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Fog Computing Advancement: Concept, Architecture, Applications, Advantages, and Open Issues

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ABSTRACT Internet of Things (IoT) is proliferating in our real world, and it is a promising technology that serves a very comfortable service to the users. IoT's underlying technology is to connect to central Cloud Computing (CC), which is a huge data center collecting the generated data by IoT devices, and it is located in different areas on demand. However, cloud computing lacks data transmission because of the infrastructure and limitations of networks which enormously decrease its performance. Therefore, a new paradigm has been founded to act as a middleware between the Cloud and IoT, termed Fog Computing (FC) Technology. Considering Fog as a cloud extension that provides computing service at the edge of the network, Fog Computing placement enables this technology to deal with numerous data locally. In this study, we surveyed Fog computing with in-depth analysis and covered the latest studies to address and overcome the existing challenges in FC. We reviewed fog computing technology conceptually and defined it based on the existing studies in the literature, together with its architecture, applications, advantages, and open issues with optimization methods being performed to obtain the optimal services.

INDEX TERMS Fog computing applications, Fog computing concept, fog computing open issues, cloud computing, Internet of Things (IoT).

I. INTRODUCTION

The Internet of Things (IoT) supports billions of physical gadgets for data gathering and transmission to different administrations, like environmental monitoring, infrastructure control, and home automation [1]. On the other hand, IoT possesses unsupported elements (e.g., with low latency, locality awareness, and geographic dissemination) that are significant for some IoT administration, including smart traffic lights, home energy control, and augmented reality [2], [3]. Several substantial devices are linked at an unequaled speed from the existence of the IoT. The relaying of information is possible due to the lining together of the devices inclusive of sensors, smart meters, mobile phones, smart automobiles, radio-frequency identification tags, personal digital assistants, and different gadgets [4]. The broadening of IoT results in the production of enormous information (Big Data) that consumes large computing assets, cache memory, and transmission capability [5]. Cisco expects that 50 billion devices will be associated with the Internet by 2020 [6].

The extension technology for IoT is Cloud Computing (CC) [7]. Many users and large organizations have used this technology. Cloud computing can be defined by creating a group of computers and servers interconnected in a network using the Internet. Using cloud computing, the cloud data center is far from the end-user that causes high latency, and the Cloud enables us to perform tasks corresponding to customer demand. There is a large number of available resources. However, even these could not be used effectively, as even distributed computing could not use it as efficiently as it could be used [8]. This situation is accepted by the corporate sector and web application domain. However, it is not appropriate

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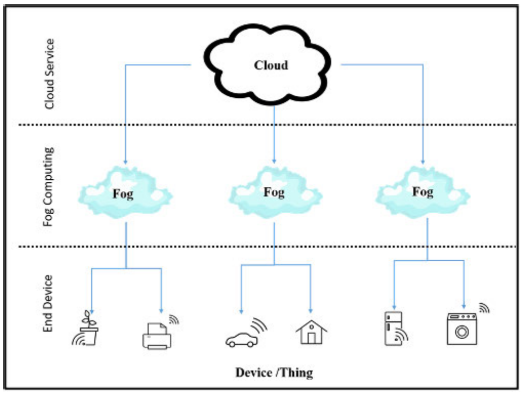

FIGURE 1. Cloud Service, IoT, and Fog environment.

in the mobility domain, which requires low latency and fast response time since data needs to be accessed more quickly. Hence, there is a pressing need for this kind of access [9]. Despite cloud computing providing migration solutions to tackle the certainty and privacy difficulties, there is still persistence of certainty and privacy difficulties because of its distinct characteristics like localized facilities, movement capability, locality recognition, and little inertia. Therefore, Cisco comes up with a new technology concept, termed Fog Computing (FC) [10]. FC provides excellent services compared to cloud computing, thanks to the restricted information storage and information dissemination serving end-users with cloud centers' absence. Fog nodes can act as representatives for the end-services to discharge reliable functions, where gadgets have a scarcity of sufficient resources [11].

Figure 1 illustrates the simple expression of the architecture of IoT, CC, and FC, which are consists of three layers [12]. Firstly, the top layer cloud service is responsible for processing all central data and contains a top tier based on the location servers [13]. Secondly, in the middle layer, the Fog layer, many Fog nodes, and servers are located close to the connected devices. Lastly [14], the lower layer or edge layer uses Internet applications and things as well as advanced devices. This layer separates the connected devices to access information from the haze server instead of connecting through the central cloud server [15]. The contributions of this study are as follows:

- Highlight the trends of Fog computing advancement in the database of IEEEXplore, ScienceDirect, ACM, Google Scholar.
- Define the Fog computing concept based on previous related studies and propose a new FC architecture for sorting the data.
- Investigate and compare the differences and benefits between Cloud computing, Fog computing, and other related technologies.
- Propose a taxonomy based on several key research questions' requirements for the infrastructures and applications for FC technology.
- Address the gaps and limitations and tackle the most recent Fog Computing studies and the appropriate enhancement methods.

Through this study, the related industries and research groups can understand the demands and core concept of designing the efficient network infrastructure and environment for FC with effective control of infrastructure in the Fog.

This article's organization can be described as follows: In section II, we state the methodology of FC. Next, the concept and definition are described in section III. Afterward, the recent technological paradigms are presented in section IV. The architecture of FC is introduced in section V, and the applications of Fog and Cloud are discussed in section VI. Section VII presents the advantages of FC, and its open issues are introduced in section VIII. Lastly, the conclusion is presented in section IX.

II. METHODOLOGY

The essential process of an effective survey study is to select the relevant research questions. In this study, we aim to select the most relevant research questions related to FC in general. Specifically, the ultimate goal of this study is to answer several questions that have unclear answers as FC is an emerging technology. The research questions have been categorized into two categories: The Main Research Questions (MRQ) and Sub-Research Questions (SRQ). Further elaboration is shown in Table 1

TABLE 1. Research Questions.

Term	Research Question
MRQ	Is Fog Computing equivalent to IoT?
SRQ	What is Fog Computing?
SRQ	What is Fog Computing's definition?
MRQ	What is the fundamental difference between Cloud Computing and Fog Computing?
MRQ	Will Fog Computing terminate Cloud Computing?
SRQ	What are the unique merits of Fog Computing?
SRQ	What are Fog Computing applications?
SRQ	What are the available facilities of Fog Computing?
SRQ	What are the Fog Computing challenges?

The search scope and keywords were specified by the most crucial information regarding FC. In this way, we picked all the terms relevant to the study subject for more precise outcomes. The present study considers a range of years between (2015-2021) to determine the direction of Fog Computing's research activities and its up-to-date information. The chosen database is IEEEXplore, ScienceDirect, ACM Digital Library, and Google Scholar.

The initial step was to determine the research questions considered as a research gap. Besides, we narrowed down the search direction to dive into the specification of FC and answer the proposed questions, which are termed MRQ and SRQ.

The keywords that we use as queries depending on the research question, for example ("Fog Computing Applications"), or ("Fog Computing") AND ("Applications"), then we apply the customized range of selected years to filter the relevant studies in FC. The selection strategy for the articles depends on analyzing the paper title and abstract carefully. If the chosen topic is related to our study and the abstract describes and tackles Fog, the paper will be considered, and we tried to cover all the resources. In summary, we have used this policy to comprehensively investigate 67% of journal articles, 25% conference articles, 3% workshop articles, 3% symposium articles, and 2% reports articles among the selected articles in the range of January 2015 until December 2020, as shown in Figure 2.

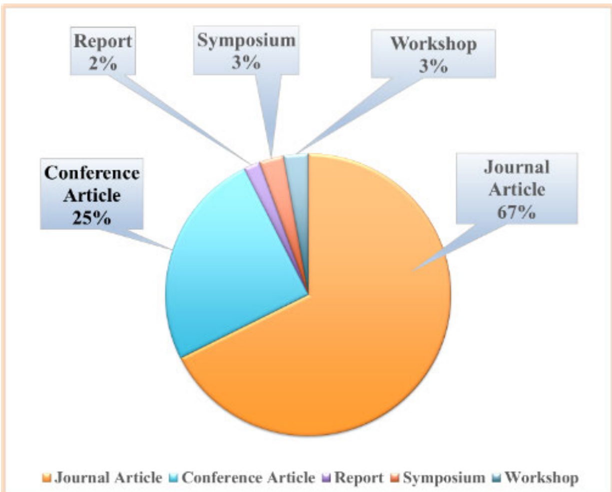

FIGURE 2. The distribution of the selected articles from different sources.

Also, some articles are out of the selected range since we try to cover all the related information of FC. The investigation for research questions in Fog Computing enabled us to propose a taxonomy in Figure 3 to gather and arrange the different architectural possibilities to be included in FC design.

The proposed taxonomy consists of six main categories. Every category answers one or two research questions and provides informative details for the selected technique. The classification of the proposed taxonomy is based on the most well-known issues. The classification in each class also lets scientists and researchers choose the strategies based on the applications that they are interested in.

III. CONCEPT AND DEFINITION

The new vision to revolutionize the wide world using Information and Communication Technologies (ICTs) has laid the Internet of Things (IoT). IoT technology aims to provide connectivity for anything, then enables accessible communication between the human and smart things, and among the smart things according to the seventh International Telecommunication Union (ITU) Internet Reports 2005 [16], [17]. Lately, unique IoT advances and norms have been effectively created for various modern areas and application situations, such as smart homes [18], smart cities [19] and smart cars [20]. Subsequently, they have produced enormous monetary and social advantages to our general public, with positive impacts on user's life.

IoT comes up now to support tens of billions of devices with limited resources, such as smartphones, which are connected to the network directly around us [21]. In addition, it is affecting all of our daily life, together with the spread of recent digital transformation. Notably, the wide deployments of IoT can be observed in monitoring our surrounding environment, for example, the monitoring of healthcare and medicine, environment monitoring, and city management, which require data processing, real-time decision making, and information extraction [22]. The increasing number of interconnected IoT devices to the network and cloud computing generates a huge number of data continuously. Simultaneously, some applications work in real-time, and any delay will face a real problem. Due to all of these challenges, the heavy amount of data exchanges will be infeasible using cloud computing to meet the strict requirements of IoT devices, as follows:

1) Low Latency: Several IoT applications have strict requirements for the delay in service, mainly for the manufacturing use cases and the Internet-of-Vehicle [23]. Particularly, the smart manufacturing systems required end-to-end response time in the order of a millisecond. The vehicle-to-vehicle communications and the drone flight controls typically require latencies below a few tens of milliseconds. This is a typical example to elaborate on the sensitive latency and its potential impact on IoT applications and services.
2) Limited Link Bandwidth: During the rapidly growing number of IoT devices and widely, the central Cloud connection will be busy and may cause an overload or even congestion upon the network bandwidth. Moreover, the sent packet can be lost, and the connection would be delayed. Particularly, the spectrum of IoT devices is limited, and it is impossible to send all the data to the central Cloud. Also, the literature studies demonstrate that most of the generated data from the user or the end-device can be addressed locally without the required transfer of it to the center cloud [24].
3) Limited Computing Power: In general, IoT devices have low processing power due to their low cost and energy constraints. The current approach is to discharge the computing load from the remote clouds. However, additional coordination and processing delays for the discharged activities would inevitably occur. Besides uploading into remote clouds, we should also attempt to unload the computing task to the nearby edge nodes and efficiently use the network's available computing resources [24].

Toward this end, the missing link between the Cloud and IoT continuum is offered by introducing FC to overcome constraints in the existing infrastructure with cloud computing for mission-critical data-dense use. FC transfers data closer selectively to a network edge for efficient computation,

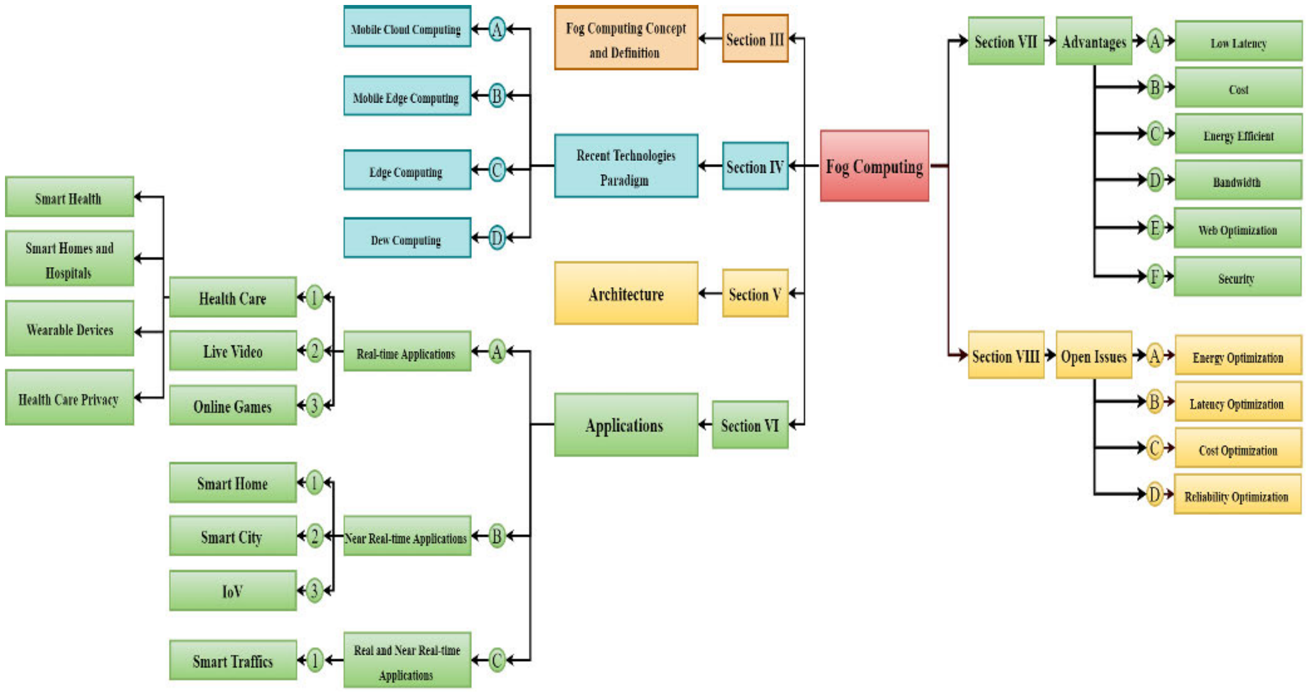

FIGURE 3. The taxonomy of Fog computing.

storage, communication, control, and decision-making [25]. Fog Computing is, by design, a system-wide horizontal architecture that distributes cloud-to-whatever functionality in computing, storage, power, and networking [26].

Fog Computing is characterized as a practical scenario for communication and cooperation with many heterogeneous, ubiquitous, and decentralized devices and the network to perform storing, processing, and processing tasks without third-party intervention [27]. Thus, the Fog infrastructure not only protects the network's parameters but also protects a continuum of cloud-to-the-things, like Cloud, at the edge of things in the network [28]. Building blocks of the Cloud and the Fog that extend the Cloud are computing, storing, and network resources according to this Fog infrastructure trend. Thus, latency-sensitive applications may be processed on the edge of the network, while delay-tolerant and computation-intensive resource-hungry applications can occur in the Cloud [29]

Lately, the data processing at the edge of the network has strongly drawn the researchers' attention and motivated them to contribute to the related technologies. Besides, Fog Computing has become a trending technology because of its appropriate placement between Cloud and IoT, and it can process a huge number of data for each technology. Therefore, we investigated and analyzed the most well-known database for researchers, including IEEE, ScienceDirect, ACM, and Google Scholar, where we used the keywords (''Cloud Computing''), (''Fog Computing'') with the specified period between the year 2015-2020. In Figure 4, we can realize the increased number of the published FC articles compared to cloud computing since the Fog-based system was first proposed in 2015. The new technology motivated the researchers because it has realized a solution to the existing cloud systems' issues and enabled promising IoT applications and services.

Specifically, Fog Computing considers a set of network computing models where computation occurs at the edge of the network with smooth convergence of the cloud infrastructure. FC allows a storage facility for IoT environments or other latency-sensitive device environments. FC facilitates the transmission process in which the data from all connected devices would require huge bandwidth and capacity for processing in the Cloud. In addition, not all devices are connected by Internet Protocol (IP) to the controller but may be connected via some other industrial IoT protocols. Consequently, the encoding or storage of IoT device information is also needed for the protocol translations. Various researchers have varying concepts of Fog Computing. There are a few notable examples, as follows:

Definition 1: Flavio Bonomi *et al.* [30] defined Fog Computing as a heavily virtualized infrastructure, usually but not necessarily be located on the edge of the network that supplies computing, storage, and networking facilities between IoT devices and conventional cloud data centers.

Definition 2: Fog Computing is a paradigm where a certain large number of heterogeneous all-around and distributed devices interact and effectively collaborate with the network to execute tasks for analyzing and retrieving without third-party intervention. These activities may be used to support simple network operations or modern security testing

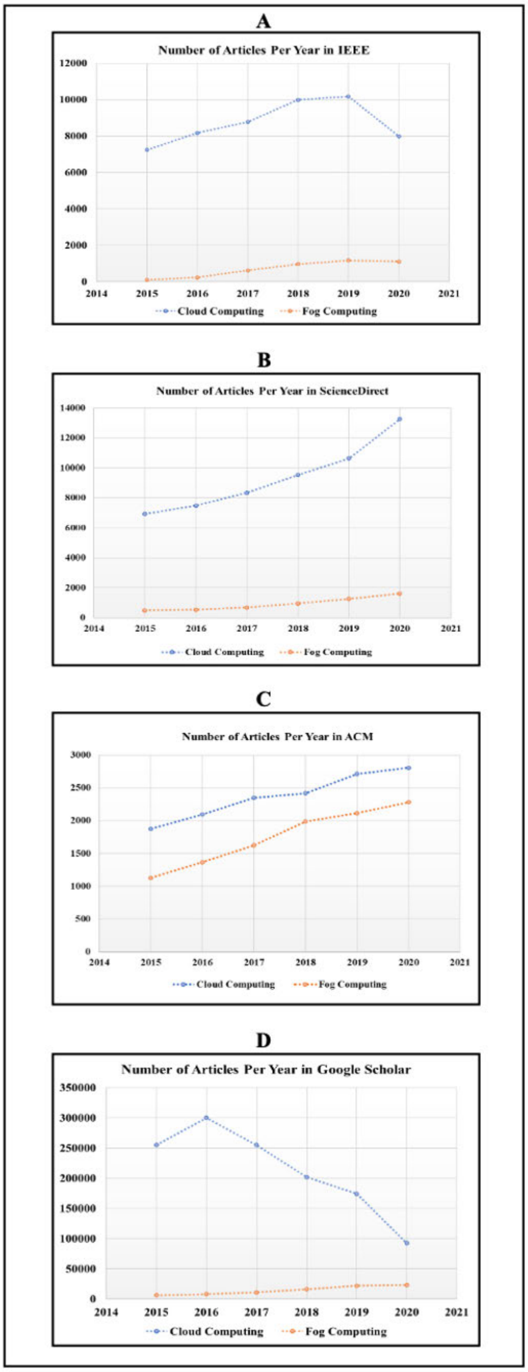

FIGURE 4. The number of publications during 2015-2020 in each database, including A IEEE, B Science Direct, C ACM, and D Google Scholar.

hardware and software. Users that hire their facilities to host these services are allowed to provide them [31].

Definition 3: Another definition is composed by Naha *et al.* [32]; the expression of FC means that FC runs on network edges instead of hosting and operating from cloud computing. As a replacement for building cloud computing storage and usage chains, it is a term to place certain processes and services at the edge of the network using Fog Computing.

Definition 4: Fog Computing is a geographically connected resource computer network consisting of one or more heterogeneous systems connected to the network and not exclusively cloud-based to provide cooperative and flexible computation, storage, and connectivity in an enclosed environment [33].

Definition 5: Fog Computing is a paradigm for communicating and theoretically collaborating a large number of heterogeneous wireless and often uncontrolled omnipotent and decentralized devices between them and with the network to execute retrieval and processing activities without the intervention of third parties. These activities may be used to support simple network operations or modern sandboxing services and software. Incentives are offered for consumers who lease part of their computers to host these services [34].

The Fog Computing model offers an ideal location for most data analysis in the neighborhood of devices that generate these data for the operation. Fog Computing stands amid 'things' that can process and function upon the generated data. The devices within Fog environment systems are known as Fog devices. These nodes are mounted everywhere with the network access, such as on the power poles, at the plant level, next to the railway line, in a taxi, on a shopping mall, and petroleum platforms. A device with the ability to process and store data with memory and network connectivity can function as a FC device. Though Fog is extending the cloud concept, it lies between Cloud and IoT devices functionally and performs tasks in close attachment with the user for processing and storage [17].

Fog Computing relies and concerns more on the infrastructure's side, while edge computing relies more on the devices or things. Moreover, no random cloud-based services such as edge computing are correlated with, such as Software as a Service (SaaS), Infrastructure as a Service (IaaS), and Platform as a Service (PaaS) [29]. In view of the above concepts, we determine FC as follows:

Suggested Definition: We define Fog Computing as the middleware technology between cloud computing and the IoT devices to enable all the devices' operation in a simple but efficient way to connect and securely transfer the data and maintain the connectivity with diminished energy consumption with respect to cost-effectiveness, which is a key factor to provide services with low cost using constrained devices (IoT devices). Besides, the Fog node's stability and the strategy of deploying the node Fog are fundamental to the feasible and successful deployment of FC.

Specifically, in our definition, we consider that all Fog nodes need to concern about time latency, energy consumption, energy distribution, renting cost, and stability so that the Fog nodes have sufficient capability for computing and capacity for storage. Table 2 elaborates on the summarization of some related studieson the concept of FC.

The concept is summarized toward Fog Computing, which reflects a fusion of technology being developed to provide seamless services with high efficiency to a large number of IoT users and the Cloud. The union of these technologies in

TABLE 2. Summary of Definitions.

Defined by	Definition
[35]	Cloud extension
	Fog devices between IoT and Cloud
	Fog nodes have the capability to connect and store data
[30]	Heavily virtualized infrastructure
	Fog devices at the edge of the network
	Supply computing and storage
[31]	A large number of heterogeneous devices
	Fog devices between the user and the Cloud
	Capability to connectivity, store, analysis
[32]	Cloud assistance to run the operations
	In the middle of the network and Cloud
	Storage and usage chains of devices
[33]	One or more heterogeneous systems
	Not exclusive connection to the Cloud
	Computation, storage, and connectivity
[34]	A paradigm for communicating and collaborating
	At the edge of the network
	Fog nodes are able to connect automatically
	Middleware technology
Suggested Definition	Between Cloud and IoT
	Fog devices are able to perform connectivity, storage, and analysis

a single place is a solution to the current standards imposed by the ubiquity of the 'smart' devices to realize efficient network and process management and data protection. As a result, the Fog will effectively move all of the developmental products to nearly every IoT and Cloud layer.

IV. RECENT TECHNOLOGICAL PARADIGMS

Several studies have tackled the essentials differences between cloud computing and FC. The general overview of cloud computing considers the center of data, where all the data are stored for processing, analysis, and transfer. The traditional IoT devices had the capability and tuned extension connectivity with cloud computing. However, the explosive growth number of IoT devices decreased the cloud capability to satisfy the required requests from IoT devices. Therefore, Cisco [35] suggests the extension of the Cloud, which is FC. This study then aims to clarify and elaborate on the differences between these models and their similarities.

Cloud computing is distributed and includes a large amount of data that can be placed across the world, far from client computers. Fog Computing is distributed and includes various small nodes positioned next to the client computers and devices [36]. Fog Computing is the layer for devices like servers, smartphones and handheld devices. Fog Computing functions as a dispatcher, and its data transmission takes less time than that of the normal process in the Cloud. Hence, cloud computing takes more time than FC to connect to the end devices [37]. Cloud computing latency is then high compared to FC [38]. Cloud processing does not decrease the data amount when data is transmitted. However, Fog Computing decreases the amount of information by the priority and sensitivity when it is sent to the Cloud [39].

Compared to Fog, cloud computing maintains a smaller bandwidth. The systems response time is relatively poor in cloud computing compared to FC. Cloud computing is safe, but Fog is even safer. Fog Computing is also stable as a cloud since FC has a distributed architecture. Without the Internet, the Cloud fails, but FC can still utilize a range of procedures and standards if no internet access is available. The Cloud has three frameworks, namely PaaS, IaaS, and SaaS in the FC's scalable architecture. Fog Computing offers user interface assistance where the Cloud can be unified or distributed to third parties. The resource control in Fog Computing is centralized or distributed across the Cloud. Table 3 gives an overview of the varios differences between cloud computing and FC in particular aspects and present the advantages, disadvatnages of each tecnology.

Some related technologies have been established in the fields of fog and cloud computing. They are located between

TABLE 3. Generic Comparison of Cloud & Fog Computing.

Application	Cloud Computing	Fog Computing
Abstraction Level	High	High
Scalability Degree	High	High
Support of Multitask	Yes	yes
Level Transparency	High	High
Run time	Real-time services	Real-time services
Type of Requests	Many small allocations	Many high allocations
Allocation unit	All shapes and sizes (wide & narrow)	All shapes and sizes (wide & narrow)
Level of Virtualization	Vital	Vital
Accessible type	IP	IP
Transmission	Device to Cloud	Device to Device
Security	Undefined	Possible, Determined
Infrastructure	3 models (PaaS, IaaS, SaaS)	Flexible
Support of Operating System	A hypervisor (VM) on which multiple Oss can run	Hypervisor virtualization
Ownership	Single	Multiple
Service negotiation	Centralized or can be delegated to third party	Centralized
Support of User management	Centralized /Distributed	Centralized
Resource management	decentralized /centralized	Centralized
Allocation /Scheduling	Web Services	Interoperability between heterogeneous resources.
Interoperability	Strong (VMs can be easily migrated from one node to another)	Rescheduling of failed tasks
Failure management	Utility pricing discounted for larger customers	Utility pricing and payment is made based on the uses
Service price	IaaS, PaaS, SaaS, Everything as a service	CPU, network, memory, bandwidth, device, storage
Type of services	Amazon, Google apps.	Fog applications involve real-time interactions rather than 228 batch processing.

fog and IoT devices and seek to efficiently create communication that bears the same Fog Computing principle but does not rely exclusively on the Cloud. In this study, we summarize some of these technologies as follow:

A. MOBILE CLOUD COMPUTING

Smartphones and mobile devices have lately become widely used. These mobile devices have access to networks through the mobile network. However, when the devices start to run, their usage for processing depends on the battery level. The battery has a limited power supply to perform other functions such as computing power, electricity, connectivity, and protection constraints. The Cisco Index [40] predicts that 79% of internet traffic in 2022 is Wi-Fi and broadband networks as opposed to 65% in 2017. These constraints result in inefficient implementations involving complicated calculations and storage. This is why these computations are best offloaded to an external computer system, such as the Cloud, through wireless communication. A new computer division called MCC has therefore been created [41]. Figure 5 elaborates the layers of MCC architecture. MCC consist of four phases and every phase presents the layer of connectivity medium

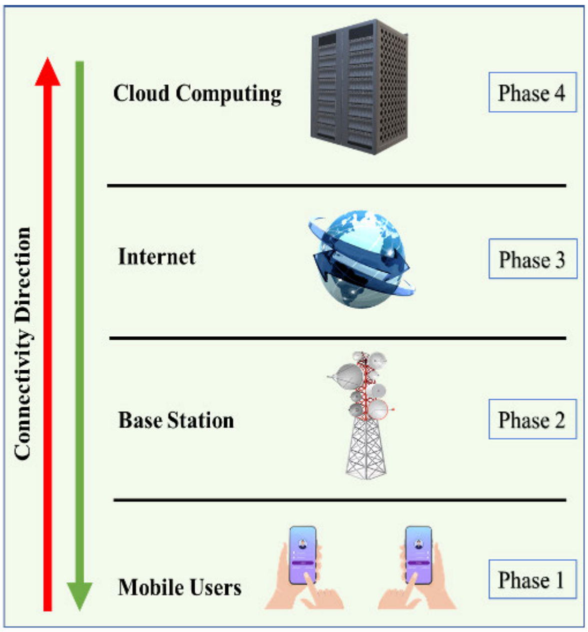

FIGURE 5. Mobile Cloud Computing Architecture.

However, the design of efficient mobile devices is required but might not fulfill these applications' requirements [42]. Instead, edge computing and coordination with the Cloud are needed for complex processing. The low latency middle level of the Cloud, programming models for smooth remote execution, simple mobile cloud services, including presence services, community technology optimization for mobile apps, is essential for mobile computing. The convergence of mobile Cloud is based on a reliable, end-to-end grid and high bandwidth in harsh environments is difficult to be guaranteed [43].

B. MOBILE EDGE COMPUTING

Mobile edge computing is considered a good complement to the existing centralized Cloud by spreading geographically computing services close to the terminal computers. MEC was first suggested in 2014 by the European Telecommunication Standards Institute (ETSI) [44]. With its proximity, MEC expects the network to alleviate congestion, accelerate the reaction, achieve high energy efficiency, and retain context information in 5G and beyond [45].

Lately, in 2017, the name MEC was formally changed to multi-access edge computing by ETSI. This computer paradigm allows individual end-users and businesses to receive new vertical market divisions and services. Various utilities, including IoT, location, increased fact, caching service, video analysis, and local content sharing, may be supplied via this computing paradigm. It provides low-latency real-time access to local content or caching content on the MEC network. Figure 6 elaborates the architecture of MEC with five phases.

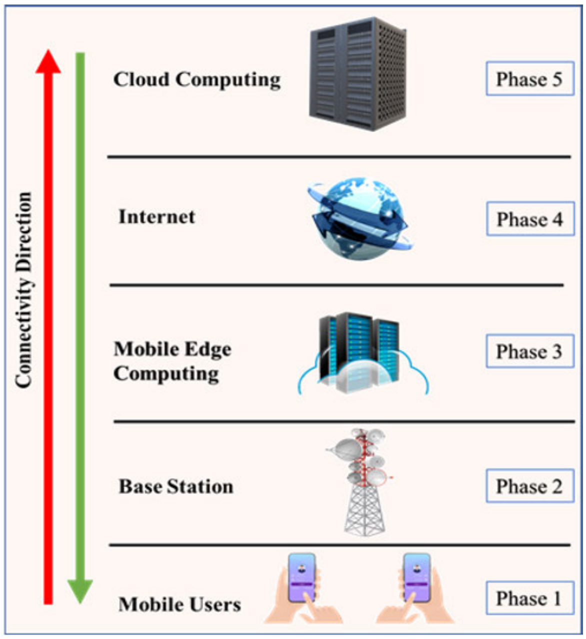

FIGURE 6. Mobile Edge Computing Architecture.

The growth in resource demand over time is another significant challenge. However, the biggest drawback of this framework is that the MEC server is built and devoted exclusively to MEC resources [46]. The Architecture of MEC contains five phases and showing the connection direction throughout the network.

C. EDGE COMPUTING

Edge Computing is also being introduced as a new model for traditional network resource distribution that has drawn considerable interest. Particularly, EC is bringing computing, bandwidth, and storage services closer to the end-user in order to decrease network traffic and response latency [47]. The motivating idea for edge computing is that the process should be placed closer to the data sources. Figure 7 elaborates the EC with the four phases based architecture.

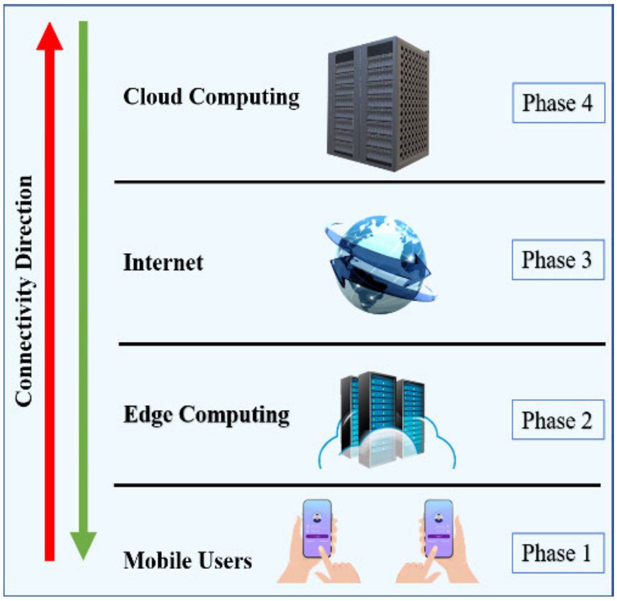

FIGURE 7. Edge Computing Architecture.

The EC uses several IoT-connected devices' storage and computing capacities to provide an intermediary layer between the terminal devices and the Cloud [48]. It minimizes the computing demand in data centers by including end devices by managing local cloud requests that need no cloud interference. This decreases the delay in resolving requests and helps a subset of requests to be handled in real-time. Based on the high availability and geo-distributed design, edge devices often facilitate versatility [49]. The primary aim of edge computing is to carry out the operation closer to data sources. Without only consuming data, items often create data by interacting in processing under the edge computing concept. Besides needing resources and content, edge devices can execute cloud computing activities. The edge node can be used for data collection, copying, encoding, and caching [50]. The edge system will also distribute queries and deliver cloud services to customers.

In these cases, edge systems are required to be carefully adapted to satisfy privacy and protection specifications.

D. DEW COMPUTING

Dew Computing (DC) is a service between the devices inside the network. DC acts as a sub-storage, and the concept of this technology follows the verticallydistributed computing hierarchy [51]. In other words, the devices are connecting to each other to generate a network, which acts as storage and interconnectivity for the other devices. Figure 8 depicts a typical DC architecture.

FIGURE 8. Dew Computing Architecture.

A contrast between cloud infrastructure and dew computing architecture is demonstrated by dew architecture, suggested as a workable alternative solution to the offline data usability dilemma. Dew computing faces a range of technological difficulties, including problems relating to power control, processor utility, and data storage [52]. Other considerations influencing the use of dew computing are the viability of the operating system, the network model, the contact model, the programming principles, the suggested dew computing, the local due network, the high productivity of the personnel protecting the database and the browsing behavior [53]. A comparison of CC, FC, MCC, MEC, EC, and DC is provided in Table 4.

In this section, we summarized that FC is an independent technology working in conjunction with cloud and IoT. Fog Computing is similar to MCC and MEC, but the essential difference is that it can perform processing at the edge. In addition, FCg promises a cozy cost, fast performance, and addresses users' privacy concerns.

V. ARCHITECTURE

The presence of a large amount of data, a heterogeneous wireless environment, and the importance of the Internet of things facilitates communication between things anywhere. However, there are some problems that we still need to face, such as storage and speed of data transfer and others, despite the discovery of FC, which contributed to solving many problems, thanks to proximity to edge devices and proximity to end-users. This study summarizes FC architectures, discusses the most fundamental proposed architectures to enhance FC, and finds suitable solutions to overcome most challenges.

In Figure 9, the general architecture of FC includes three layers, which are generally used to describe Fog Computing's perspective. The first layer is the IoT layer realizing various IoT applications/services in different scenarios, such as smart cities, smart homes, streaming videos, online games, and the smart grid. The second layer is the FC layer, where the servers and devices for FC are located due to the high demand requests for processing and storing the number of data. The third layer is the central cloud server, where all the required data are stored to serve potential customer's requests. Fog

TABLE 4. A Comparison of CC, FC, MCC, MEC, EC, and DC.

Tec.	Connectivity	Bandwidth	Storage	Application	Processing	Users	Reference
CC	Internet	Central Server	High	All application required for cloud service	High	Device to Cloud	[38]
FC	Internet	Local Server	Limited	IoT application, games, video streaming, Big Data, Smart cities, smart homes.	High	Device to Fog and Cloud	[39], [114]
MCC	Internet	Base station + internet	Low	Mobiles applications	Low	Users and Internet to Cloud	[40], [41], [42], [43]
MEC	Internet	Base station + MEC server + internet	Low	Mobiles applications	Medium	User and base station to Cloud	[44], [45], [46]
EC	Internet	Data center + internet	Low	IoT applications	Low	User to server and Cloud	[47], [48], [49], [50]
DC	Internet /without Internet	Bluetooth or NFC or IR or RFID	Limited	Healthcare applications, wireless body area network	Low	Device to device	[51], [52], [53]

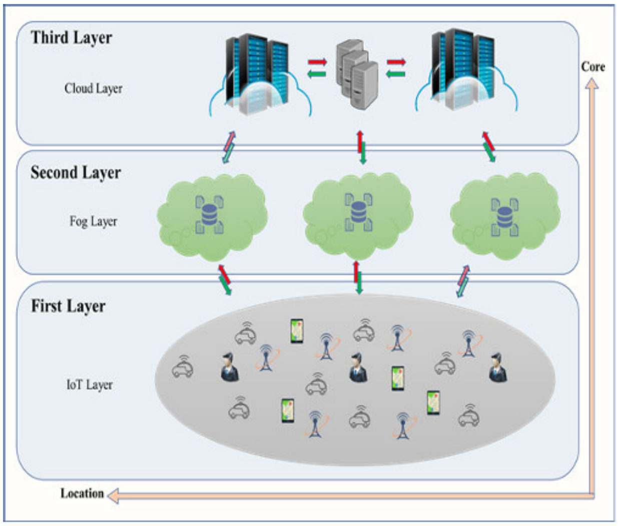

FIGURE 9. Fog computing general architecture.

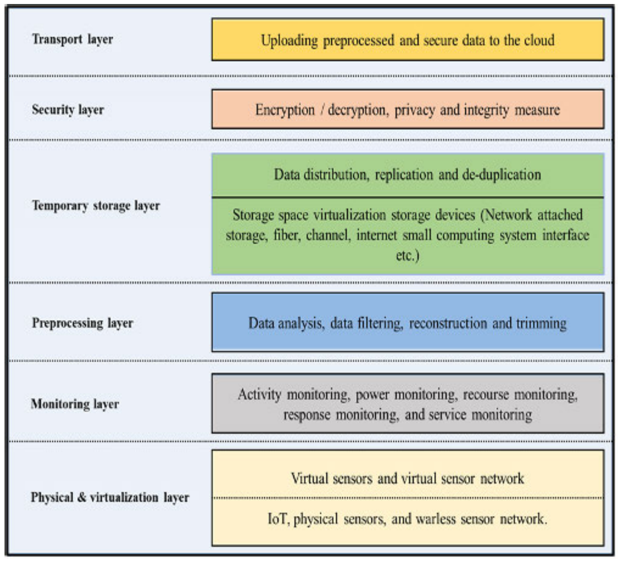

FIGURE 10. Fog computing local architecture.

Computing architectural or local architecture contains six layers, as shown in Figure 10.

The first is the Physical & Virtualization Layer comprises multiple IoT devices. This layer is the lowest layer of Fog dealing with each independent oasis to expand services and communicate. The second layer is the Monitoring Layer, which monitors activities, energy, resources and services. The third layer is the Pre-Processing Layer responsible for data management. Pre-processing layer decomposes the data, and the obtained results are filtering data to minimize unnecessary information. The fourth layer is Temporary Storage, which is responsible for storing data inside the Fog. Most of these data are stored through a timer, and data that is stored long enough can fit the cloud more because it contains all the requested resources. The fifth layer is the Security Layer, and this layer is responsible for security by providing privacy to protect data that will be sent through a public channel at risk. Lastly, the transport layer is responsible for transferring the generated data [54].

In this section, we propose an efficient local architecture for Fog. Technically, we consider serving the user's requests efficiently and timely to minimize any potential delay since some IoT applications need real-time efficacy. Figure 11 shows the proposed seven-step FC local architecture. First, we simulate the Fog receiving a packet of data from the user Route Request (RREQ) in step one (Row data). Step two: Fog computing's task manager will divide the data more straightforwardly. Step three: each part of the divided data is assigned with a number used to identify it. In step four, the assigned data is sorted correspondingly to its priority. Then the sorted data will be uploaded to known channels preparing to enter the FC server in step five. Step six: the server processes data based on the user's request, such as call some data or store it and forward the data to the cloud. Step seven: In the last step, the post-fog computing server decides that the data will be uploaded again for channels preparing for the Route Reply (RREP) with the sorted data.

Although Fog Computing decreases the pressure on the network for the users and ensures there is not any End-to-End (E2E) delay and overhead, with the increased number

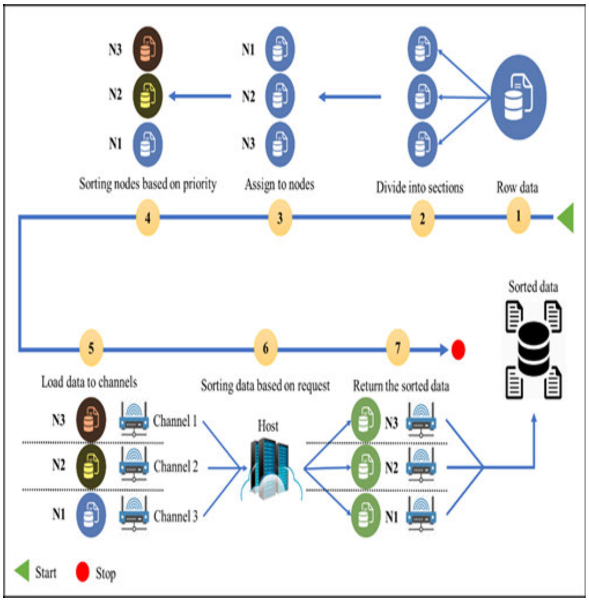

FIGURE 11. Proposed Fog computing local architecture.

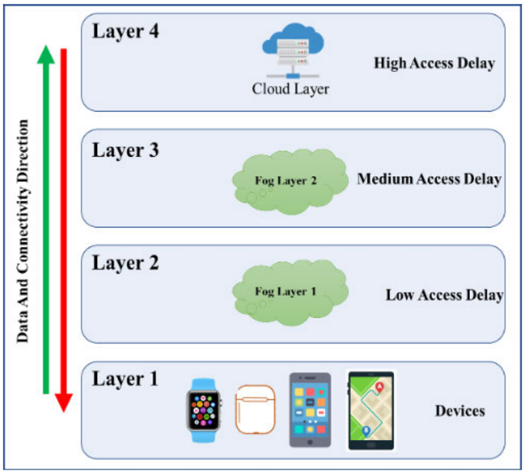

FIGURE 12. Fog computing local architecture [55].

of packets at the same time. Some requests need low cost and less response time. Fog Computing will be lacking to manage these requests due to the high number of requests. Therefore, some studies have suggested new paradigms to enhance the efficiency of FC. Souza *et al.* [55] suggested a new topology, called Combined Fog Cloud architecture (CFC). The proposed architecture consists of four main layers with a further layer that varies from the standard model, shown in Figure 12.

The first layer comprises end-user devices connected with different access technologies like Wi-Fi or 3G, 4G, and LTE. Such end-user devices can request and provide CFC models with services. Typical examples of these applications include Mobile Ad-hoc Network (MANET), Vehicle Ad-hock Network (VANET) and IoT devices.

The second layer: is the default layer of Fog Computing near the end-user and provides the service by wireless connectivity in one or multi-hop, and Fog servers receive the requests with low latency and cost.

The third layer: is the proposed layer. The concept is to generate a new sub-server to host the requests from mobile nodes and the fixed node simultaneously to ensure the Fog computing will serve the users optimally with high accuracy.

The fourth layer: is the traditional layer, which is cloud computing. The third layer will forward the requests being hosted on cloud computing servers. The architecture of Fog Computing generally comprises three layers, and each layer has tasks different from the others, as we explained previously in this section. In short, Fog computing has become an important layer for IoT and cloud computing and plays as an active medium for data transmission securely and efficiently. The particular architecture of FC is flexible based on the static location and users' requests. This means Fog is a default environment for open-source applications so that the developers can add any feature based on types of tasks.

VI. APPLICATIONS

Fog Computing is a whole new paradigm in computing and network technology. In this context, academia and industrial players have a strong interest in FC research and developments. In the era of fostering a smart and lively connected world, the deployment of IoT applications is widely used for automation, monitoring, measurement, navigation, and management. IoT framework encompasses three main components to connect the network with the users. These components are actuators, sensors, and embedded computing systems. Thus, it requires stable resources available in real-time to keep activities and business running smoothly.

Fog Computing infrastructures are operating on local Fog nodes or devices between cloud and IoT end-users; thus, it is also called edge computing or micro data centers to complement the existing cloud data centers. This infrastructure can optimize the bandwidth, improve location-consciousness and minimize latency. Researchers and industry experts are now focusing more on developing high-quality applications with low latency to take advantage of this largely distributed infrastructure.

Fog computing applications comprise two major categories, and each category contains several applications that deal with FC to work efficiently and serve the users a high Quality of Service (QoS). These categories are real-time applications and near-real-time applications. Moreover, some applications use the two categories based on the user's request, i.e., the applications are on-demand. Figure 13 illustrates the taxonomy of Fog Computing applications and their categories in our real life.

A. REAL-TIME APPLICATIONS

For real-time applications/services, responses in the order of milliseconds and even micro-seconds are usually supposed. A device that is not specified in real-time will typically not guarantee a response within any time span, although the response times can be normal or anticipated. If the processing falls within a given required period, for real-time processing, the deadline on receiving data must still be fulfilled

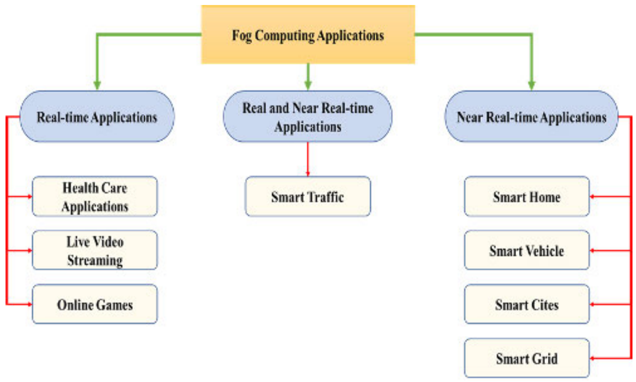

FIGURE 13. Taxonomy of Fog computing applications.

irrespective of the load on the device. The term real-time was often used in the simulation to mean that the simulation clock operates at the same speed as a real clock. Systems used by certain mission-critical applications such as online surgeries, autonomous cars, body sensors, and live streaming need to provide a real-time and reliable functional solution.

1) HEALTHCARE

Nowadays, IoT and Fog Computing contribute to higher performance than traditional cloud computing, especially in the healthcare sector [56]. The healthcare system's goal is to link patients and their caregivers more instantaneously to provide communities the real worth treatment via communication networks. Many research papers in various healthcare directions demonstrate that FC is the fundamental infrastructure to transform IoT from invention to practice [57]. The following are numerous examples of environments in which Fog Computing is operated efficiently.

- **Smart Health:** Fog Computing-based smart health is an architecture that provides patients with wearable or portable medical devices. The medical devices' main tasks are to provide measurements, monitor, report, store, and perform other tasks to reveal the body's essential signs. For example, sensors can track the body temperature, blood pressure, stress level and respiratory rate [58]. Smart health devices connect to FC with many options such as Bluetooth Low Energy (BLE), Wi-Fi, Zigbee, 2G, 3G, 4G, 5G, and LTE. These devices' generated information can be transferred to the data center using the Fog nodes located in the health center preparing to analyze the data [59]. This will ensure the permanent connectivity between the patients and the healthcare centers and monitor their health without required attendance with saving cost.
- **Smart Home and Hospitals:** The idea of smart homes and hospitals is increasingly developing with the advancement of information technology. Smart Home solutions allow individual residents to conduct their daily lives and provide customized services based on their particular routines and desires while safeguarding their privacy [60]. Meanwhile, Smart Hospital is a virtual hospital that integrates all departments and agencies intelligently through optimized and automated processes focused on state-of-the-art medical technologies. So many studies have been done with FC-based IoT healthcare. The IoT is linked to a lot of sensors and computers. However, these instruments are manufactured by various manufacturers for different platforms, which makes it impossible to operate together.
Furthermore, certain activities require significant computing and storage. Most of these problems are solved by Fog Computing. It combines all various platforms and allows scalable tools for intelligent home applications [61].
- **Wearable Healthcare Monitoring System:** The Wearable Healthcare Monitoring System (WHMS) realizes critical, remote communities. The emerging of currently distributed computing paradigms, including wearable devices with the medical IoT for remote healthcare, resulted from wearable devices for medical applications [62]. WHMS devices monitor healthcare and fitness, screen patients constantly, pre-diagnose patients, and monitor biomarkers. By using Fog computing in medical applications, we can lower therapy costs and reduces latency restrictions.
- **Healthcare system privacy:** Data privacy security is introduced in many cases, including traffic surveillance, smart healthcare, intelligent home systems, and location-based services [63] with the development of IoT technologies. In the healthcare sector, the essential aspect of a good healthcare system is that patient privacy with private data in the cloud can be secured using a FC device.

2) LIVE VIDEO STREAMING

Video streaming is increasing in popularity, and heavy streaming leads to reduced latency. Constant and continuous streaming, particularly for audiences in distant regions, has become a challenge. Streaming service has also become one of the most effective web services [64]. Latency reduction is also used by pre-processing many copies of each video and caching video in a geographical region based on the users' repeated requests in the region. In general, video distribution services have to store various formats with the same video and stream a format dependent on viewer device characteristics.

Therefore, different studies have been done to increase the quality of streaming with low latency. Firstly, it is required to measure the video's hotness, which is provided as a model in the study [65]. Another model was developed, which is focused on the hotness calculation and how videos are pre-transcoded to reduce stream providers' expense. Fog Delivery Networks (FDN), the study of [66] was proposed a Federate F-FDN model to enhance the latency of video streaming by decreasing the number of viewers or called Quality of Experience (QoE) based on developing a platform for users in far distance areas. A method in each FDN enables multiple FDN video streaming continuously with the study of the effect of F-FDN on the QoE of users, with common complications features.

The privacy concern was considered in Algimantas *et al.* suggested a lightweight, stable Fog Node End System streaming protocol. The purpose of this protocol is to promote lightweight, unconnected broadcasting and multi-cast playback. Furthermore, the protocol offers data source authentication, energy concern, and data integrity [67].

3) ONLINE GAMES

The additional advantages of cloud computing and Fog Computing enable the gamers to use the platform for online games without caring about the hardware components, such as the memory and the hard disk. While it was an important requirement for high-speed performance to run the games, in recent years, cloud gaming providers have extended or used cloud technology rapidly to offer Games on-Demand services (GoD) to Internet users. The end-users can easily get remote access to enable interactive gaming, and several studies consider the growing number of gaming in this direction. The effect of the growing number of cloud gaming is the increase of high latency and energy. To solve this problem, the study of Yuhua and Haiying [67] has proposed a model termed Cloud Fog, which is a flexible system that contains the super-nodes in charge of generating and streaming game videos to local players. Li *et al.* [68] have proposed an appropriate request that sends an algorithm that assigns play requests to the expected end times of games. In addition, they test a set of groups of algorithms to estimate end times of gaming and choose a neural networked algorithm, and at the end, suggest using actual traces from many online games to carry out thorough assessments of the algorithms.

B. NEAR REAL-TIME APPLICATIONS

In the telecommunication and computer industry, the terminology Near Real-Time (NRT) refers to the time delays between the incident occurrence and the utilization of the transmitted data, e.g., for display or feedback and control purposes, by automatic data processing or network transmission. An almost-actual display, such as displaying an occurrence or circumstance as it occurs at the present time minus the transmission time, is almost the same as the live event.

1) SMART HOMES

A smart home or smart house is a wireless networking system that regulates and tracks the home's functionality, such as lighting, air conditioning, television, and appliances [69]. Home protection can also provide access control and alarm devices. With Internet connectivity, smart homes are an integral part of the Internet of Things. The study of Stojkoska *et al.* [70] has proposed a hierarchical approach for the smart home base on IoT. The proposed model aims to provide low power consumption using FC. Besides, this study proved FC eligibility to be a feature extension in the smart home. Another study [71] discussed the benefit of FC by proposing a model to monitor a patient's health in the smart home in real-time analysis.

2) SMART CITIES

The smart city is an urban area that collects data through different electronic methods and sensors. Data obtained from this knowledge system is used better to control assets, energy, and facilities in return and enhance the region's activities [72]. This comprises data from people, equipment, constructions, and properties that are processed and evaluated to track and control transit systems, power plants, infrastructure, water delivery networks, pollution, and criminal identification. Several studies have conducted in the smart city sector using Fog Computing technology to be enhancing the QoS in smart cities.

The study of [73] presented a model hierarchical distributed using Fog Computing to support the massive number of infrastructure components in the smart cities with the respect of security issues and big data analysis in real-time. Another study of [74] was considered the large scale and ensure high QoS for the smart cities and analyzed the generated big data using FC technology. The model was termed multitier Fog, and the benefit of this study was proved Fog could improve the efficiency of smart cities compared to cloud computing. Moreover, another study of [75] was developed to decrease the workload, and latency minimization, by using two phases. Firstly, a model is built for mapping the data sources. Secondly, a Genetic Algorithm (GA) is used to optimize the latency.

3) INTERNET OF VEHICLES

Smart cars, autonomous driving, self-driving cars, and many more are terms used for smart vehicles. The purpose of these is efficient communications for vehicles due to the high demand for the transport sector which can provide very comfortable services. Fog Computing has been taking an important part in this technology.

FC enables the developers to help more omnipresent cars, increase connectivity performance and solve latency. limitations, location recognition, and real-time responsiveness in traditional vehicular communications [76]. Lately, the concept of autonomous driving was changed into the Internet of Vehicle (IoV) [77]. Fog cloud-based IoV was tackled in the study of [78] by developing FC into information-centric IoV to ensure mobility support and avoiding incessant.

In addition, we developed a mechanism for a data dissension-based information-centric IoV environment. An energy-aware dynamic offloading scheme model was also proposed to increase the battery's lifetime in the IoV by using the battery capacity required to run further applications. For the optimization aspect, a new algorithm was proposed [79].

C. REAL AND NEAR REAL-TIME APPLICATIONS

1) SMART TRAFFICS
Smart traffic lights or intelligent traffic lights are a traffic management system that integrates conventional traffic lights with various sensors and artificial intelligence for smart traffic and pedestrian traffic. Smart traffics light is located in the middle of real-time applications and near-real-time applications. The study conducted by Almuraykhi *et al.* [80] considered the smart traffic light real-time applications. The justification is that the emergency cases, such as ambulance and criminal issues, required emergency patrolling to avoid death cases in high accuracy.
Another study by Rezgui *et al.* [81] was described the traffic as not real-time applications, and the influencing is traffic congestion. Therefore, emergency cases will suffer from congestion and might cost a delay and endanger the patient's life. Several studies were tackled regarding smart traffic [82] was proposed a smart system for efficient control of the intensity of streetlights. Xu *et al.* [83] implemented and designed an emergency light-based smart building solution.

VII. ADVANTAGES

Fog Computing is an environment of high virtualization operating as a middleware between the end devices (IoT) and the data center (cloud computing). It provides networking, storage and computing services. The characteristics of Fog Computing are as follow:

A. LOW LATENCY

Critical applications require real-time processing for interactive services. Robotics-based clouds, smart vehicles and cloud drones, for example, are based on the data generated from the sensors of these devices. The generated data is held by the cloud's control system since the huge number of requests and time to processing and store the data might cost time [84]. Therefore, FC was founded is to help the control system in the cloud computing at the same time very close to these are devices and ensure real-time supplied service. Placing the process near the device in a lower latency compared to the Device to Cloud (DC) architecture because the physical range is shorter, and the possible response time in the center can be eliminated [85]. These can be lower compared to the Device Only (DO) architecture since computationally intensive tasks require more time on sensing devices with limited resources that can be transferred to more powerful Fog calculation nodes.

The motivation can also be to make the delay predictable [86]. Most of the critical application requires a fast response for processing the data and make a decision. Cloud computing is not suitable for this kind of task. Therefore, Fog Computing will be useful in this type of situation [87]. To understand IoT's advantages, it must support the rapid response time and low response time and provide adequate computing and network infrastructure of these IoT applications. Cloud computing is the primary provider of IoT applications with extensive storage and processing capacity [88]. However, because cloud-backed IoT systems are far from users, they face many difficulties.

These difficulties include high response time, lack of mobility, and heavy load on cloud servers. Baccarelli *et al.* mentioned that traffic security, facility, surveillance, and online games could also benefit from Fog Computing's low latency [89]. When data traffic is implemented in the cloud to reduce unprocessed data collected by a group of devices, this reduced time is generally transferred to long-term storage devices. This data can be aggregated, filtered, and processed to obtain knowledge and generate a diminished data set, which is then stored. Instantly refer to other devices as loop sensors.

In these cases, the Fog calculation model can decrease network traffic of the edge to the data center [90].

B. ENERGY EFFICIENCY

Cloud computing requires a large amount of energy, whereas Fog Computing can work as a solution to reduce energy consumption. Several studies showed that energy consumption is low for the device that generates static data for the edge user site and has a low connection. The energy consumption also depends on the amount of time that the connection is idle [91].

On the other hand, FC reduces the energy consumption of sensor devices differently. First, the gateway can act as communication agents so that the device can increase the duration of its sleep cycle. During sleep mode, the gateway is responsible for all requests or updates, then processes when the sensor is activated [92]. Second, energy-intensive accounts and other services can be offloaded from the battery-powered nodes. Additionally, Fog nodes are highly distributed over the spatial domain, and all of them are connected to the network via wireless.

These doses do not have a battery with a limited power charged by renewable energy such as wind turbines and solar panels. The objective of FC is to reduce networking and computing's energy consumption through the adaptive horizontal and vertical scaling of the overall available resource pool [93].

C. BANDWIDTH

Fog computing reduces the amount of data sent to data centers compared to the DC architecture. The amount of data by filtering, pre-processing, analysis, or compressing is processed so that a reduced amount of data is forwarded to the data centers [86].

It is unnecessary to communicate with the data center because the local node can likewise respond to the device's requests based on data cached locally [94]. In another similar study, an FC decreased the bandwidth consumption due to the usage of data processing functions (aggregation, filtering, extraction, and compression) implemented at the edges of the network to decrease data traffic from the edge user to a central location [95].

All the function is implemented for various purposes and is designed to meet application service providers' requirements. To assess the framework's performance, they designed a structure that performs the data compression function between a cloud server and an end device. Results evaluations identified savings in network infrastructure at the expense of latency increase.

If the scene does not change from frame to frame, the developed prototype shows increased bandwidth in video surveillance when applying image compression [96].

D. WEB OPTIMIZATION

Fog Computing increases the performance of the websites. Fog nodes do not have to come and go since each content of the HTTP request for redirects, style sheets, scripts, and images, and we can get through, execute and combine them at once using FC with the help of the web. Besides, users can be identified based on different cookies or MAC addresses, user tracking requests, and determine local network conditions and cache files [97].

Feedback scripts can also be embedded in web pages to measure the user's browser's speed of representation. This directly informs the Fog node and informs the user reception of the current zone, the graphics resolution (if wireless), and network congestion [86].

E. SECURITY

Security is among the most crucial elements in any system. Since Fog Computing is connected to numerous nodes, and the platform could be very complicated, it should maintain a high-security level. FC has all relevant protection controls and approaches, which solve protection risks and mitigate threats [89].

Fog computing retains several benefits of cloud computing and is in excellent condition and can address local performance and problems. Its specific services and resources are done by default and are at the edge of the customer's premise [26]. In FC, the data's security is a crucial challenge, mainly when its data is transmitted, and the Fog is frequently held in its environment. FC helps location awareness, wherein Fog nodes are located in distinct places [98]. The Fog offers a low latency when processing the end-device information because it is closer to the end-device [99]. Due to this closeness to end-device, FC allows estimating the number of connected services and devices [26].

A similar research paper stated that FC allows the user to connect multiple devices to a single network. Instead of a single central location, it can become weak. Power and activity occur between different local endpoints, making it easier to detect threats, including potential intrusions, infected documents, or malware.

Also, threats are recognized very early and can be contained at the device level rather than affecting or risking the entire network [100].

F. COST

Fog Computing has a low operational expense due to low bandwidth. The reason is that FC decreases the volume of data forwarded to the data centers compared to DC architecture. FC evaluates locally selected data rather than transferring it to the cloud for evaluations.

Besides, FC allows a combination of different physical environments and platforms between multiple services. Also, FC is energy efficient, while cloud computing requires a large amount of energy [101].

G. SUMMARY

To summarize this section, we surveyed various Fog Computing applications and can study them as follows: once IoT entered the world rapidly and became like a part of our life, we can expect an explosively increasing number of billions of interconnected devices. This great number of devices generates a huge amount of data based on user's demands. Because of the network's limitations, cloud computing lacks the ability to cover all of these data.

Also, there are three major categories of FC applications: Near-Actual time or Near Real-time applications, Real-time applications, and Real and Near Real-Time applications. The priority and sensitivity of these applications make data transmission become challenging for any technology. In this context, Fog Computing promises the eligibility and promising ability to serve these applications efficiently, as discussed.

VIII. OPEN ISSUES

The optimization mechanism includes several approaches and methods, and the aim is to enhance the performance of any model by examining a high number of expected solutions. Different categories of optimizations include minimizing and maximizing the number of inputs and outputs. In its simplicity, flexibility, and scalability, the conventional stand-alone integrated systems are constrained.

The Fog Computing platform is a promising mechanism approach for the support and strengthening of conventional embedded systems. By pushing cloud services to the network edge, cost management is often a crucial challenge for system deployment success. This section tackles the optimization studies of FC technology and the differences between each method, the corresponding advantages, and disadvantages. Optimization problems are also expressed in formulae specifically, with objective functions of minimization and maximization as shown in (1) and (2), respectively.

$$Min_{x \in R}(x^2 + 1) \tag{1}$$

where Min denotes the minimum value of the objective function for (x2 + 1) when x is selected from a set of real numbers R, and the optimal value is obtained when x = 0; and:

$$Max_{x \in R}(2x) \tag{2}$$

where Max denotes the maximum value of the objective function for (2x) when x is selected from a set of real numbers R. There is no threshold exists since the objective function is infinite, and the consideration for the optimality is infinite or unlimited. Researchers may either use algorithms resolving in a finite number of steps to overcome issues, iterative methods converging to a solution, particularly the class of problems, or heuristics that can solve a number of problems effectively [102].

A. ENERGY OPTIMIZATION

New proposals for energy consumption optimization for FC based on different aspects have been considered in recent years. Many studies demonstrate that virtualization management must be focused on the logic of each virtualized entity's granularity in this relation. The study conducted by Zheng *et al.* [103] presents an optimized design for energy consumption issues with clear consideration of delay performance, a computational challenge when considering the mobile devices with a central computer and the Fog node, which means the edge devices are limited resources.

The study contributes to the simulation of the mobile device and Fog node execution processes by two queuing models. The balance between the energy and delay ensures the consumption of the energy will be minimized. Therefore, the study of Liu, *et al.* [104] was considered the balance and implemented a model using the queuing theory to carry out a detailed analysis of the energy usage, execution delay, and payment costs of the offloading processes in the Fog Computing system.

A multi-objective optimization problem is conceived with a shared aim of reducing energy consumption, delay of execution, and cost of payment by finding the optimum offloading probability and transmission power for each mobile device. In addition, we are using the queuing principle to carry out a detailed analysis of the energy usage, execution delay, and payment costs of the offloading processes in the FC system.

In specific, there are three queuing models for the mobile device, FC, and cloud computing centers, respectively, and it specifically considers the data rate and power usage of the wireless connection. Another study has tackled the offloading workload in a Fog Computing environment to decrease the energy consumption and Quality of Experience (QoE) by data forwarding. The study was designed an algorithm termed as Fairness Cooperation Algorithm (FCA) to ensure the optimal collaboration between fog nodes [105].

Energy-Aware Load Balancing and Scheduling (ELBS) is a proposed model based on Fog Computing using two phases. Firstly, it brings up a model for energy consumption relevant to the fog node workload and formulates a function to improve the load-balancing. Secondly, an algorithm termed Particle Swarm Optimization (PSO) algorithm was enhanced to achieve optimal solutions [106].

B. LATENCY OPTIMIZATION

Latency is a metric in computer networking about how long it takes for a data packet to journey from the source to destination. The latency is preferable as close as possible to zero. The network latency can be calculated by specifying the Round-Trip Time (RTT) for a data packet to and from the destination.

The latency aspect is addressed as one of the major challenges in Fog Computing since it is a new technology and has a limitation. Tang *et al.* [107] studied the latency by developing a model comprising the tasks offloaded from mobile devices by the proposed Road Side Unit (RSU). It is fitted with computer and storage facilities to serve as a gateway to a remote cloud base and a consolidated infrastructure responsible for preparing cars' tasks.

In addition, a greedy heuristic-based scheduling strategy and algorithms. Another study [108] has proposed a latency-aware fog device module management policy that satisfies the diverse latency of service transmission and the sum of data signals to be processed for various applications per unit time. The strategy aims to guarantee QoS applications to reach the service delivery deadline and maximize resource utilization in the Fog Computing environment.

Latency reduction was the goal of [109], which proposed an approach covering device-driven and human-driven intelligence as an enabler to reduce latency in Fog Computing based on two cases.

Firstly, the authors use machine learning for Medium Access Control (MAC) layer scheduling between sensor devices to detect user behavior and perform adaptive low-latency networking. Secondly, they address the task offloading challenge and design an algorithm for the end-user by performing a selection in several fog nodes nearby, then picking the offloading decision while minimizing its energy consumption and reducing the function's latency.

C. COST OPTIMIZATION

Cost efficiency, known as cost optimality/optimization, is the computation measure for efficiency regarding how well parallel computing at the same time can solve a particular problem. In other words, cost optimization is achieved when the asymptotic operation time is equal to the running time of the best sequential algorithm in terms of the number of processing units involved in the machine's operation.

Low-cost run-time synchronization infrastructure was proposed as a cost optimization model in [110]. Time synchronization infrastructure developed using the most recent technologies, including Network Time Protocol (NTP), Precision Time Protocol (PTP), Pay Per Sale (PPS), Global

TABLE 5. Summary of The Studies on Open Issues.

Methodology	Application	Advantage	Work
An alternating direction method of multipliers (ADMM)-based distributed algorithm	Mobile devices and Fog Computing	Execution delay constraints to minimize the energy consumption	[99]
This study developed a framework using queuing models for the mobile device, fog computing, and cloud computing centers	Mobile device, fog computing, cloud computing	Balancing the energy and delay to minimize the energy consumption	[100]
Proposed a model FCA to offloading workload in fog computing environment between the fog nodes	Edge devices and fog nodes	Energy-efficient fair	[101]
ELBS model to and develop an algorithm to minimize the energy consumption	Fog computing and smart factory	Formulating a model and control the load balance	[102]
RSU model to control the offloading of tasks in mobile devices	Mobile vehicles, smart city, and fog computing	Considered the smart vehicle as fog nodes and optimized the latency	[103]
Various service transmission delays and a number of data signals to be transmitted per unit time for various applications.	Fog computing environment	Latency-aware application module management	[104]
Two cases study was considered which is machine learning and end-user algorithm.	Fog computing	Decrease the energy consumption and reduce the latency	[105]
A low-cost approach using hardware device and software applications	Fog computing	Low-Cost efficiency	[106]
Distribute a getaway to minimize the cost with high performance and DMGA model for good quality solutions and high computational rate	Fog computing in industry logistic	Cost-Efficient	[107]
Merge Fog computing with MCPF and formulate a form of mixed-integer non-linear programming.	Fog computing in MCPF	Cost-efficient	[108]
Cost-Makespan aware Scheduling to balancing the applications and cost.	Cloud and Fog computing	Cost- and performance-effective \newline Control system	[109]
A model to distribute the layers of Fog computing.	Fog computing	And reliability enhancement	[110]
FCSD for latency and reliability aspects. ADMM for minimizing the energy consumption	Swam drones and Fog computing	Reliability, latency, and energy.	[111]
A generic architecture for Fog computing and VANET	Fog computing and VANET	Reliability	[112]

Position System (GPS), and Linux with real-time extensions, aims to run on using Beagle Bone Black hardware device.

Fog Computing has wide usage in our live and easy to implementation, especially in the industry. A study proposed a model for deploying gateways [111] to minimize the overall installation expense under the limits of maximum specifications, maximum duration, coverage, and maximum computer capacities. In addition, two meta-heuristic algorithms were proposed to solve the NP-hard problems: the discrete monkey algorithm to search for good quality solutions and the genetic algorithm to increase computational efficiency.

The contribution comes up with a hybrid algorithm termed discrete Monkey Algorithm Genetic Algorithm (DMGA) the optimization, and the results achieved well performed in mild logistics center challenge cases. Medical Cyber-Physical Systems (MCPSs) is a technology that enables smooth and smart interaction between computer elements and medical equipment, and this sector was considered in the study of Gu *et al.* [112] aims to link FC with MCPF because Fog Computing eligible to support these devices with real-time actions and low cost.

Addressing the problem into a non-linear mixed-integer and they linearized it to Mixed-Integers linear program (LP) then proposed a two-phase heuristic algorithm. The study achieved a model termed minimization problem in mixed-integer non-linear programming (MINLP) for satisfied QoS and Low cost. Fog Computing aims to reduce cloud transmission delay and reduce computational costs. Therefore, another study was tackled the perspective delay and cost, respectively. The proposed model's conduct is a scheduling algorithm termed as Cost-Makespan aware Scheduling heuristic aims to balance the mandatory cost and application execution. An efficient task for task reassignment is based on the critical path to ensure Cost-Makespan awareness performance's output to achieve satisfying performance for the user [113].

D. RELIABILITY OPTIMIZATION

Reliability measures the security system in the cloud and Fog Computing to provide a smooth service and ensure a high-performance level. Several variables can influence the associated system negatively. Failures such as system downtime, program failure, compliance infringement, user mistakes, and other unforeseen events are prominent examples.

Therefore, proper preparation and cloud visualization will help address the problems easily and avoid significant issues occurred. Several studies have considered the reliability and its facilities. For instance, in the study of Melnik *et al.* [114], a new approach was proposed, termed control system reliability enhancement, to solve the complexity of the problems by the optimization method, and the problems were proposed as follows: the estimation for computational complexity, and the distribution of fog layers.

Fog Computing aided Swarm of Drones (FCSD) is a proposed model for the study of [112]. The proposed model considers two concepts: latency and reliability with the tough environment and the short lifetime batteries of drone awareness. The study tackled energy consumption minimization by formulating a mathematical model called the Proximal Jacobi Alternating Direction Method of Multipliers (ADMM). Another study is an architecture model for FC. The proposed environment is the VANET, enabling two applications: city traffic anomaly detection and the smart bus time arrival.

A new hybrid environment consists of Fog Computing and VANET and achieving reliability in real-time for the buses [113]. Table 5 expresses the summary of the optimization section.

The new technologies have limitations because the implementation in real-life needs time, cost and space for example. Several methods apply for these models to develop and simulate virtual environments to study every issue and find the proper solutions. Thus the potential solutions help avoid any errors or problems in real environments with less cost and time.

Overall, one of the well-known methods is optimization, which can formulate any problem in real objects into virtual form based on the problem formulation to maximize or minimize the solutions, such as minimizing energy consumption and maximizing the number of sending packets. In optimization, there are also several methods to solve the problems depending on the number of problems.

IX. CONCLUSION

The purpose of this article is to conduct a complete and fundamental survey to study the reality of Fog Computing technology on our real-life and its impact by understanding its core concept. We also define FC based on previous studies and clarify the difference between cloud computing and Fog Computing concerning other related technologies. Moreover, the architecture of FC was tackled in this review article based on FC literature. We demonstrate that FC has a flexible environment to be adjusted based on the users' customized requests. The limitations of cloud computing enabled Fog Computing to be a significant technology that serves as a broker for IoT to facilitate the practical deployments of new types of services matching user's QoS demands and the network operator's requirements at the same time.

From the previous studies in FC, we demonstrate that the optimization method is very effective and plays a vital role in FC. Different optimization categories were applied, especially in terms of energy, latency, cost, and reliability. The enhancements of FC ensure reliable services and high performance with lower cost. As a result, all of these features motivate researchers and related industries to grab the opportunity and develop FC technology. With the numerous merits, FC promises a bright future for the latest technologies, especially those dealing with real-time services with low latency in various industries, such as the healthcare, commercial, financial, and educational sectors. In the near future, a high consideration required to focus on important certain issues such as security, latency, energy, reliability, and stability.

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