly the cloud data centers are located geographically in a centralized manner and are also situated far from the client devices. This results in latency and real-time delays by the cloud data centers and the consequences of which lead to degradation of service quality, network congestion, and round-trip delays. To resolve such issues, a new computing namely "Edge Computing" was proposed [16]. The main idea of Edge computing is to create a hybrid architecture that combines peer to peer and cloud servers with mobile terminals. The main aim is to diverge the traffic by performing computations closer to the edge of the network [17]. Edge computation is supported by end devices (mobile phones, smart objects.), edge devices (switch boxes, bridges, hotspot), edge servers, etc. All these components have required capabilities to support computations at the edge. However, the Edge computing paradigm concentrates on the edge [18] and does not associate with the services of CC like IaaS, PaaS, SaaS, etc. With the concept of Edge Computing and CC other computing paradigms have been introduced like Mobile Edge Computing (MEC), Mobile Cloud Computing (MCC). The MEC focusses on a 2 or 3 tier application in the network along with mobile devices with modern cellular base stations [19,20]. It enhances network efficiency along with content distribution and development of the application [21,22].

MCC is another paradigm of computing where consumers want to run all their applications in their mobile devices other than the old-style computers [23]. MCC is targeted at application execution time, storage, energy, and resource barriers [24]. However, when critical applications are executed it is better to run the applications outside the handheld devices. In such scenarios, MCC has come up with various computations to assist such scenarios to offload the mobile applications and to execute near the end consumers [25,26]. MCC contains mirrored servers that are light-weight called cloudlets [27]. They are located at the network edge. A three-tier architecture is formed with mobile devices, cloud servers, and cloudlets which develops a hierarchical application to increase the Quality of Experience (QoE) of mobile users and gives many

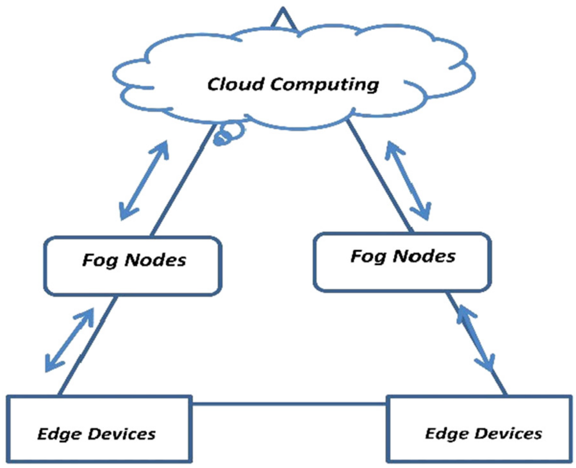

Fig. 1. Fog computing is an expansion of the CC but near to Edge devices.

business opportunities for cloud service providers and network operators.

Similar to MEC and MCC, Fog computing also carries computations at the edge of the network and the core component side. The core components are core routers, wan switches, regional servers, etc. which are used in the infrastructure for computations in the Fog environment. As a result of which a large number of IoT devices can easily be integrated with Fog. Furthermore, the components of Fog computing at the network edge can be positioned nearer to the IoT sensors or devices compared to mobile edge servers and cloudlets. As IoT sensors or devices are tightly dispersed and need immediate replies to the service demands, this method allows IoT information to be computed and stored within the surrounding area of IoT sensors or devices. As an outcome, service transfer waiting time for IoT requests in real-time will be reduced to an excessive degree. In contrast to Edge computing, the CC services like SaaS, IaaS, PaaS, etc. can be extended by Fog Computing to the network edge. Because of these stated features, Fog Computing is believed to be well organized and more prospective for IoT in contrast to other associated computing paradigms.

3. Fog Computing

This section presents an outline of fog computing, features, architecture, and advantages.

3.1. Definition of Fog Computing

Fog computing is defined as "an extremely virtualized environment that delivers networking, storage, and compute resources between outdated CC information centers, usually, but not entirely situated at the network edge" [28]. A fog structure contains various edge nodes with few processing competences, which are frequently called fog nodes. These nodes of fog have less processing facilities and storage. In fog network, sometimes edge and many servers are called cloudlets [29,30] which take part in the shared computing surroundings, not outside the network edge. By using these devices of fog, the clients might obtain a real-time response for sensitive latency applications. Even though the phrase was initially devised by Cisco [31], various researchers and industries defined fog computing from many different perspectives. A broad spectrum of Fog computing is provided by Yi et al. [32]. It is specified as "geographically shared computing framework with a pool of requirements that contains different universally linked heterogeneous computing devices at the network edge and not entirely flawlessly supported by services of cloud to collectively offer transmission, storage and elastic computation in remote surroundings to an enormous scale of users in closeness" [32]. A spectrum of Fog Computing is provided by OpenFog Consortium [33] as "system-level flat framework that divides storage, resources, computing services, and networking from every place along with the range from Cloud to Things"

3.2. Features of Fog Computing

Fog computing is an expansion of CC but nearer to things that perform with IoT information. Fog Computing performs as an arbitrator between the end devices and CC which brings storage services, networking services, and computation services nearer to the edge devices. This is illustrated in Fig. 1. These end devices are known as fog nodes and can be positioned which has network connection at any place. The device which has computation, computing, network connection, and storage can be called a fog node. These fog nodes can be switches, servers, surveillance cameras, and routers [34,35]. Structure blocks of CC are deliberated to be Fog computing. According to Yi et al. [32] and Ai et al. [36], the main features of Fog Computing can be precise as follows:

a. Adaptability: There are extensive network sensors that keep track of the neighboring environment. The fog delivers storage resources and disseminated computing which can operate with such extensive end devices.
b. Real-time communications: Fog computing solicitations provide simultaneous communications amid fog nodes relative to the batch analysis utilized in the cloud.
c. Physical distribution: In divergence to the integrated cloud, fog delivers applications and services that are decentralized and can be hosted in any location.
d. Less latency and position awareness: Fog is near to edge devices, it delivers less waiting time when computing the information of edge devices. Besides, it assists position responsiveness in which fog nodes can be hosted in various places.
e. Compatibility: Fog modules can adapt and interoperate with dissimilar platforms through diverse service providers.
f. Provisions for web-based analytics and integration with cloud: The fog is positioned amid edge devices and cloud to act as a vital role in the raptness and computing of the information near the edge devices.
g. Heterogeneity: Edge devices or fog nodes are devised by various companies and thus originate in diverse arrangements and need to be hosted conferring to their display place. Hence fog can adapt on dissimilar platforms.

Table 1
Comparison between Fog Computing and Edge Computing.

S. No	Fog Computing	Edge computing
1	It shifts the edge computing operations to CPU that are linked to the local area network or into the hardware of local area network so that they may physically be more far away from the IoT sensors and IoT actuators	It generally takes place instantly on the IoT devices in which the IoT sensors are connected or an entry point of IoT device that is physically "nearby" to the IoT sensors
2	The information is computed inside the fog nodes or gateway of IoT which is located inside the local area network	The information is computed on the sensor or IoT device, without being relocated to datacenters or cloud.
3	It can manage more information at a particular time intervals which essentially rallies upon the capabilities of edge through its capacity to handle real time needs.	It keeps all information and computation on the device which initially generated it.
4	The perfect period to adopt fog computing is when you have billions of IoT devices connected, exchanging the information in bi directional	Works well when high amounts of information have to be handled and instantly.
5	It can compute high volumes of information with very less or no interruption delay	The information resides on the network "edges" and can be processed instantly.
6	Clients can handle various data locally and depend on their safety methods.	It stalls the time and saves the resources by looking after the processes by gathering and examining the information generated in real-time
7	It does not necessitate continuous connected access. The information can be kept locally or drawn up from local storage	The information is primary computed locally, and then sent to the central data centers.

h. Provision for flexibility: One of the significant features of fog solicitations is the capacity to link straight to devices such as mobiles and hence enable flexibility techniques, for instance, Locator ID Separation Protocol (LISP) which desires a dispersed indexed system.

3.3. Edge Computing

The computation capabilities in Edge computing are provided by edge servers or devices of edge. Overall edge computing never impulsively link through any kinds of services of cloud and focusses further on the device side IoT [18]. A particular study states that edge computing as the processing of resource or a network which are in the middle amidst the data centers of cloud and sources of data. Any sensor or devices which are intelligent can have sources of data, however edge computing is diverse. Some IoT sensors and intelligent device can be the source of data, however edge computing is diverse. For instance, a small data processing center or a cloudlet is the edge of cloud computing and applications of mobile, while the gateway of IoT is the edge amid cloud computing and sensors of IoT. Likewise, if an application of cloud computing is running on a mobile phone, then the mobile phone acts as the edge amidst the cloud and the application. The key impulse of computing in edge is that, execution must be carried out at a nearer place from where the information is generated. From the edge computing perception, devices not only store the information but also generate the information by involving themselves in transitioning. These devices of edge can carry out execution job from the central cloud, additional demanding the delivery of services. Information storage, unloading allocation, and data execution, everything will be completed by the edge node. The devices of edge are also handy in allocating the requirements and delivering the service as a representative of cloud computing to the clients. In such situations, the devices of edge need to be properly developed to meet confidentiality requests, dependability policies, and safety concerns. Fog and edge computing both offer the identical features from the perspective of sending both intelligence and information to analytical environment that are located nearby where the information is generated from, such as IoT sensors, audio, videos, etc. Fog and edge computing are significantly similar. Both are fretful with respect to handling of the computing abilities inside a confined network to attain the computation jobs that would usually have been done on the cloud. Both fog and edge can assist industries decrease their dependence on cloud platforms to examine their data, which regularly drives to latency challenge, and rather be able to take data driven choices quicker. Table 1 describes the comparison between fog computing and edge computing.

3.4. The architecture of Fog computing

Fog computing is a method that adopts few operations of the data center to the network edge. It offers less storage, processing, and service network in a shared approach amidst CC data centers and end devices. Fog Computing's main aim is to deliver less and foreseeable latency for IoT functions which are time-sensitive [44]. Different reference architectures of fog have been developed by various researchers. A summary of related works that investigated the different architectures of Fog Computing are discussed in Table 2. As discussed, these architectures are designed based on different topologies specific to user applications and services. Conferring to the works of Ranesh et al. [45], Aazam and Huh et al. [38,46], Muntjir et al. [47] and Mukherjee et al. [48] a reference framework of fog computing is designed comprising of the seven levels namely level 1: virtualized and physical, level 2: fog devices, servers, and gateway, level 3: monitoring, level 4: preprocessing and post-processing, level 5: storage and resource management, level 6: security and level 7: application. Fig. 2 shows a layered architecture of fog comprising of the above levels. These levels of the fog framework are

Table 2
Summary of different Fog architectures.

Author	No. of layers	Summary of Fog architecture
A.V. Dastjerdiet al. [4]	5	The reference architecture consists of the following layers: (a) sensors, edge, devices, gateways, and apps, (b) network (c) cloud services and resources, (d) software-defined resource management and (e) IoT Applications
T. H. Luan et al. [37]	3	This architecture is a Mobile-Fog-Cloud hierarchy. Discusses on the intermediate Fog layer.
Aazam et al. [38]	6	Each layer is dedicated to specific tasks based on network components.
Taneja et al. [39]	3	The tier division is categorized as follows: (a) Endpoint containing the sensors, (b) Edge /Fog intelligence contributing the Fog layer and (c) Cloud Intelligence contributing to the Cloud layer.
Sarkar et al. [40]	3	This architecture supports a network structure where the Fog layer provides optimal support to terminal nodes.
Giang et al. [41]	3	Distributed Data Flow Approach comprising of a programming model where there are sub-flows into the three layers.
Open Fog Consortium [42]	4	This architecture has multiple layers based on network topology. OpenFog Infrastructure is composed of CloudServices, OpenFogFabric, OpenFogServices, and Applications.
Munir et al. [43]	4	The IFCIoT architecture is a layered fog node architecture comprising of Hardware and Reconfigurable layer, Virtualization layer, Analytics layer, and Application layer.

categorized based on different applications. The importance of each level is discussed and the usage of the level in various applications is explained. The goal of these levels is to work together to push a task for execution from an IoT to fog nodes and then to the cloud. These levels focus on carrying different tasks such as information management, data analysis, processing of data, categorizing of information to cloud servers and fog servers, and various other tasks based on services of the fog and cloud, and the demand of applications from the users.

3.4.1. Level 1: Physical and virtual sensors

The different forms of information produced by the sensors are the basic information generator of Fog Computing [39]. This information could be produced from different devices such as intelligent homes and devices, surveillance systems of CCTV and traffic, automated driving vehicles, humidity and temperature sensors, and so on. For example, in an intelligent surveillance system of traffic, we need to obtain continuous traffic status of all the routes from different sensors, devices from pathways, and roadside CCTV monitoring which will assist in managing traffic signals. It is essential to anticipate future traffic requirements by gathering information from different GPS sensors. In addition to physical sensors, virtual sensors also play a critical role [49] when there is any road accident. With the help of one sensor, it will not be probable to conclude whether to block the road or allow the traffic to keep going. The path may have many lanes one route which may be impacted by this incidence while the alternative path may permit road traffic movement to carry on. Nonetheless, the traffic management ability will be reduced owing to this incidence. For this scenario, a virtual sensor may provide an instant resolution on traffic rerouting, multiplexing, road environments, etc. Therefore, the physical level contains virtual and physical sensors, where any information producing device may fall into any of these clusters.

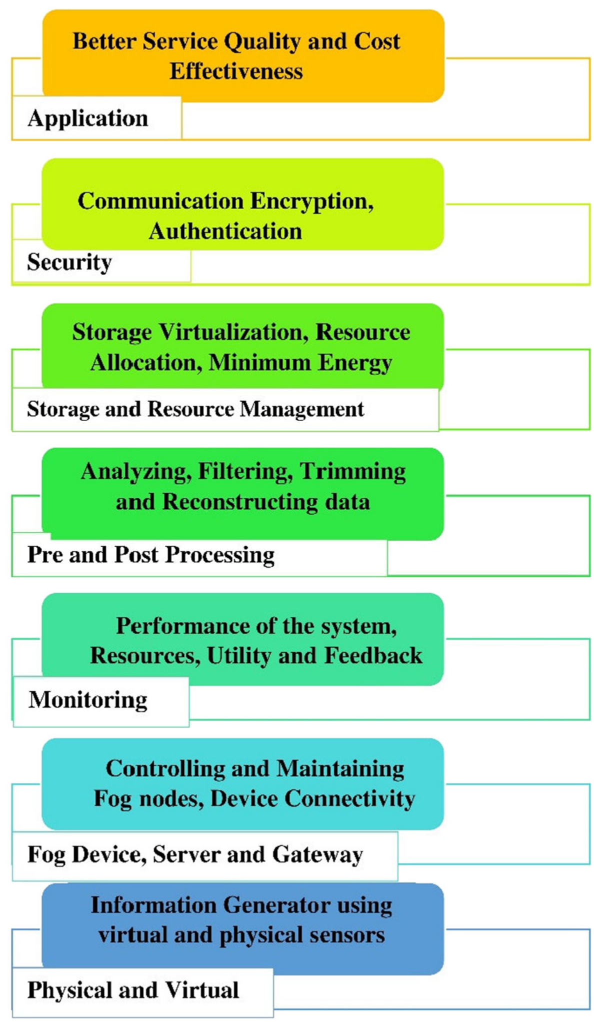

Fig. 2. A framework of Fog Computing.

3.4.2. Level 2: Fog device, server and gateway

An IoT or an independent device may be a fog server, fog device, or a gateway [39,41,50]. Nevertheless, it is noticeable that the fog server must have a better configuration than the fog gateway and devices since it controls numerous fog devices. To make fog server run many factors are involved like configuration of hardware, network connectivity, devices it can control, etc. The role of the fog server is defined based on its fragment of IoT. A cluster of virtual sensors and physical sensors are networked to fog devices. Likewise, a cluster of fog devices will be networked to the fog server. The fog server must have better computation and storage capability with fog devices. It should also have advanced computation and storage ability relative to the fog device. A precise group of fog devices which are linked to the identical server can broadcast with one another when needed. In an intelligent transport use case, few applications computation may be determined by other fog groups. For instance, if a request needed to search a fuel-effective path it may require data about various fog device groups or sensor groups. To conclude a suitable decision, computation needs to be performed on various servers and fog devices. The device level and fog server are accountable for controlling and sustaining data on software and hardware configuration, the network connectivity of servers and devices. This level also controls the processing needs to be demanded by many applications. Processing needs depends on information movement and the entire number of devices linked to IoT associated with the devices of fog and an entire number of devices of fog are linked to the servers of fog. The communication amid various servers of fog is maintained at this level. For instance, a Cisco router can be utilized as a device of fog, and the Cisco information service of fog devices can be utilized as the server of Fog [51,52].

3.4.3. Level 3: Monitoring

The performance of the system and resources are kept track by the monitoring level [39] along with utility and feedback.

During an operating system monitoring facilitates are chosen as the relevant resources. Different operations run in scenarios of systems having smart transportation. A scenario could occur where the availability of the resources will negate for calculations or storage on fog device. Similarly, the same scenario can occur on the server-side of fog. To handle such scenarios the devices and servers on the fog side will access help from different peers. Hence, the components of the system monitoring will decide these efficiently. The component of resource demand audits the present resources and predicts the resources of the future based on the activities of the user and usage. The method shall handle any risky situations where a failure could occur. Based on the network load and availability of the resources the prediction monitor can signal the performance of the fog system. This is required as it is used to maintain the required QoS attributes in SLA's. If consistently SLA violation takes place then there would be an increase in the cost of the system due to penalty. This cannot be omitted by the performance prediction but it will minimize the overall violations of the SLA by forecasting the usage and performance of the structure.

3.4.4. Level 4: Pre and post processing

This level works on data analysis of basic and advanced data, it has multiple components. In this level, it plays the role of obtaining the data by analyzing, filtering, trimming, and reconstructing the data as and when required. Once the data is processed, the component named data flow selects where the data should be stored whether locally at the fog or in the cloud for storage for a long duration [41]. The extreme issue in fog computing is that the information gets processed at the edge and the minimum amount of information needs to be stored. The main idea is to send the data to be used frequently to the fog servers and data which is used rarely or not used for a prolonged period to the cloud. In an application of smart transportation, data is generated from multiple sensors. This information will be explored and processed to get the generated information. This generated information could not be useful. In a few scenarios, it is not ideal to store all this generated data. For instance, depending on the application requirements the information from the sensor is produced each second, from where the mean value of the data within minute and hour is stored. In this way, data is trimmed and a large volume of storage is retained. In another scenario, if the information values do not differ in a fixed period but the performance gets affected then the number of readings taken would be reduced. In this way, a large volume of information could be altered. The accuracy achieved would not be cent percent but the requirements would be fulfilled. Another component in this level is the data reconstruction which takes care of data generation that is incomplete by the sensors and faulty tolerance. This component also takes care to reform the information based on the information pattern if one or more sensors fail and prevent application failure and other interruptions.

3.4.5. Level 5: Storage and resource management

The storage module is in charge of storing data using storage virtualization. The component named data backup is responsible to ensure the data availability and data loss. The concept of storage virtualization contains a pool of devices that are responsible for storage in a network that acts as an individual storage device. This individual storage device is easily manageable and maintainable. The main benefit of storage virtualization is that the cost of hardware and storage is low which provides better enterprise functionality. It also minimizes storage complexity. There are chances that the storage may fail [53] and it is crucial to back up data. The data backup module is responsible to customize the backup schemes of data periodically. Resource management level contains components that are responsible for allocating resources followed by scheduling and also deals with issues of energy saving. There is a component named reliability which maintains the reliability of scheduling the application and allocating the resources. When the demand for the resources is high during peak hours, the scalability is ensured to the fog resources. Horizontal scalability is achieved by the cloud platform while fog platform focusses to achieve both the vertical and horizontal scalability [54]. A critical issue arises in the distributed resources where the process of allocation is involved as storage is to be carried out in a system of distributed resources. The component of resource allocation does the allocation, de-allocation, and reallocation of all the related problems. One more important issue is that multiple applications use fog surroundings simultaneously which requires appropriate scheduling of the application. The component named application scheduling is responsible for various objectives of the application. This level contains the energy-saving component

Table 3
Comparison between cloud and Fog Computing.

Parameters	Fog Computing	Cloud Computing
Hosting	Dispersed	Integrated
Positing of server nodes	At the confined network edge	Within the web
Delay	Less	More
Range amidst server and client	Single hop	Many hops
Protection	Difficult to measure	Measured
Hardware	Less computing energy and storage	Expanding computing energy and storage
Information attack	More likeliness	Less likeliness
Position knowledge	Accepted	Denied
Running surroundings	Inside or Outside (Pathways/Hotels)	Data centers or Warehouse

used to manage all the resources efficiently. This manages to minimize operational costs. The reliability of the system is managed by the reliability component which focusses on different measures and metrics of reliability. The metrics could be evaluated based on the following parameters redundancy of data at the data centers, redundancy of fog nodes, mean time between fog node failures, meantime of critical failures of IoT applications. The fog system is a complex architecture that focusses to maintain all IoT devices, fog nodes, fog servers, and clouds.

3.4.6. Level 6: Security

The security level maintains all the issues related to security like communication encryption and protected information storage. This level also secures the information of the fog users. The fog environment is proposed to be installed as a system of utility like a cloud environment. In the cloud environment, the user demands all the services from the cloud by connecting to it, whereas in the fog environment the clients connect to the fog system for all the services while the middleware in the fog manages and maintains all the communications with the cloud. Therefore, the user who intends to associate with a service should be authorized. So, the component of validation is responsible for giving the authentication requests to all the users in the fog [37]. To avoid intrusion of malicious users it is important to maintain security by having encryption between different communications. Encryption component will encrypt various connections to and fro from the IoT devices and the cloud. Most of the fog components are connected through a wireless connection, so it is important to maintain security. The data of the users should not be disclosed in the fog environment, it is important to maintain the privacy of user data. Few smart city services or smart house services have issues because they have user-related data in their system which should not be disclosed. In current scenarios, users accept most of the security policies without giving a proper read to them. Hence, it is extremely important to consider these types of services where the involvement of the privacy of the user is crucial.

3.4.7. Level 7: Application

Initially, the fog was introduced to serve the IoT applications [55], many applications based on Wireless Sensor Network (WSN) started to support fog computing. Almost all applications that have latency as an issue started to take advantage of the fog environment. These included any type of utility services that could integrate with fog to provide better service and minimize cost. In an application, in which the system uses Augmented Reality can adopt fog infrastructure as it will change the current world in the future. The requirements of processing in real-time using augmented reality can be catered by fog environment which can cause prolonged improvement in many services of augmented reality.

4. Fog Computing with the Internet of Things (IoT)

The present integrated CC framework is facing different issues for the Internet of Things applications. For example, time-sensitive requests such as augmented reality, audiovisual streaming, and game-playing [14] cannot be supported. In extension, it does not have position responsiveness as it is an integrated prototype. These issues are addressed by Fog Computing. Table 3 sums up the variances between CC and Fog Computing. Fog computing acts as a link between IoT, storage devices, and CC. Conferring to Cisco [56], fog computing is a portion of the CC model that brings the cloud near to the network edge. It offers a vastly virtualized prototype of processing, storage, and resource networking between cloud servers and end devices [57]. To upsurge the effectiveness of IoT requests, most of the information produced by these IoT devices must be transformed and examined instantaneously [58]. Fog Computing takes the processing, storage capacity, and cloud network until the network edge to tackle the instantaneous issue of IoT devices and deliver safe and well-organized IoT solicitations [59]. Fog Computing delivers many applications and services with broadly dispersed positioning.

The fog can deliver effective instantaneous transmission amid several IoT solicitations such as linked vehicles, etc. Fog Computing is well-thought-out to be the better option for applications with less waiting time requests such as augmented reality, audiovisual streaming, and game-playing, etc. [60]. The inclusion of IoT with Fog Computing will fetch several advantages to different IoT requests. Fog Computing assists instantaneous communication amid IoT devices to decrease waiting time, particularly for IoT requests which are time-sensitive. Furthermore, one of the significant aspects of fog computing is the capability to back sensor networks of large-scale.

As shown in Fig. 3, Fog Computing could deliver several advantages to different IoT applications. This part discusses the various research articles on how IoT and Fog computing

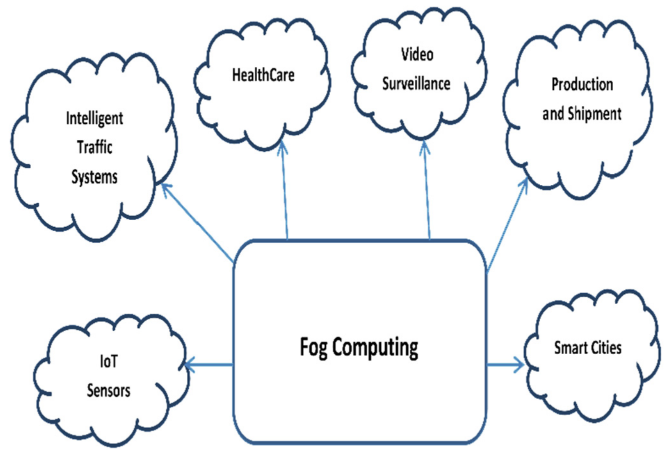

Fig. 3. Fog Computing delivers several advantages to different IoT applications.

are interrelated with each other. In this segment, we examine the present works that discuss the merging of IoT and Fog Computing in different applications. Many related research articles cover several characteristics of fog computing. Saharan et al. [61] have presented a survey on CC and Fog Computing. The authors have addressed the motivation and features of IoT applications for Fog Computing. Likewise, a study on Fog Computing was presented by S. Yi et al. [62] by deliberating several application situations for Fog Computing and many concerns that may ascend while executing such methods. The critical features in healthcare schemes of Fog Computing were discussed by Y. Shi et al. [44].

Fog Computing and its instantaneous applications are presented by N. Peter [63]. It shows data information generated by IoT devices that can be handled by fog. Moreover, it states the problems concerning waiting-time and congestion that can be controlled by fog. The article also illustrates that Fog Computing can assist a smart platform to control the decentralized and rapidly developing IoT setups and improve novel services at the edge network; which confine the outcome in the establishment of different business prototypes and prospects for network organizers. An outline of the integration of IoT with fog is presented by M. Chiang et al. [64]. The authors started by deliberating different problems in developing systems of IoT and how challenging it is to determine these concerns with existing models of networking and computing. The authors then debate the need for a novel structure of networking, processing, and storage. The way this structure can be utilized to make innovative business prospects. The framework also discusses the features of Fog Computing and its merits and recommends a few answers for several IoT issues. The problem of mobility backup in Fog Computing surroundings was examined by C. Puliafito et al. [65]. It emphasized on cellular IoT scheme and explored the key issues that will be encountered.

Moreover, they recognized and defined three situations of the unifying Fog Computing and IoT in which flexibility support is vital. A reference framework prototype for Fog Computing was surveyed by Dastjerdi et al. [4]. Rather than engaging the cloud, the prototype helps the need for IoT to be localized in the fog. In the reference framework [66], the central fog services are positioned in a software specified resource control layer. This offers a cloud-based middleware which stops fog clusters from behaving independently. As an alternative, fog cells are examined, monitored, and arranged through cloud-based middleware. Moreover, the integration of Fog with IoT was studied by F. Bonomi et al. [67] in which vital features of fog and how it spread CC by complementing it through the fog. Furthermore, the authors discussed an ordered distributed framework for the fog. To examine the features of their framework, they delivered an application scenario for a wind farm with an intelligent traffic light system. Few research articles concerning managing resources of Fog Computing have been examined. For instance, a method for resource management utilizing Fog Computing is provided by Aazam et al. [38]. The method uses the allocation and prediction of resources to control resources vividly and realistically. They claimed that their effort can be better criteria in achieving more accurate development and study allied to Fog Computing and IoT that can adjust to diverse requests connected with service providers of the cloud. Furthermore, the architecture of fog delivery resources is presented by O. Skarlat et al. [60]. The authors have formalized an optimization problem to provide stalled responsiveness operation of accessible fog-based processing resources. They assessed their architecture which marks in a reduction in latency by comparing with existing methods.

A suggested model of the Fog Computing paradigm has been examined by Bonomi et al. [33]. The authors discussed that their prototype is the finest method to back IoT devices which are resource-based restrictions. Furthermore, they present three impulse states comprising wireless sensor networks (WSNs), intelligent cars, and intelligent grid to prove that their fog policies can be applied to several applications and services. Also, Hong et al. [68] surveyed on fog mobile that can allocate applications of IoT through many devices in an ordered structure framework from the edge network to CC. The fog mobile utilizes an active node detection method to integrate devices combined in a master–slave link where master nodes utilize the processing resources to compute the information got from slave nodes. Fog mobile delivers many merits to applications of IoT as they can cumulate and operate the information in the vicinity at the edge of the network. Fog mobiles backload balancing among master nodes so that the slave nodes are linked with the further loaded master which enhances the whole scalability of the system.

An architecture has been suggested by A. Yousefpour et al. [69] to model service latency, apprehend, and assess fog-IoT-CC application situations. The authors have suggested a latency reducing method for the nodes of fog which tend to reduce latency services for IoT nodes. They suggested a method that establishes fog to fog transmission to minimize service latency by distributing the load. For offloading computation, the method reflects not the only length of the queue but also several demand categories that have a diverse computation time. An analytical prototype has been established by A.

Yousefpour et al. to assess the latency service in fog-IoT-CC situations in specific and executed widespread simulation research to back the method and the suggested strategies.

Vital issues conveyed by commercial IoT were examined by V. Gazis et al. [70]. The authors identified the critical assisting technologies applicable to fog paradigm. Furthermore, an adaptive platform for operations is proposed for Fog Computing to offer end to end operability of fog concerning the need to organize the process. Privacy and safety problems in IoT surroundings have been proposed by A. Alrawais et al. [71] and they suggested a method for safety improvement that deploys the fog to enhance the delivery of certificate reversal data amid IoT devices. Moreover, they suggested a use case to unravel safety problems in certificate reversal data in IoT surroundings through fog computing.

K. Lee et al. [72] examined the privacy and safety issues by combining IoT with fog computing. They claimed that embracing of fog with IoT presents many security threats. Furthermore, they deliberated present security methods which may be helpful to protect the fog with IoT emphasizing the demand to organize a safe fog computing surrounding using various security techniques. Few research articles deliberated on the role of vehicles in fog computing. An outline of automobiles listed as infrastructure for transmission and processing acknowledged as Fog Computing in automobiles. They suggested the benefit of this framework to simplify the synergy amid clients to carry out transmission and processing grounded on vehicle resources. They also deliberated four situations containing running and stationary vehicles as the transmission and processing infrastructures while accomplishing a measurable study of the capabilities of Fog Computing in automobiles.

Moreover, M. Sookhak et al. [73] surveyed on fog vehicles to use the unexploited means of automobiles to influence Fog Computing. Also, the authors anticipated a framework that is cross-layer for fog vehicles to describe the measures of the policymaking procedure and in a way to diverse categories of services that are dispersed between vehicles such as fog nodes. Likewise, to recognize the safety problems of existing prototypes of fog computing, S. Khan et al. [74] delivered a survey on Fog Computing requests to classify usual safety concerns. They claimed that several fog requests do not contain safety as part of the structure, but relatively emphasize on functionality, which fails in many fog policies were exposed. Hence, their effort focused on defining the influence of safety problems and probable answers able to offer upcoming safety-related guidelines for fog computing. Additionally, the state-of-the-art of fog computing was discussed by I. Stojmenovic et al. [75], they focused on the privacy and safety concerns of the present Fog Computing model.

The man-in-the-middle attack was used as a use case to study the memory utilization and central processing unit (CPU) of fog devices. Mahmud et al. argued taxonomy of Fog Computing conferring to its characteristics and issues [76] conversed the variances among mobile CC, edge computing, and fog computing. The structure of the fog node, several parameters of fog computing, and networking devices of fog were also examined.

5. Fog system algorithms

This segment discusses the classification of fog algorithms based on three scopes namely job planning, resource allocation and loading, and unloading of fog nodes and devices.

5.1. Job planning

While fog computing presents further computing abilities at the network edge, a key interrogation that they bring up is in what way to handle in carrying out the job. More exactly in what way to choose, which jobs to perform in the IoT or client layer, fog layer, and the cloud layer? Intharawijitr et al. [50] examine the job planning issue in the fog layer. On the other hand, when compared to Oueis et al. [77], they study, that the nodes of the fog in the fog layer that signify the compute servers. In this framework, they intent at defining a plotting amongst the jobs and servers, that decreases the job stalling probability. They also examine the job planning issue in a mobile network established on the fog layer, where tiny cells are permitted with computing abilities that form the nodes of the fog. Aazam and Huh [38,49] examine the issue of job planning in the fog layer, by taking into account adaptive resolutions with respect to the client's performance. Zeng et al. [78] determine job planning and image positioning in parallel. More specifically, they deliberate that jobs can execute on the server in the fog layer or on the integrated devices that can be able to task images and can be stored on the data centers. Agarwal et al. [57] present an algorithm that permits resourcefully allocating the jobs over the cloud layer and fog layer. Deng et al. [79] address the issue of job planning over fog nodes and cloud. They intent at performing with very less power utilization while captivating added limitations into consideration like bandwidth.

5.2. Loading and unloading allocation

Many Job planning algorithms have been suggested with respect to fog systems. Although they permit allocating compute jobs over compute fog nodes through the different layers, they have not deliberated the likely destabilization between the fog nodes with respect to the amount of work. Ye et al. [80] and Hassan et al. [81] emphasized unloading the devices with respect to IoT or clients layer to fog node layer. Rather, Ningning et al. [82] and Fricker et al. [83] have emphasized the fog layer and addressed unloading and load redeployment. Alternatively, Li et al. [84] address on the fog layer alone and present a coding structure that directs towards reallocating the job or introducing additional ones in the structure. Lastly, Ottenwalder et al. [85] examine relocations in the entire system, a normal feature to Unloading and loading allocation.

5.3. Resource allocation

The primary feature that has been examined in fog system computing is the collaboration between the fog nodes and assessing the sharing of the resources. In the fog layer, these features have been handled with the aim of performing the computing requirements. The authors [86–88] discuss these features. Oueis et al. [86] analyze the issue of determining the resource allocation between the fog nodes to perform computing requirements, the author focuses on tiny cells of mobile structure which are fog enabled. These cells form tiny groups where each group signifies a cluster of tiny cells that exchange resources for load shedding the cellular gadget from their amount of work. Nishio et al. [87] address a similar problem but deliberate the instance of fog system in mobile. It contains a fog layer formed by cellular gadgets and a cloud accessible through the mobile structure. Thus, they aim at optimizing the CPU, bandwidth, and common storage to assist the computing requirements. Owing to the variety of these resources, they plot them into various intervals of resources to permit enumerating them in a similar unit. Abedin et al. [88] present an algorithm that permits to the computation of the resource exchange between the fog nodes inside the similar fog area of the fog layer thereby permitting the carrying out the client's computing requirements.

Five benchmarks are taken into consideration namely diversity (B1), QoS (B2), flexible expandability (B3), agility assistance (B4), and alliance principle (B5). For each of the authors mentioned below in Table 4 describes which author has met the benchmark criteria based on the fog algorithms they have adopted and which benchmark they have not met in the form of yes or no according to job planning, Loading and Unloading allocation, and Resource allocation classification. It also examines the key contribution of the various survey and their proposed algorithms concerning the scope and benchmarks [14]. In summary, all the key contributions of different works with their proposed algorithm suitable for fog platforms are mentioned.

6. Fog Computing: Research challenges

The field of Fog computing has evolved from Cloud Computing as an economic and merchandise resolution to provide computational resources to the clients. With the recent trends in the development of IoT devices (sensors, smart-phones) having the minimal cost of hardware. The computation has been done near the fringe which ultimately reduces computations and data offloading costs at the cloud, it also provides security and privacy solutions to the data at the user's end. Nevertheless, computing at the fringe has a lot of challenges related to network, security, devices, and integration of fog with IoT which are currently being explored. Fog computing works in a distributed environment which takes into consideration a lot of challenges. In this section, a brief discussion on the challenges faced for developing fog solutions is discussed.

6.1. Challenges in the device and network

The different challenges faced related to the device and network are decentralized framework, networking resources, device heterogeneity that are discussed as follows.

6.1.1. Decentralized framework

The framework of Fog computing is decentralized which leads to a redundant structure. There is a repetition of the same code at the devices which are at the edge of the network [89, 90]. As a result, the fog environment should focus on reducing the redundancy in the decentralized architecture.

6.1.2. Networking resources

In the fog architecture, the network resources are randomly distributed at the edge. This increases the complexity of connectivity. A proper network which has a middleware to maintain a common set of resources at the edge can be managed to allow the resources to the required application.

6.1.3. Device heterogeneity

The end devices in the fog architecture are heterogeneous. The nature of heterogeneity has caused the structure to be more varied [67]. The applications which are developed using fog should consider this aspect of the heterogeneity at the device and network as well.

6.2. Computational challenges

Computing at the fog level is quite challenging due to the following aspects of computations at different levels and distribute computation resources are discussed.

6.2.1. Computations at different levels

The fog system should always interact with cloud servers. The main aim of the fog system should be to respond to the users within a particular time limit at the lower level and also carry forward the required computations to the cloud which will take a longer time. Few computations are offloaded to the clouds that are not constrained to response time and computational power whereas other parts of the computation will be executed near the edge with low cost of computation. There is a challenge to identify which computations need to be carried at the cloud and to be computed at the fog.

6.2.2. Distribute computation resources

Computation at the edge might not have the required resources. These resources can be acquired from alternative fog nodes. This demand has raised the requirement to assign the computations of the resources among various fog nodes. This requires an approach to combine the memory, computations, and networking resources to form a common pool. Different applications can approach the pool and reserve their resource according to their requirement [91,92]. The present research is focusing the need to develop a pool which is common containing the resources rather than the devices at the edge for computing.

a. Portability:
The nodes on the edge of the fog environment may be portable which arises the need for computing from anywhere, anything, and anywhere. This requires the need for ubiquitous computing in the fog environment [93]. The portability is a constraint in the fog architecture.

Table 4
Key contribution of various works and their proposed algorithms.

Scope	Paper	Key contribution	BenchMark				
			B_1	B_2	B_3	B_4	B_5
Job planning	Aazam et al. [49]	A job allocation algorithm based on loyalty is presented.	Yes	Yes	No	No	No
	Oueis et al. [77]	An algorithm to handle the carrying out of a job in small cell fog stratum.	Yes	Yes	No	No	No
	Zeng et al. [78]	Image placement and job allocation algorithm are presented which reduces the total finish time.	Yes	Yes	No	No	No
	Agarwal et al. [57]	To reduce cost and response time a distribute workload algorithm is presented.	Yes	Yes	No	No	No
	Deng et al. [79]	An algorithm to distribute workload in Fog/CC at less power cost.	Yes	Yes	No	No	No
	Aazam et al. [38]	A job allocation algorithm based on loyalty examining various kinds of devices is presented.	Yes	Yes	No	No	No
	Intharawijitr et al. [50]	To choose fog nodes to implement jobs three policies were examined.	No	Yes	No	No	No
Loading and Unloading allocation	Ye et al. [80]	Examined a method to unload mobile devices and cloudlets to fog assisted buses.	No	Yes	No	Yes	–
	Fricker et al. [83]	The efficiency of the data center is evaluated by the unloading method in the fog layer.	Yes	Yes	Yes	–	No
	Hassan et al. [81]	A method to unload mobile device applications is presented.	Yes	Yes	No	No	No
	Li et al. [84]	A coding architecture to manage duplication in job processing in fog nodes is presented.	Yes	Yes	No	No	No
	Ningning et al. [82]	Presents a load balancing algorithm that is dynamic to the fog layer that permits dynamic entry and departure of fog nodes.	No	Yes	No	Yes	–
	Ottenwalder et al. [85]	Presented a method that permits relocation operators at less relocation cost.	Yes	Yes	Yes	Yes	Yes
Resource allocation	Oueis et al. [86]	An algorithm to group little cells to permit resource allocation amid them is presented.	Yes	Yes	No	No	No
	Nishio et al. [87]	A method to improve the resource allocation to enhance the utility is presented.	Yes	Yes	No	No	No
	Abedin et al. [88]	An algorithm to permit resource allocation amid fog nodes is presented.	Yes	No	No	No	–

b. Computations in a Distributed Environment:
Fog Computing is a domain which has distributed computation where the correctness of the computations needs to be verified. The applications involving the fog framework need to be developed in a manner where there are fewer discrepancies in computations [49,84]. These discrepancies should be provable.

6.2.3. *Mobilization challenge*

From the Mobilization perspective, OpenFog is specified as N level environment. Nevertheless, the extreme upsurge in the number of Fog level layers may cause delayed issues in the recently developing Fog paradigm. Thus, the number of levels established in the case study must be firm. Mobilization results will be accepted when established on requests like the type of job done by each level, overall sensors used, competency of fog devices, and dependability and latency of Fog devices. Nevertheless, it is essential to examine how these requests will be satisfied.

6.2.4. *Utilization of resource challenge*

Utilization of resources are utmost vibrant and dissimilar in an environment like a fog for the reason that the devices are diverse in nature and they are accessible. All these fog devices are liable for executing the application on their own. For instance, a PC that depends on administrative workers to carry out a few normal file work and emails may be an element of the fog and may also behave as a Fog device. In this situation, utilizing these resources that are accessible for computation of fog is vibrant but anticipated via the study of the prolonged period action of its resources. This expectation is essential since once the fog job begins its execution, and for a given period, the position of the resources may vary owing to the demands by the requested application for which the system of fog devices is accountable.

6.2.5. *Fog device breakdown challenge*

The breakdown probability of the fog devices is continuously on the rise because the fog devices are disseminated, and the controlling of these devices is not centralized. Therefore, the devices of fog may breakdown for several grounds like end consumer activity, hardware breakdown, and software crashing. In addition to these issues, few other issues that may play a major role are source of power, connectivity, and flexibility. Several fog devices may be linked via Wi-Fi, it is understandable that Wi-Fi linking is always not dependable. The majority of them are mobile devices that are connected wireless, therefore these devices might alter the position to other clusters regularly.

6.2.6. Request provision handling challenge

Fog paradigm handles millions of IoT devices that are periodically responsive and unresponsive applications. The level of service obtainability and nature are of utmost dissimilar in fog. Therefore, service obtainability is a distinctive challenge for the complete Fog demesne. Additional research is essential to discover the likelihood of fog centered solutions.

6.2.7. Complexity challenge

In Fog computing there are several sensors and devices of IoT that are developed by many companies, selecting the ideal mechanism is becoming difficult, mainly with diverse hardware structure, software configuration, and individual demands. Moreover, in few instances, maximum security application demands necessitate explicit protocols and devices to work, which upsurges the setback of the process.

6.3. Security challenges

Fog Architecture consists of various heterogeneous devices. They may be vulnerable to different attacks [94] discuss the man in the middle attack in the fog environment. The two main issues which are of concern in the fog environment are data and network. It also depends on other factors at the cloud datacenters. The devices of the fog are deployed in an environment that is not highly secure, so any vulnerable or physical attack can easily be carried out. There is a need to run the devices at the edge securely in the fog.

6.4. System management challenges

There are several challenges related to fog at the system level like service-oriented computing, management of resources and integration between cloud and fog nodes are discussed as follows.

6.4.1. Service-oriented computing

In fog computing architecture, client services are classified into many small services and these small services are spread throughout cloud and edge. This specific dispersal of facilities above the fog devices is a method of service-oriented computation through edge devices. Nevertheless, performing small services through fog nodes has their private issues. The appropriate organizing of the framework thereby acquiring the services is the major issue in the fog computing area. There are many issues in small service administration. These are the following implementation stages service combination and placement, etc. We require an appropriate composition structure so that these services are delivered to the clients within minimal time through the fog architecture.

6.4.2. Management of resources

The nature of fog computing is adjustable and adaptive to various issues like shortage of resources and short-term failures. Failure of any fog node will cause the entire system to run down and there will not be any resources available from the respective fog node. These resources are virtualized in the fog environment. There are many challenges related to resource virtualization like migration, latency, initialization, etc. which need to be properly managed so that the resources can be available during downtime.

6.4.3. Integration between cloud and fog nodes

Another major factor is to provide end to end services from the fog nodes to the cloud along with the provision of QoS attributes for different users according to their services [95,96]. The fog framework consists of the cloud as well as the edge devices. The orchestration of these devices at the edge which is heterogeneous should be taken care of along with handling the cloud architecture to perform computation and storage in a distributed environment [95,96]. Therefore, there is a need to dynamically allocate the end to end integration of the fog devices and the cloud servers.

7. Conclusion

In current existence, the IoT has fascinated the focus among industry and researchers. This attraction has transformed our lives and becoming essential to the modern world. It can associate anything in our surroundings. The devices of IoT are vigorous and have less processing and storage capacity. Nevertheless, the customary integrated CC has several problems, such as failure of networks and increase latency. To address these problems, fog computing has turned out to be an extension of CC, but nearby to the devices of IoT in which complete information computation will be done at fog nodes, thus decreasing the waiting time, particularly for crucial applications. The combination of IoT with fog computing carries several advantages to several IoT applications. In this paper, we put forward the various computing paradigms, features of fog computing, an in-depth architecture of fog computing with its various levels, a detailed analysis of fog with IoT. The discussion also concentrated on various fog system algorithms and fog computing research challenges. In outline, the objective of this research work was to show upcoming study and open challenges concerning incorporating fog with IoT and to present a study to review current contributions in research on fog computing and IoT in the present world.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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