JOIV : Int. J. Inform. Visualization, 8(2) - May 2024 564-575

INTERNATIONAL JOURNAL
ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

A Review of Fog Computing: Concept, Architecture, Application, Parameters, and Challenges

Naveed Ghani [a, b,*], Aznida Abu Bakar Sajak [a], Rehan Qureshi [c], Megat Farez Azril Zuhairi [a], Zaid Mujaiyid Putra Ahmad Baidowi [d]

[a] *MIIT, Universiti of Kuala Lumpur, Bandar Wawasan, Kuala Lumpur, 50250, Malaysia*
[b] *SZABIST University, Karachi, Karachi City, 75600, Pakistan*
[c] *University of Southern Queensland, Toowoomba, Darling Heights QLD, 4350, Australia*
[d] *Pusat Asasi, Universiti Teknologi MARA, Dengkil, Selangor, 43800, Malaysia*
*Corresponding author: *naveed_ghani@hotmail.com*

***Abstract*— The Internet of Things (IoT) has become an integral part of our daily lives, growing exponentially from a facility to a necessity. IoT has been utilized extensively through cloud computing and has proven an excellent technology for deploying in various fields. The data generated by the IoT devices gets transmitted to the cloud for processing and storage. However, with this approach, there are specific issues like latency, energy, computation resources availability, bandwidth, heterogeneity, storage, and network failure. To overcome these obstacles, fog computing is utilized as a middle tier. Fog computing gathers and processes the generated data closer to the user end before transmitting it to the cloud. This paper aims to conduct a structured review of the current state of fog computing and its architectures deployed across multiple industries. This paper also focuses on the implementation and critical parameters for introducing fog computing in IoT-cloud architecture. A detailed comparative analysis has been carried out for 5 different architectures considering various crucial parameters to identify how the quality of service and quality of experience for end users can be optimized. Finally, this paper looks at the multiple challenges that fog computing faces in a structured six-level approach. These challenges will also lead the way for future research in resource management, green computing, and security.**

***Keywords*—Fog computing; cloud computing; fog architecture; edge computing; Internet of Things (IoT); architectural analysis.**

Manuscript received 3 Oct. 2023; revised 19 Jan. 2024; accepted 3 Mar. 2024. Date of publication 31 May. 2024.

I. Introduction

Data Networking has come a long way from centralized to distributed approaches and then to cloud computing and IoT. Whenever ubiquitous computing is under the limelight, parameters like efficiency, power usage, availability, and connectivity are pivotal for the network. With a growing number of wireless sensor networks (WSN) and IoT devices every second, a colossal amount of data is being generated that traverses long distances to reach destinations. This data needs efficient processing, storing, and traversing [1]. With cloud computing and its various approaches, such as infrastructure-as-a-service (IaaS), platform-as-a-service (PaaS), and software-as-a-service (SaaS), many models have been deployed to suit business needs. However, data that travels long distances to be processed or stored can be optimized through fog computing. The IoT devices network under pervasive computing to produce raw data, which can be processed in fog and relayed onto the cloud for delay-sensitive implementations. Being closer to the edge, fog can improve response time by processing and consolidating the output, optimizing it for the long haul while saving time and bandwidth [2]. Many areas in fog computing need dire considerations to regulate and benchmark the standards compared to cloud computing.

Fog computing is still a relatively new networking technology. There is no set Fog Federation [3] to govern the communication and benchmark the architecture [1]. Many studies on the comprehensive implementation of fog computing are concerned with efficient task offloading, considering bandwidth, waiting time, availability, security, and energy [2], [4]. However, the Cloud Federation has already defined a well-structured architecture in cloud networking [1]. Therefore, the main challenges in fog computing that need further investigation are quality of service (QoS), cost, energy, bandwidth, and security [4]–[8].

II. Materials and Methods

A. Background of IoT

Communication was restricted to mostly voice-over telephone lines or handwritten letters in the 80s. Later, the Internet existed, and communication started diverting over the digital platform. This was when VoIP was introduced and transformed the entire meaning of communication. With the inception of the Internet and its role in our daily lives today, the term IoT can be defined as all the things that can be connected through the Internet. MIT Auto-ID Labs was the first to give an initial concept of IoT in the 1990s [9]. The first IoT application that came into existence was the Trojan Room coffee pot which gave birth to the term IoT [10], [11]. ITU-T refers to IoT as "Global infrastructure for Information Society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving, interpolative information and communication technologies" [12] which has been referred to in [10] also. Khanna and Kaur [13] have elaborated that the transition from the Internet to IoT has many phases. In the pre-internet phase, communication was based on fixed telephone lines, and then mobile telephony gave mobility in terms of wireless connectivity. The author described the second phase as the Internet of Content, which could exchange large-sized digital content. The third phase was defined as the Internet of Services, which comprised e-commerce, and the fourth phase was described as the Internet of People, which associated people with social media and similar platforms. Shortly, the next phase may be related to Artificial Intelligence, where the IoT devices will be capable enough to make their own decisions without the intervention of humans.

Since IoT is a concept that comes from the Internet, it incorporates IP-based services through IPV4 and IPV6 standards. Therefore, IoT aims to develop an architecture that provides mobility and interoperability between heterogeneous platforms and standards to integrate into cloud computing. Figure 1 shows various communication technologies of IoT.

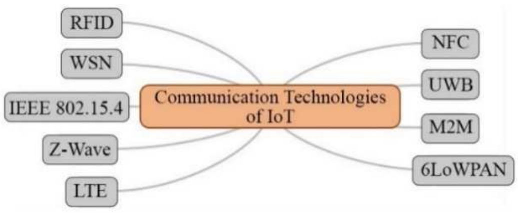

Fig. 1 IoT communication technologies [13]

B. Cloud Computing

Cloud computing has existed since early 2006 and has matured over time to provide virtualized resources based on a vastly deployed infrastructure. Customers use this infrastructure on pay-per-use models with various pricing options. Cloud computing is mainly based on data centers spread worldwide and placed in the middle of the network to be accessed easily via the Internet. These data centers comprise voluminous resource-rich standardized physical servers interconnected by a redundant and stable network [14]. A resource orchestration framework is in place to optimize infrastructure and compliance with SLA. According to the National Institute of Standards and Technology NIST [15], cloud computing is a model that enables global, convenient, as- and when-needed network access to a shared pool of customizable computing resources that can be quickly provisioned and deployed with minimal intervention. Because of these characteristics, the cloud computing industry expected exponential growth from $67 billion in 2015 to $162 billion in 2020 [16].

Cloud computing can be categorized based on their deployment models. These categories are mainly distinguished depending on the availability of the data center and service types. Users can select the most suitable architecture depending on their business needs. As shown in Fig. 2, these models can be private, public, hybrid, or community [15], [17], [18], considering the client of the cloud and the availability of the data center. As for the service type, there are three most commonly used cloud service models. Software as a Service, Platform as a Service, and Infrastructure as a Service [17]–[19] as shown in Fig. 3. The SaaS platform gives responsibility to the end user for the application, programming interfaces, and the GUI, however the OS, virtualization, the middleware and the servers along with the network are not of concern for the end user [15], [17], [20]. In the PaaS deployment model, the cloud provider is responsible for infrastructure, OS, and services platform, and the end user for application, data, and deployment [20]. In IaaS, as defined by Bhardwaj et al., "the delivery of hardware (server, storage, and network), and associated software (operating systems virtualization technology, file system), as a service" [21], the cloud provider offers the infrastructure, OS and virtualization to the end user who is responsible for the entire management from application to storage [15], [20].

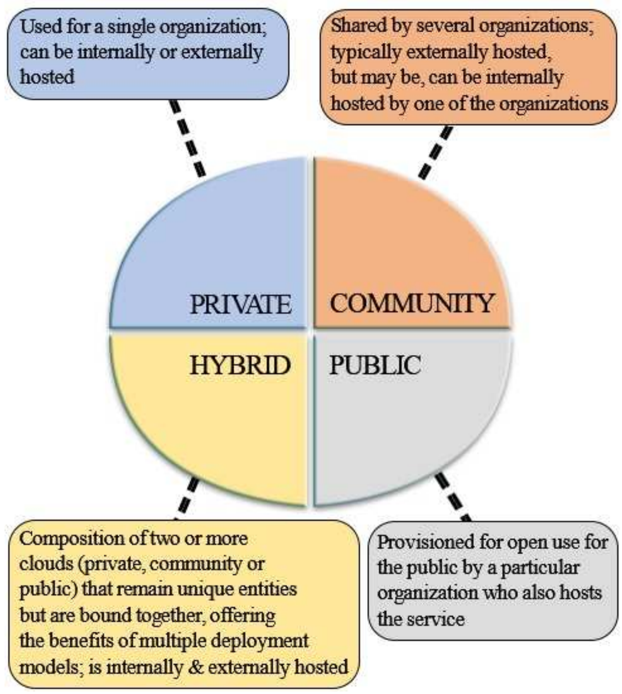

Fig. 2 Cloud computing models [22]

In the past few years, with technological advancements in processing capabilities, storage, and communication, an overabundance of things has been updated with computational capacity, creating what we know today as the IoT era. The devices of this era include but are not limited to smart wristbands, smart building devices, smart city power grids, smart watches, etc. Over the years, the computing power of mobile devices has increased drastically, and the desired interaction and integration with these new smart devices create a scenario in which several heterogeneous devices are combined to work on the same application or service. Due to the characteristics mentioned above of cloud computing and the fact that cloud computation is very far away from the end user, cloud computing cannot deliver the high computation demand in a delay-tolerant environment.

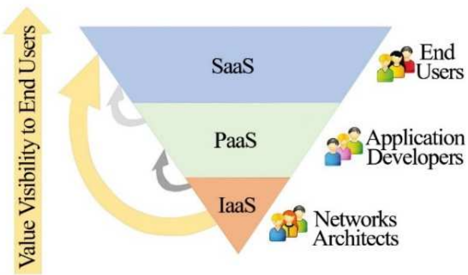

Fig. 3 Cloud computing service models [22]

C. Fog Computing

The entire concept of fog computing is conceptualized when the cloud is closer to the ground. The idea of fog computing was bred to describe the computational paradigm to bring the fruits of the cloud closer to the IoT devices [23]. Therefore, it is also considered a highly distributed computing model integrated with the cloud to carry out the processing at the edge. This will enable the execution of applications that, until then, were not possible because of high latency, which hindered communication between the IoT and the cloud [24]. According to Cisco, fog computing is an expansion of the cloud that spreads from the center to the edge (IoT devices) to enhance performance and data analytics [25]. This expansion comprises many fogs nods spread across various locations to provide application and data services [26]. These fog nodes are like a lighter version of cloud servers and can provide computational capabilities [27]. This scenario can give information and processing capabilities much closer to the end-user devices or the IoT. Fog computing offers a seamless collaboration of assets that can automate processing and storage functionalities in real time [28].

Customization of software and hardware is possible at the fog nodes according to the application's requirements or the environment where it will be positioned [29], which is also discussed in [25] and [27]. Since fog computing offers edge-level processing with suitable latency for enterprises, and because the data are not standardized, the fog analyzes them at the edge before sending the data to the cloud [30], [31]. Heterogeneity, low latency, scalability, mobility, security, and position awareness are all supported by fog technology [32]. As shown in Fig. 4, fog computing aims to enhance and strengthen cloud computing efficacy rather than compete with cloud computing [33].

Fog computing has several benefits, such as helping expand cloud architecture. Fog and cloud computing use similar resources in computing, networking, and storage and feature virtualization and multi-tenancy. However, fog computing introduces some benefits to IoT devices [34].

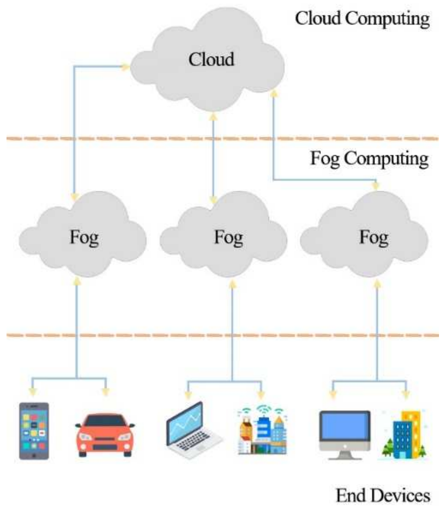

Fig. 4 Fog computing working at the edge to assist the cloud [34]

The benefits of fog can be described as follows:

- Lower latency: Fog computing can support live environments and real-time services [35], [36].
- Higher business agility: Fog computing applications can be easily and quickly developed, deployed, and programmed according to user needs [34], [37].
- Large-scale geographical distribution: Fog computing provides a distributed environment for computing and storage for large and widely distributed applications [35].
- Cost-effective operations: Network bandwidth and energy can be saved by processing the IoT data locally before transmitting it to the cloud for analysis [34], [36].
- Heterogeneity and flexibility: Fog computing can accommodate various network architectures and environments, providing a synchronized data output for the cloud [34], [37].
- Scalability: IoT devices can be increased as and when required as the fog area is closer to the end device [35]–[37].
- Security: Fog computing is deployed closer to the end devices with a minimum delay and can provide high-level security [36].

Table 1 compares various features shared by cloud and fog computing simultaneously. Fog computing is not an alternative to cloud computing, but it boosts the system's efficiency overall for a better end-user experience.

TABLE I
FEATURE COMPARISON BETWEEN CLOUD AND FOG [38]

Features	Cloud	Fog
Service Latency	High	Low
Network Delay	High	Very Low
Location of Service	Within the internet	Edge of local network
Geo-distribution	Centralized	Distributed
Mobility	Limited support	High support
Location awareness	No	Yes
Last mile connectivity	Leased line	Wireless
Distance between client and server	Multiple hops	Single hop

D. *Architecture of Fog Computing*

Fog works with cloud computing to provide delay-tolerant service by bringing some cloud-run operations to the end of the network closer to the IoT devices. Generally, in an orthodox cloud architecture, the data sensed from the sensors or acquired from actuators is sent to the cloud for processing. As a result, the cloud produces a response that can be a command or action carried out on end devices. In such an environment, delay caused by jitter or latency on the network can cause undesired results at the end devices. A fog layer is introduced in the cloud architecture to address this issue, bringing the immediate processing capability closer to the IoT devices. A three-layered approach is used in fog computing architecture, as shown in Fig. 5.

According to Singh [39], the IoT devices are connected to the fog layer, which processes the raw data received by the IoT devices and takes actions as required by the fog application to either send relevant commands back to the IoT devices or send the data to the cloud for further analysis or storage. Once the data reaches the fog layer, it is routed to the relevant fog node for processing. At the fog layer, multiple fog nodes may interact with each other depending on the fog application.

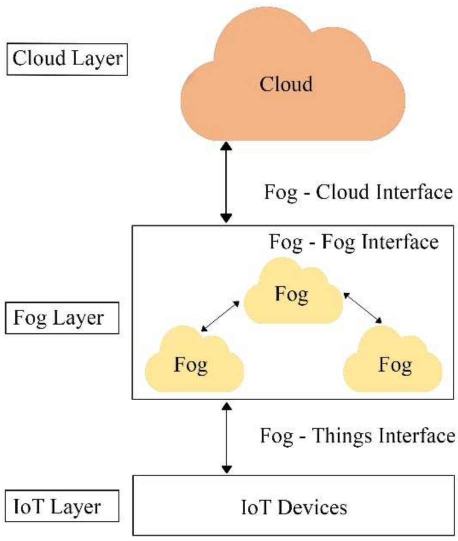

Fig. 5 Fog-cloud interface [39]

This approach reduces the time it takes to process the data and the relevant actions for the IoT devices. This also makes sure that various factors that cause delays over the Internet will not be a problem as the fog nodes are geographically closer to the IoT devices, ensuring quick response and processing in a highly delay-sensitive environment. In addition, having the data processed at the fog layer means the bandwidth and energy can also be conserved. Once the data has been processed at the fog layer and the required actions have been performed at the IoT layer, the results can be sent to the cloud for analysis or storage.

According to Aazam and Huh [40], [41], Mukherjee [24], and Muntjir [42], the fog architecture is built upon six layers, as shown in Fig. 6. The physical and virtualization layer consists of various types of physical and virtual nodes and virtual sensor networks, which are maintained according to their specific type and service demands. The data collected from sensors are sent to upper layers through gateways for cleaning and processing [43]. The monitoring layer monitors all the network elements, resource utilization, and availability of sensors and fog nodes. The tasks carried out by nodes are observed in this layer and include type of tasks, time, and schedule monitoring. Applications and services deployed on the infrastructure are monitored regarding status and performance [24]. This layer observes energy consumption as fog nodes can consume different power levels, making energy management effective and timely [24], [41]. The pre-processing layer manages the raw data extracted from the IoT devices. This data is analyzed, filtered, and trimmed to extract meaningful or required information. A temporary storage layer is used to store this information temporarily. Once the data is sent to the cloud, the storage can be wiped and used again as required [41], [42]. The security layer involves encryption/decryption of the data, and integrity efforts are applied to protect the data that traverses the network. In the transport layer, pre-processed data is physically transmitted to the cloud, which is further processed, analyzed, and stored as required [41], [42].

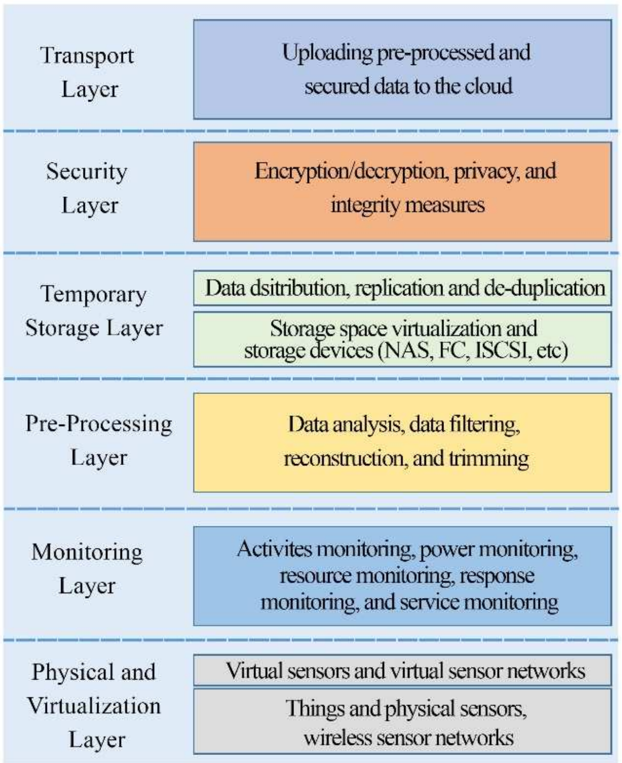

Fig. 6 Fog layer architecture

The OpenFog Consortium has proposed OpenFog [44] hierarchical architecture for fog computing. OpenFog focuses on increasing intelligence in the system by deploying fog nodes at various levels. Fig. 7 shows how the fog nodes are positioned in multiple deployment views. The fog layer is spread out from the end devices to the cloud in different hierarchical orders and is deployed based on the size, type, and latency requirement of the jobs being processed. The fog nodes' tiers differ in capabilities, such as processing, networking, and reliability, therefore creating more intelligence in the architecture. Data acquisition and normalization are performed in the bottom tier, whereas the upper tier controls data filtering, transformation, and compression.

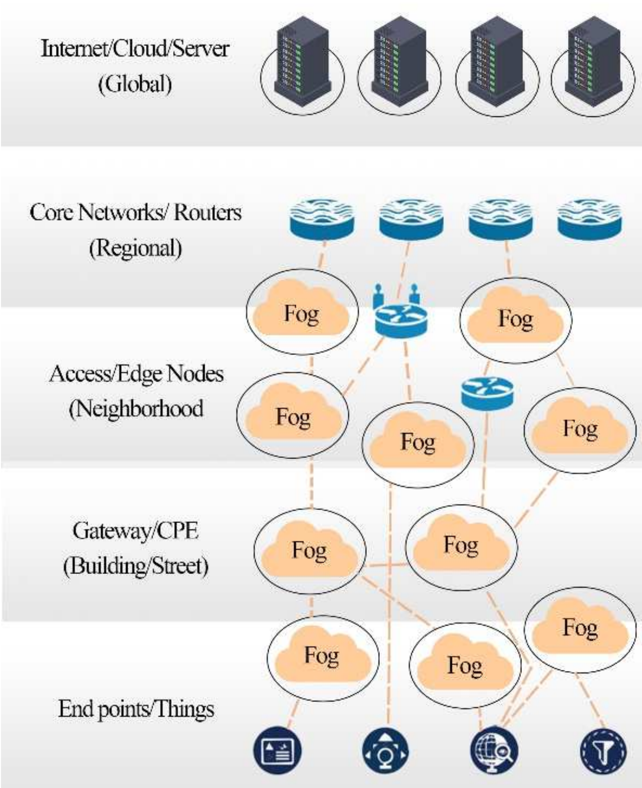

Fig. 7 OpenFog Consortium reference architecture

Clouds Lab has also proposed a fog computing architecture [45], as shown in Fig. 8. This reference architecture aims to reduce complexity by introducing a software-defined resource management layer. This architecture has five layers: the access layer, the network layer, cloud services and resources, software-defined resource management, and IoT applications. At the lowest layer, called the access layer, there are end devices with their software, edge devices, and gateways to connect to the network. The cloud layer provides the computational platform for IoT applications. The software-defined resource management layer organizes and manages all the resources available in the architecture based on an abstract view of the resources, which helps to reduce the complexity. This particular architecture aims to maximize the use of fog to improve the performance of the applications in delay-sensitive environments. The software-defined resource management layer is the key to this architecture; as shown in Fig. 8, 8 critical responsibilities are allocated to this layer.

Another fog computing architecture was proposed by Flavio Bonomi et al. [46], as shown in Fig. 9. In this architecture, the author envisioned the need for heterogeneity and seamless resource management across a diverse set of platforms. In addition, the architecture should be supple enough to support a varied set of application use cases. The proposed reference architecture consists of some components. The heterogeneous physical resource layer is the fundamental component of fog physical resources, including sensors, access points, edge routers, servers, and mobile phones. The fog abstraction layer maintains the heterogeneity of varied platforms for a uniform and programable interface to provide seamless resource management through higher layers. This is achieved using generic APIs to monitor, provision, and control all physical and digital resources.

This layer also incorporates security, isolation, and privacy policies for various architecture components. The service orchestration layer is intended to manage a wholly distributed fog computing environment and offer live, policy-based lifecycle management for all the fog services. This layer comprises a policy manager, capability engine, life-cycle manager, and a distributed database. Foglet enhances orchestration capabilities as a software agent on edge devices. The distributed message bus is employed to piggyback control messages for resource management and service orchestration.

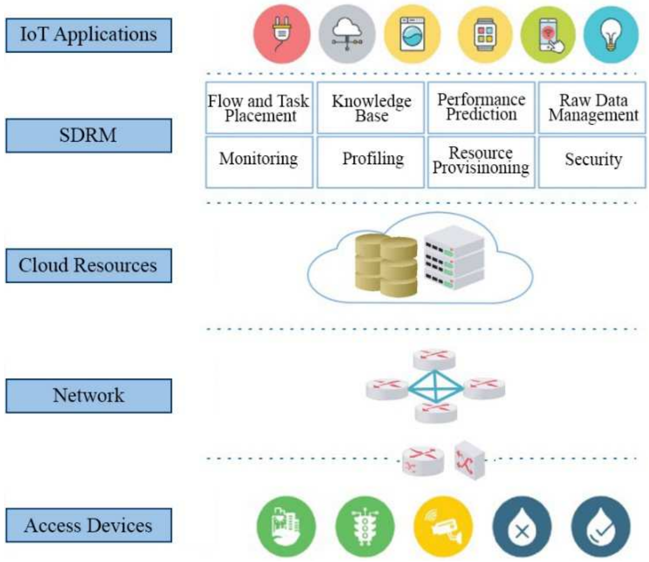

Fig. 8 Cloud Lab fog architecture [45]

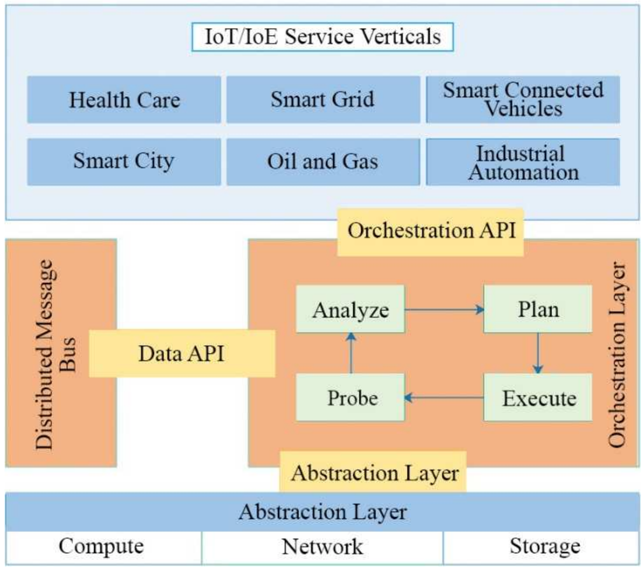

Fig. 9 Cisco-Bonomi fog architecture [46]

Based on the extension and integration of the ETSI NFC framework [47] and ONF's Software-Defined Network architecture [48], Habibi et al. [49] proposed an AUT reference architecture for fog computing. They also discussed interfaces between system components and elaborated on open interfaces mainly derived from OpenStack open APIs [50].

This architecture comprises 5 components, as depicted in Fig. 10. The infrastructure layer is divided into 4 parts: ground (consisting of end devices), fog (hosting fog VNFs), cloud, and network. Fog nodes can be tiny in terms of small storage, network, and computational capabilities or rich fog nodes in high storage, network, and computational capabilities. The Abstraction layer serves the purpose of maintaining heterogeneity and complexity of the infrastructure through high-level API. The Control and Management layer comprises software-defined network controllers and virtual resource management. The SDN controllers provide generic APIs for provisioning, monitoring, and managing the resources. The resource management unit provides inventory, virtualization, monitoring, and performance measurements. The Application and Services layer is responsible for user software, services, and virtual functions installed on physical or virtual resources by the control and management layer. The End-to-End Orchestration layer provisions the control and management layer as and when demands are received from the application and services layer. This may include determining network slices, connectivity, instantiating, allocating, and administering network functions and resources needed for seamless delivery of end-to-end services.

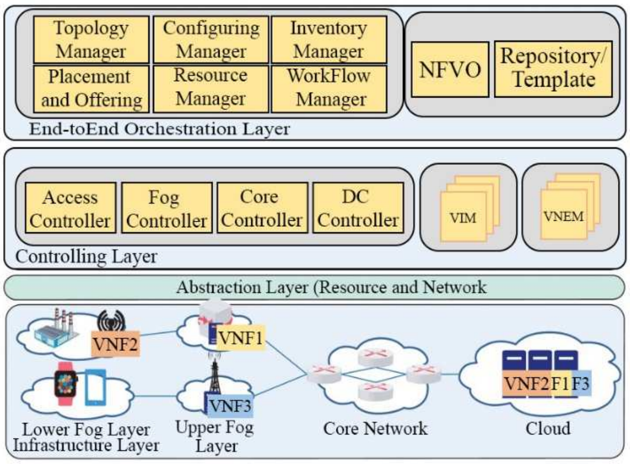

Fig. 10 AUT reference fog architecture

Velasquez et al. [51] proposed SORTS for service orchestration, which comprises three layers, namely the IoT layer, the Fog layer, and the Cloud layer, as shown in Fig. 11. The IoT layer has Virtual Clusters that are a collection of communication terminals. In this paper, the author shows the orchestrator components used to manage and orchestrate all the resources and functions. The Orchestrator comprises of multiple modules. The communication manager is responsible for seamless communication between different orchestrator instances, whereas the resource manager is responsible for monitoring the resource utilization of the infrastructure. The Service Discovery module is responsible for looking up services available in the nearest locations, while the Status Monitor keeps track of tasks and activities in the system. The Security Manager provides privacy and authentication mechanisms. The Planner Mechanism carries out the scheduling of processes and where they will be allocated. The last module, the Optimizer Mechanisms, is located at the upper layer and is responsible for improving the system's performance.

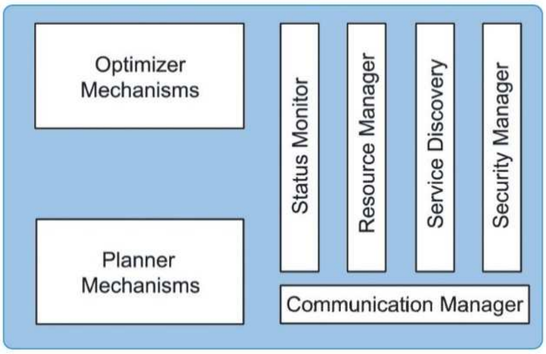

Fig. 11 SORTS hybrid fog architecture

Brito et al. [52] proposed SOAFI reference architecture for fog computing that leverages TOSCA and NFV MANO [53]. As shown in Fig. 12, this client-based reference architecture includes two main components: the Fog Orchestrator and the Fog Orchestration Agent. The Fog Orchestrator is an entity that collects the fog nodes together into logical groups called Logical Infrastructure. This particular formation allows the handling of multiple domains and the carrying out of federation. The Fog Orchestrator comprises the Infrastructure Manager, Orchestration, Monitoring, and Security. The infrastructure Manager keeps an inventory of all resources in the fog domain and performs resource allocation and discovery. The information produced by the infrastructure management module is forwarded to the Orchestrator to carry out the required activities. The Monitoring unit provides the details like the topology of fog nodes in the domain to the Orchestrator. Fog Orchestration Agent is available in each cloudlet, which includes management interfacing for the Fog Orchestrator.

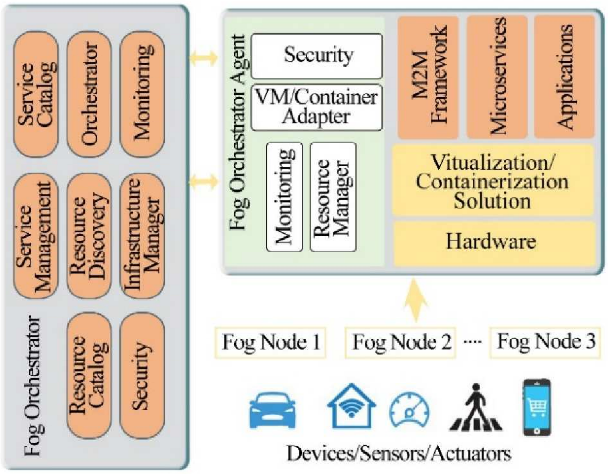

Fig. 12 SOAFI reference architecture for fog computing

Fog computing faces many challenges in terms of the proposed architecture. These parameters have been studied, and a comparative analysis has been carried out, as per Table 2. The parameters have been examined to increase the quality of service for the system and the quality of experience of the end users. It gives a bird' s-eye view of the challenges fog computing faces and its field of research.

TABLE II
COMPARATIVE ANALYSIS FOR FOG ARCHITECTURE

Parameters	AUT	SORTS	Cloud Lab	SOAFI	Cisco-Bonomi
Scalability	Support available at the management and control plane through hierarchical design	Not Available	Not Available	Not Available	Through distributed message bus to provide scalable management channel
Orchestration	Available	Available	Not Available	Available	Available
Heterogeneity	Through virtualization and abstraction layers	Not Available	Available in IoT device layer	Through fog agent withing the fog node level	Through fog abstraction layer within fog node level and physical resources
Scheduling	Through VIM, VNFM, and VNFO	Through Planner mechanisms for processes and their locations	Through SDRM	Orchestrator carries out service management and catalog	Not Available
Path Computation	Through SDN controllers	Not Available	Not Available	Not Available	Not Available
Discovery and Allocation	Service Discovery module	Service Discovery mechanism	Not Available	Through Infrastructure Manager	Not Available
Interoperability	Through OpenStack and REST APIs	Not Available	Not Available	M2M interoperability through standard communication	Through generic APIs (Orchestration and data API's)
Latency	Service placement module	Service placement mechanism	Not Available	Not Available	Not Available
Resilience	Supported through topology manager module	Survivability mechanism at Orchestrator	Not Available	Not Available	Not Available
Prediction and Optimization	Not Available	Global mechanism to improve performance	Through knowledge base system	Through policies for virtual environment	Not Available
Security and Privacy	Not Available	Through Security Manager	Not Available	Data security mechanism as dependencies of the Orchestrator	Not Available
Authentication, Access, Control and Accounting	Through keystone and LDAP	Security manager provides an authentication mechanism	Not Available	Not Available	Not Available

III. RESULTS AND DISCUSSION

With all the advantages of fog computing, it becomes an ideal solution for real-time, delay-sensitive, heterogeneity, low latency, and resource-hungry applications. There are many sectors that incorporate fog computing to enhance QoS and end user experience through fog computing. A few applications have been discussed below.

A. Fog Computing for Smart Home

The idea of smart homes is rapidly developing with technological advancements. Smart homes are an idea where home residents can spend their daily life in a more efficient manner based on their particular routine. The concept of smart home is where the home appliances are IoT devices which can be monitored, administered and controlled from distance. Hassan et al. [54] has described how IoT can support colossal number of gadgets for gathering and transmitting data to different administrations such as monitoring of environment, home automation and infrastructure control. L. U. Khan et al. [55] describes how fog computing can help wirelessly regulate home appliances such as lighting, television, air conditioning, and fans. Another study proposes a hierarchical distributed fog computing architecture for integration of various IoT devices for home automation [56] which has also been discussed in [57]. There are various applications of smart homes using fog computing for efficient power consumption and energy management where authors have proposed fog architecture that use data from home appliances to manage and control these devices intelligently [58]–[62]. There are multiple studies available where authors have proposed fog computing architecture for data confidentiality, authentication and enhanced security [63]–[66]. Al-Syouf et al. [67] has proposed a smart home system based on fog computing that helps prevent or limit DDoS SYN flooding attacks through 3-way handshake with webserver, and a query tokenization technique to detect SQL injection attacks. The author has also proposed fog layer with hash-based security system to prevent theft of sensitive data.

B. Fog Computing for VANETs

Vehicular Ad-hoc Network has been around since 2000 when car-to-car communication began and has evolved to a complex network of shared computational resources. It is a concept in which cars communicate with the fixed infrastructure on the roadside as well as other cars that are traveling on the road [68], which is later used in Intelligent Transport Systems (ITS) offering traffic management solution that integrates humans, cars, street protection, and traffic management systems through telecommunication technologies like Wi-Fi, GPS and IoT sensors [69]. VANET can offer various services, like traffic control for congestion areas and real-time safety measures to prevent accidents [70]–[72]. In such an environment, delay and latency are of utmost concern as decisions must be made in real-time.

Therefore, fog computing has proven to be an essential role player in VANETs. Security, confidentiality, and data integrity are important aspects of VANET's growth. Samara et al. [73] have developed a fog-cloud layer that decreases the time taken for real-time applications on VANET for queries and responses by addressing the challenges faced by VANET, such as reaction time, storage, and reliability. The author has proposed a system that brings the computation closer to the vehicles to cater to latency caused by long-distance communication to the cloud. Liu et al. [74] formulated the problem of service delay via the cooperation of vehicle-to-cloud, vehicle-to-fog, and vehicle-to-vehicle communication.

To address this problem, the author proposed a Clique Searching Scheduling (CSS) algorithm, which caters to the heterogeneous nature of interfaces and vehicle mobility in scheduling and enables effective and timely transmission among the fog nodes, cloud, and vehicles. Paul et al. [75] studied the traffic congestion issue with the exponential rise in road traffic. The author has proposed a Real-time routing algorithm designed for ITS-enabled fog-oriented VANET. The system gathers real-time traffic data and aims to re-route vehicles through a Next Hop selection algorithm to avoid traffic congestion.

Another issue of grave importance for VANET is security. Bousselham et al. [76] have discussed the importance of security in VANETs and have introduced Decoy Technology (DT) and User Behavior Profiling (UBS) as an alternative solution when traditional cryptographic algorithms fail, and the security keys have been compromised. Through fog computing architecture, this solution helps cater to security, privacy, and trust in vehicular fog nodes and servers. Another paper by C. Tang et al. [77] discusses the possibility of resource pooling in Vehicular Fog Computing in a way that the computational resources of vehicles are pooled up and combined to provision computational capabilities jointly in a community through a genetic algorithm to solve optimization problems.

C. *Fog Computing for Healthcare*

In the age of IoT, the primary concern comes down to computational availability, storage readiness, heterogeneity, and mobility. The healthcare sector has become drastically patient-centric, and therefore, these characteristics of fog computing have a significant role in healthcare systems and applications where real-time, delay-sensitive, and highly confidential data traverses over the network. Optimization of such real-time networks has become of paramount importance. Aiswarya et al. [78] have discussed the need for a multi-layer architecture to manage the gigantic size of data generated by healthcare systems and have proposed a time optimization architecture to cater to the system needs, including speed, heterogeneity, accuracy, and latency. Shukla et al. [33] have proposed the Fuzzy Reinforcement Learning Data Packet Allocation (FRLDPA) algorithm. It is a hybrid of fuzzy and reinforcement learning to enhance the network latency in a hospital environment. This approach integrates the hospital IoT devices with fog services to manage the QoS required for latency-critical tasks. Pourkiani et al. [80] have discussed the necessity of fog computing in Wireless Body Sensor Network (WBSN) based healthcare applications.

When communicating with the cloud, these applications cannot perform well due to their delay-sensitive nature; therefore, fog computing brings the computational power closer to the end user in real-time. Winnie et al. [81] have discussed the colossal size of data in the healthcare environment generated by IoT devices sent to the cloud for storage. This data must be processed, optimized, and secured before being sent to the cloud for storage. The author has proposed fog computing as a solution to gather data from devices and encrypt it in fog nodes using the AES algorithm, and then it is sent to the cloud for storage. Adanur et al. [82] have discussed the application of blockchain in healthcare on top of fog computing. The author has proposed a blockchain application based on fog architecture that caters to heterogeneity, latency, and delay sensitivity in the healthcare sector. Other studies in the healthcare sector discuss fog computing as an ideal solution for providing real-time solutions for delay-sensitive and resource-hungry applications alongside providing heterogeneity and security measures to the end users [83]–[87].

D. *Fog Computing for Live Video Streaming*

With the advancements of social media, online movie streaming, and other applications, video streaming has become one of the most bandwidth-consuming services on the Internet. The quality of streaming videos has increased to 8k HD and above, making video content delivery a challenge [88], which is also discussed in [89]. A common approach to reducing this latency in delivery and smooth streaming of video content is to pre-process various quality versions of each video and cache them using content delivery networks specific to a particular geographical area.

This approach is also failing as the sheer size of video content grows exponentially by the second, and content delivery networks are becoming inefficient. Veillon et al. [89] have discussed this issue faced by content delivery networks and proposed an architecture for Fog Delivery Network (FDN). The author has provided methods to federate the FDN to reduce the latency in video streaming. As for caching functionality, FDN can process on-demand videos. Federated FDN pulls cached video content on surrounding FDNs to further reduce latency. It has an evaluation mechanism to calculate the cost-benefit of pulling or processing the video together. Gama et al. [90] have also studied the issues related to video streaming services and have proposed a multi-tier architecture with a set of services for video streaming in fog computing architecture to design and assess a reliable and low-latency multi-tier architecture for the smart city environment. This architecture provides heterogeneity and video on demand by dynamically deploying multimedia services for fog to cloud networks through the ETSI framework while taking advantage of SDN and NFV principles. Ledakis et al. [91] propose a novel and adaptive architecture for smart surveillance that utilizes cloud, fog, and edge resources. The system uses a camera-embedded system at the edge, such as CCTV, a publicly accessible cloud data processing infrastructure, and fog computing, which is utilized for data fusion of video streams in targeted areas.

To overcome the issues with real-time applications such as multimedia streaming and emergency notifications, which need timely response and low latency, Lai et al. [92] have proposed a QoS-aware streaming service over fog computing infrastructure by changing the video quality according to the network service and conditions. The author has run experiments to prove that this mechanism has improved resource utilization and QoS by adapting the video to the best possible quality depending on the network connectivity over fog computing infrastructure. Other authors have also proposed fog computing as a solution for traditional storage and data processing in the cloud that does not satisfy latency-critical streaming [93]–[96].

E. Fog Computing for Smart Grid

Fog computing works as an intermediary between the cloud servers and the end users, ensuring that the delay-sensitive processing takes place closer to the end user to enhance QoS and minimize the load on cloud servers. Smart Grids are used for efficient electricity management to cater to the user demands of electric supply. A smart grid is a two-way communication system that provides electricity to consumer houses from a powerhouse based on their requirements [37].

For this purpose, fog computing is an ideal candidate as it can monitor smart grid data and maintain the information to predict future electricity loads and requirements. Ashraf et al. [97] have proposed an efficient real-time electric management system that minimizes energy wastage and routes the excess energy between deficient grids. The author proposes a three-layered approach for efficient and prompt communication between the end users and the smart grid through fog computing, as it can reduce the processing and response time of cloud data centers. The author has also stated that Active Monitoring Virtual Machines and Throttled load balancing algorithms outperform round-robin scheduling for fog server electricity requests. A. Mohanty et al. [98] state that cloud computing is a good solution for on-demand computational needs. Still, it has drawbacks, such as response time and latency.

Therefore, the author proposed a fog-aided cloud-based model for efficient resource management in smart grids. The author has encompassed four meta-heuristic algorithms for load balancing assisted by fog computing: gradient-based optimizer, swarm optimization, any colony, and artificial bee colony. Barik et al. [99] have applied fog computing in a distribution generation system known as Microgrid. Fog computing is introduced to relieve the cloud from heavy processing and multi-tasking when dealing with large data volumes. The fog framework is hardware-oriented and based on Intel Edison, which increases the system's effectiveness by lowering power consumption, overlaying analysis capabilities, and reducing storage requirements. Redondo et al. [100] state that smart meters have capabilities such as control and communication and have efficiently enhanced energy delivery. However, they have also given way to threats that need countermeasures. Unexpected variations in energy consumption can be an eye-opener and result in an unsolicited set of events. The author has introduced an approach based on fog computing that supports analysis of electricity usage, alongside establishing a mechanism to avoid injection of incorrect data in the smart grid monitoring system. Chouikhi et al. [101] have investigated the problems smart grids face regarding increasing energy demands, energy costs, and total blackouts.

The author aims to distribute energy consumption daily to avoid congestion during peak hours by proposing a fog-based model for demand scheduling using cost as a motivation. This model lets fog nodes schedule appliance operations by monitoring consumers' preferences to reduce energy consumption. The author proposes a fog node assignment scheme to decide which appliance will be managed by which node. This assignment scheme aims to optimize the usage of fog node resources alongside decreasing the schedule processing latency. Other studies [102]–[106] also discuss fog computing applications in smart grids to assist with various resource scheduling schemes, latency issues, and energy management issues in real-time applications.

F. Concerns and Challenges

Although fog computing has its charms and advantages, such as assisting cloud computing to maximize QoS and QoE, it also comes with a few concerns and challenges. This paper studies these challenges in a structured approach through six identified levels.

1) Application Level: Fog applications can be deployed over areas with different service providers, which means that fog nodes will require control and data interfaces for interoperability at both the provider and fog levels. Developers find it challenging to incorporate heterogeneous resources to work under one system. Reliability is paramount for fog computing environments, especially for mobility applications. Checkpoints and rescheduling can be utilized to ensure reliability, but end users will have a tradeoff with latency and response time. The devices in fog computing may have hardware and software errors and unexpected real-time situations unique to a particular system or application. Therefore, fault tolerance is a factor that needs consideration when implementing fog computing as it will cause delay and latency.

2) Monitoring and Security Level: since fog nodes are connected to the Internet, they are susceptible to DoS attacks and Man-in-the-Middle attacks. Although studies and research are discussed in this paper incorporating Transport Layer security mechanisms and handshaking protocols to avoid such attacks, more reliable and stern monitoring and security protocols dedicated to fog computing are yet to be seen to prevent such attacks. Privacy and access control are also a concern as the nature of fog nodes are lightweight and energy-limited, which makes fog computing strategy for access control a difficult task

3) Storage Level: By nature, fog computing nodes store data temporarily, which is sent to the cloud for storage once processed. When this data is required again, it takes time to arrive from the cloud. Also, protection is a concern in fog computing, as it is challenging to manage nodes to encrypt or decrypt the data while sharing it with the cloud.

4) Processing Level: As discussed in this paper, fog computing processes the data locally and then forwards it to the cloud for further analysis and storage. The nodes do not have enough computational resources to complete the task on their own. Also, fog provides lower latency solutions for applications like VANETs and Smart Cities; however, centralizing the analysis and processing of data may result in higher latency.

5) Management Level: Resource management is the biggest challenge discussed in this paper. With fog computing, the resources are limited and must be managed efficiently for a smooth user experience. For geographically separated user devices, it is hard to locate the data and then map the user's tasks to the appropriate node with the required resources concerning task complexity, the sensitivity of time, and the uniform distribution of resources.

6) Infrastructure Level: There is no doubt that IoT devices are increasing exponentially and are distributed across a wide variety of heterogeneous platforms. To enhance user experience, these platforms require interoperability through fog computing to provide heterogeneity. It is challenging to allocate computational resources and tasks in a foggy environment while incorporating heterogeneity to users, especially with low latency and energy-efficient requirements. Fog nodes utilize wireless sensor networks with virtual machines containing operating system, storage and applications. Managing these virtual machines in a foggy environment is also a challenge.

IV. Conclusion

This paper aims to complete a review of fog computing technology and its applications in our daily lives. After detailing the concept of fog computing, this paper has identified the shortcomings of cloud computing. It has proposed fog computing as a solution for various sectors like the automobile industry, smart homes and grids, healthcare, and online streaming. The nature of cloud computing and its limitations led to fog computing. It works efficiently as a middle tier to overcome the drawbacks of cloud computing. Fog computing has proven to be a technology that can cater to the QoS demands of low-latency requirement applications with higher performance and energy consumption efficiency. The architecture of fog computing has been reviewed extensively, and a comparative analysis has been carried out in this paper to identify the key parameters of fog computing. The current state of fog computing faces challenges that have been reviewed in a structured six-level approach for future works. Fog computing has a brighter future for real-time applications with low latency requirements. However, strong consideration is required to focus on security, resource management, and reliability issues.

References

[1] C. Anglano, M. Canonico, P. Castagno, M. Guazzone and M. Sereno, "*A game-theoretic approach to coalition formation in fog provider federations,"* 2018 Third International Conference on Fog and Mobile Edge Computing (FMEC), Barcelona, Spain, 2018, pp. 123-130.

[2] K. Arikumarand V.Natarajan,"Fiot: A QoS-aware fog-IoT framework to minimize latency in IoT applications via fog offloading," in *Evolution in Computational Intelligence*, Springer,2021, pp. 551–559.

[3] H. Shamseddine et al., "A Novel Federated Fog Architecture Embedding Intelligent Formation," in *IEEE Network*, vol. 35, no. 3, pp. 198-204, May/June 2021

[4] FY.K.Teoh,S.S.Gill,andA.K.Parlikad,"IoT and fog computing based predictive maintenance model for effective asset management in industry 4.0 using machine learning," in *IEEE Internet of Things Journal*, pp. 1–1, 2021.

[5] M. S.Aslanpour, A.N.Toosi, C.Cicconetti, B.Javadi, P.Sbarski, D.Taibi, M.Assuncao, S.S.Gill, R.Gaire, and S.Dustdar,"Serverless edge computing: vision and challenges," in *2021 Australasian Computer Science Week Multiconference*, ACM, 2021, pp. 1–10.

[6] P.Habibi, M.Farhoudi, S.Kazemian, S.Khorsandi, and A.Leon-Garcia, "Fog computing: a comprehensive architectural survey," in *IEEE Access*, vol.8, pp. 69105– 69 133, 2020.

[7] M. Abbasi, E.Mohammadi-Pasand, and M.Khosravi, "Intelligent work load allocation in IoT-fog-cloud architecture towards mobile edge computing," in *Computer Communications*, Elsevier, 2021 Volume 169, pp. 71-80.

[8] M. S.Aslanpour,S.S.Gill,andA.N.Toosi,"Performance evaluation metrics for cloud, fog and edge computing: A review, taxonomy, benchmarks and standards for future research," in *Internet of Things*, Elsevier, 2020, Vol. 12, pp. 100273.

[9] Ma, HD, "Internet of things: Objectives and scientific challenges", in *Journal of Computer science and Technology*, Springer, 2011, vol. 26(6), pp. 919–924.

[10] Madakam, S., Ramaswamy, R., & Tripathi, S., "Internet of Things (IoT): A literature review", in *Journal of Computer and Communications*, Scientific Research, 2015, vol. 3, pp. 164-173.

[11] Abou-Zahra, S., Brewer, J., & Cooper, M, "Web standards to enable an accessible and inclusive internet of things (IoT)", in *14th Web for All Conference on The Future of Accessible Work*, ACM, 2017, article 9, pp. 1–4.

[12] M. Elkhodr, S. Shahrestani and H. Cheung, "The Internet of things: Vision & challenges", in *IEEE 2013 TENCON - Spring Conference*, pp. 218–222.

[13] Khanna, A., Kaur, S. "Internet of Things (IoT), Applications and Challenges: A Comprehensive Review", in *Wireless Personal Communications,* Springer, 2020, vol. 114, pp. 1687–1762.

[14] Ashkan Yousefpour, Caleb Fung, Tam Nguyen, Krishna Kadiyala, Fatemeh Jalali, Amirreza Niakanlahiji, Jian Kong, and Jason P. Jue. "All one needs to know about fog computing and related edge computing paradigms: A complete survey". in *Journal of Systems Architecture*, 2019, vol. 98, pp. 289–330.

[15] P. M. Mell and T. Grance, "The NIST definition of cloud computing," National Institute of Standards and Technology, 2011. doi: 10.6028/nist.sp.800-145.

[16] V. Jaruhar, T. Nema, and V. Kulshrestha, "Cloud Computing: Future and Challenges," in *International Journal of Advance Research in Science and Engineering (IJARSE),* 2018, vol. 6, pp. 378-388.

[17] A. Jain and N. Mahajan, "Introduction to Cloud Computing," in *The Cloud DBA-Oracle*, Springer, 2017, pp. 3-10.

[18] L. Sahi, M. Sood and S. Saini, "Analysis and Evaluation of Mobile Cloud Computing: Service Models, Applications, and Issues," in *4th International Conference for Convergence in Technology (I2CT)*, Mangalore, India, 2018, pp. 1-7.

[19] Mohammed, F.; Ali, A.M.; Al-Ghamdi, A.S.A.-M.; Alsolami, F.; Shamsuddin, S.M.; Eassa, F.E., "Cloud Computing Services: Taxonomy of Discovery Approaches and Extraction Solutions", in *Symmetry 2020*, vol. 12(8), 1354.

[20] A. S. Al-Ahmad and H. Kahtan, "Cloud Computing Review: Features And Issues," in *International Conference on Smart Computing and Electronic Enterprise (ICSCEE)*, Shah Alam, Malaysia, 2018, pp. 1-5.

[21] S. Bhardwaj, L. Jain, and S. Jain, "Cloud computing: A study of infrastructure as a service (IAAS)," in *International Journal of engineering and information Technology*, vol. 2, pp. 60-63, 2010.

[22] http://bigdatariding.blogspot.com/2013/10/cloud-computing-types-of-cloud.html

[23] M. Abdel-Basset, N. Moustafa, R. Mohamed, O. M. Elkomy and M. Abouhawwash, "Multi-Objective Task Scheduling Approach for Fog Computing," in *IEEE Access*, vol. 9, pp. 126988-127009, 2021

[24] Mithun Mukherjee, Lei Shu, and Di Wang, "Survey of fog computing: Fundamental, network applications, and research challenges", in *IEEE Communications Surveys and Tutorials,* 2018, vol. 20, 3, 1826–1857.

[25] Y. Chen, E. Sun, and Y. Zhang, "Joint optimization of transmission and processing delay in fog computing access networks," in *9th International Conference on Advanced Infocomm Technology (ICAIT)*, Nov. 2017, pp. 155–158.

[26] B. H. Husain and S. Askar, "Survey on Edge Computing Security," in *Int. J. Sci. Bus*., vol. 5, no. 3, pp. 52–60, Jun. 2021.

[27] A. Khakimov, A. Muthanna, and M. S. A. Muthanna, "Study of fog computing structure," in *IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*, Jan. 2018, vol. 2018-Janua, pp. 51–54.

[28] C.-C. Lin and J.-W. Yang, "Cost-Efficient Deployment of Fog Computing Systems at Logistics Centers in Industry 4.0," in *IEEE Trans. Ind. Informatics,* vol. 14, no. 10, pp. 4603–4611, Oct. 2018.

[29] W. Steiner and S. Poledna, "Fog computing as enabler for the Industrial Internet of Things", in *Elektrotechnik und Informationstechnik*, Springer, vol. 133, no. 7, pp. 310–314, Nov. 2016.

[30] M. Aazam, S. Zeadally, and K. A. Harras, "Deploying Fog Computing in Industrial Internet of Things and Industry 4.0," in *IEEE Trans. Ind. Informatics*, vol. 14, no. 10, pp. 4674–4682, Oct. 2018.

[31] K. D. Ahmed and S. R. M. Zeebaree, "Resource Allocation in Fog Computing: A Review", in *Int. J. Sci. Bus.*, vol. 5, no. 2, pp. 54–63, 2021.

[32] A. B. Manju and S. Sumathy, "Efficient Load Balancing Algorithm for Task Preprocessing in Fog Computing Environment," in *Smart Innovation, Systems and Technologies,* Springer Singapore, 2019, vol. 105, pp. 291–298.

[33] S. Shukla, M. F. Hassan, L. T. Jung, and A. Awang, "Architecture for Latency Reduction in Healthcare Internet-of-Things Using Reinforcement Learning and Fuzzy Based Fog Computing," in *Advances in Intelligent Systems and Computing*, vol. 843, 2019, pp. 372–383.

[34] Atlam, H.F.; Walters, R.J.; Wills, G.B., "Fog Computing and the Internet of Things: A Review", in *Big Data and Cognitive Computing*. 2018, 2, 10.

[35] G. Peralta, M. Iglesias-Urkia, M. Barcelo, R. Gomez, A. Moran and J. Bilbao, "Fog computing based efficient IoT scheme for the Industry 4.0," in *IEEE International Workshop of Electronics, Control, Measurement, Signals and their Application to Mechatronics (ECMSM)*, Donostia, Spain, 2017, pp. 1-6.

[36] T. -A. N. Abdali, R. Hassan, A. H. M. Aman and Q. N. Nguyen, "Fog Computing Advancement: Concept, Architecture, Applications, Advantages, and Open Issues," in *IEEE Access*, vol. 9, pp. 75961-75980, 2021.

[37] A. M. Farooqi, S. I. Hassan and M. A. Alam, "Sustainability and Fog Computing: Applications, Advantages and Challenges," in *3rd International Conference on Computing and Communications Technologies (ICCCT)*, Chennai, India, 2019, pp. 18-23.

[38] S. N. Shirazi, A. Gouglidis, A. Farshad and D. Hutchison, "The Extended Cloud: Review and Analysis of Mobile Edge Computing and Fog from a Security and Resilience Perspective," in *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 11, pp. 2586-2595, Nov. 2017.

[39] S. K. Singh and S. Kumar Dhurandher, "Architecture of Fog Computing, Issues and Challenges: A Review," in *IEEE 17th India Council International Conference (INDICON),* New Delhi, India, 2020, pp. 1-6

[40] M. Aazam and E. -N. Huh, "Fog Computing and Smart Gateway Based Communication for Cloud of Things," in *International Conference on Future Internet of Things and Cloud*, Barcelona, Spain, 2014, pp. 464-47

[41] M. Aazam and E. -N. Huh, "Fog Computing Micro Datacenter Based Dynamic Resource Estimation and Pricing Model for IoT," in *IEEE 29th International Conference on Advanced Information Networking and Applications*, Gwangju, Korea (South), 2015, pp. 687-694.

[42] Muntjir, M.; Rahul, M.; Alhumyani, H.A. "An Analysis of Internet of Things (IoT): Novel Architectures, Modern Applications, Security Aspects and Future Scope with Latest Case Studies," in *Int. J. Eng. Res. Technol.* 2017, 6, 422–447.

[43] Liu, Y.; Fieldsend, J.E.; Min, G. "A Framework of Fog Computing: Architecture, Challenges and Optimization", in *IEEE Access,* 2017, 4, 1–10.

[44] C. Byers and R. Swanson, "OpenFog reference architecture for fog computing", in *OpenFog Consortium, Feb 2077, Available:* https://www.iiconsortium.org/pdf/OpenFog_Reference_Architecture_2_09_17.pdf

[45] A. Vahid Dastjerdi, H. Gupta, R. N. Calheiros, S. K. Ghosh and R. Buyya, "Fog computing: Principles architectures and applications" in *Distributed, Parallel, and Cluster Computing, Available:* https://doi.org/10.48550/arXiv.1601.02752

[46] F. Bonomi, R. Milito, P. Natarajan and J. Zhu, "Fog computing: A platform for Internet of Things and analytics" in *Big Data Internet Things: A Roadmap for Smart Environments*, Cham, Switzerland:Springer, pp. 169-186, 2014.

[47] "Network Functions Virtualization (NFV) Architectural Framework", in *ETSI GS NFV 002 V1.2.1*, ETSI, 2014, www.etsi.org/deliver/etsi_gs/nfv/001_099/002/01.02.01_60/gs_nfv002v010201p.pdf

[48] Haleplidis, Evangelos et al. "Software-Defined Networking (SDN): Layers and Architecture Terminology." in *RFC* 7426 (2015), 1-35.

[49] P. Habibi, S. Baharlooei, M. Farhoudi, S. Kazemian and S. Khorsandi, "Virtualized SDN-based end-to-end reference architecture for fog networking", in *32nd Int. Conf. Adv. Inf. Netw. Appl. Workshops (WAINA),* pp. 61-66, May 2018.

[50] T. D. Fleming, A. Gentle, L. Hochstein, J. Proulx and E. Toews, "OpenStack Operations Guide", Newton, MA, USA, O'Reilly Media, 2014.

[51] K. Velasquez et al., "Service Orchestration in Fog Environments," in *IEEE 5th International Conference on Future Internet of Things and Cloud (FiCloud),* Prague, Czech Republic, 2017, pp. 329-336.

[52] M. S. de Brito et al., "A service orchestration architecture for Fog-enabled infrastructures," in *Second International Conference on Fog and Mobile Edge Computing (FMEC),* Valencia, Spain, 2017, pp. 127-132.

[53] "GS NFV-MAN 001 - V l. l. l - Network Functions Virtualisation (NFV); Management and Orchestration", ETSI, vol. 1, pp. 1-184, 2014.

[54] R. Hassan, F. Qamar, M. K. Hasan, A. H. M. Aman and A. S. Ahmed, "Internet of Things and its applications: A comprehensive survey", in *Symmetry*, vol. 12, no. 10, pp. 1674, Oct. 2020.

[55] L. U. Khan, I. Yaqoob, N. H. Tran, S. M. A. Kazmi, T. N. Dang and C. S. Hong, "Edge-computing-enabled smart cities: A comprehensive survey", in *IEEE Internet Things Journal*, vol. 7, no. 10, pp. 10200-10232, Oct. 2020.

[56] B. Tang, Z. Chen, G. Hefferman, T. Wei, H. He and Q. Yang, "A hierarchical distributed fog computing architecture for big data analysis in smart cities", in *ASE BigData & SocialInformatics.*, pp. 1-6, 2015.

[57] Y. -D. Chen, M. Z. Azhari and J. -S. Leu, "Design and implementation of a power consumption management system for smart home over fog-cloud computing," in *3rd International Conference on Intelligent Green Building and Smart Grid (IGBSG)*, Yilan, Taiwan, 2018, pp. 1-5

[58] M. Kutseva, "Adaptation of Seven-Layered IoT Architecture for Energy Efficiency Management in Smart House," in *10th International Scientific Conference on Computer Science (COMSCI),* Sofia, Bulgaria, 2022, pp. 1-5

[59] U. Mir, U. Abbasi, T. Mir, S. Kanwal and S. Alamri, "Energy Management in Smart Buildings and Homes: Current Approaches, a Hypothetical Solution, and Open Issues and Challenges," in *IEEE Access*, vol. 9, pp. 94132-94148, 2021

[60] S. Javaid, N. Javaid, S. K. Tayyaba, N. A. Sattar, B. Ruqia and M. Zahid, "Resource Allocation using Fog-2-Cloud based Environment for Smart Buildings," in *14th International Wireless Communications & Mobile Computing Conference (IWCMC)*, Limassol, Cyprus, 2018, pp. 1173-1177

[61] R. Madani, B. Alturki, S. Reiff-Marganiec and W. Alsafery, "My Smart Remote: A Smart Home Management Solution for Children," in *1st International Conference on Computer Applications & Information Security (ICCAIS),* Riyadh, Saudi Arabia, 2018, pp. 1-8

[62] B. R. Stojkoska and K. Trivodaliev, "Enabling internet of things for smart homes through fog computing," in *25th Telecommunication Forum (TELFOR)*, Belgrade, Serbia, 2017, pp. 1-4

[63] A. S. Hamzah and L. A. Abdul-Rahaim, "Smart Homes Automation System Using Cloud Computing Based Enhancement Security," in *5th International Conference on Engineering Technology and its Applications (IICETA),* Al-Najaf, Iraq, 2022, pp. 164-169.

[64] A. Kanyilmaz and A. Cetin, "Fog Based Architecture Design for IoT with Private Nodes: A Smart Home Application," in *7th International Istanbul Smart Grids and Cities Congress and Fair (ICSG),* Istanbul, Turkey, 2019, pp. 194-198.

[65] A. K. Ray and A. Bagwari, "IoT based Smart home: Security Aspects and security architecture," in *IEEE 9th International Conference on Communication Systems and Network Technologies (CSNT)*, Gwalior, India, 2020, pp. 218-222

[66] K. Sha, R. Errabelly, W. Wei, T. A. Yang and Z. Wang, "EdgeSec: Design of an Edge Layer Security Service to Enhance IoT Security," in *IEEE 1st International Conference on Fog and Edge Computing (ICFEC)*, Madrid, Spain, 2017, pp. 81-88

[67] R. Al-Syouf, B. Al-Duwairi and A. S. Shatnawi, "Towards a Secure Web-Based Smart Homes," in *12th International Conference on Information and Communication Systems (ICICS)*, Valencia, Spain, 2021, pp. 195-200.

[68] E. Eze, S. Zhang and E. Liu, "Vehicular ad hoc networks (VANETs): Current state challenges potentials and way forward", in *20th International Conference on Automation and Computing*, 2014, pp. 176-181.

[69] S. Ravi and M. R. Mamdikar, "A Review on ITS (Intelligent Transportation Systems) Technology," in *International Conference on Applied Artificial Intelligence and Computing (ICAAIC*), Salem, India, 2022, pp. 155-159

[70] G. Samara, "Intelligent reputation system for safety messages in VANET", in *IAES International Journal of Artificial Intelligence*, 2020, vol. 9, no. 3, pp. 439.

[71] J. Bhatia, R. Dave, H. Bhayani, S. Tanwar and A. Nayyar, "SDN-based real-time urban traffic analysis in VANET environment", in *Computer Communications*, vol. 149, pp. 162-175, 2020.

[72] E. Qafzezi, K. Bylykbashi, E. Spaho and L. Barolli, "A new fuzzy-based resource management system for SDN-VANETs", in *International Journal of Mobile Computing and Multimedia Communications (IJMCMC)*, vol. 10, no. 4, pp. 1-12, 2019.

[73] G. Samara, M. Rasmi, N. A. Sweerky, E. A. Daoud and A. A. Salem, "Improving VANET's Performance by Incorporated Fog-Cloud Layer (FCL)," in *22nd International Arab Conference on Information Technology (ACIT)*, Muscat, Oman, 2021, pp. 1-5.

[74] K. Liu, K. Xiao, P. Dai, V. C. S. Lee, S. Guo and J. Cao, "Fog Computing Empowered Data Dissemination in Software Defined Heterogeneous VANETs," in *IEEE Transactions on Mobile Computing*, vol. 20, no. 11, pp. 3181-3193, 1 Nov. 2021.

[75] A. Paul and S. Mitra, "Real-Time Routing for ITS Enabled Fog Oriented VANET," in *IEEE 17th India Council International Conference (INDICON)*, New Delhi, India, 2020, pp. 1-7.

[76] M. Bousselham, N. Benamar and A. Addaim, "A new Security Mechanism for Vehicular Cloud Computing Using Fog Computing System," in *International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*, Fez, Morocco, 2019, pp. 1-4

[77] Tang, C., Xia, S., Li, Q. et al. “Resource pooling in vehicular fog computing,” in *Journal of Cloud Computing* 10, 19, 2021.

[78] S. Aiswarya, K. Ramesh, B. Prabha, S. Sasikumar and K. Vijayakumar, "A time optimization model for the Internet of Things-based Healthcare system using Fog computing," in *International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES),* Chennai, India, 2021, pp. 1-6.

[79] S. Chakraborty, S. Bhowmick, P. Talaga and D. P. Agrawal, "Fog Networks in Healthcare Application," in *IEEE 13th International Conference on Mobile Ad Hoc and Sensor Systems (MASS),* Brasilia, Brazil, 2016, pp. 386-387.

[80] M. Pourkiani, M. Abedi and M. A. Tahavori, "Improving the Quality of Service in WBSN Based Healthcare Applications by Using Fog Computing," in *International Conference on Information and Communications Technology (ICOIACT),* Yogyakarta, Indonesia, 2019, pp. 266-270.

[81] Y. Winnie, U. E. and D. M. Ajay, "Enhancing Data Security in IoT Healthcare Services Using Fog Computing," in *International Conference on Recent Trends in Advance Computing (ICRTAC),* Chennai, India, 2018, pp. 200-205.

[82] B. Adanur, B. Bakir-Güngör and A. Soran, "Blockchain-based Fog Computing Applications in Healthcare," in *28th Signal Processing and Communications Applications Conference (SIU)*, Gaziantep, Turkey, 2020, pp. 1-4.

[83] Amir M. Rahmani, Tuan Nguyen Gia, Behailu Negash, Arman Anzanpour, Iman Azimi, Mingzhe Jiang, Pasi Liljeberg, “Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach,” in *Future Generation Computer Systems*, Volume 78, Part 2, Pages 641-658, ISSN 0167-739X, 2018.

[84] Aparna Kumari, Sudeep Tanwar, Sudhanshu Tyagi, Neeraj Kumar, “Fog computing for Healthcare 4.0 environment: Opportunities and challenges,” in *Computers & Electrical Engineering*, Volume 72, Pages 1-13, ISSN 0045-7906, 2018.

[85] Mohammed Al-khafajiy, Lee Webster, Thar Barker, Atif Waraich, “Towards fog driven IoT healthcare: challenges and framework of fog computing in healthcare,” in *ICFNDS '18*, Article No.:9, Pages 1-7, 2018.

[86] Mutlag, A.A.; Khanapi Abd Ghani, M.; Mohammed, M.A.; Maashi, M.S.; Mohd, O.; Mostafa, S.A.; Abdulkareem, K.H.; Marques, G.; de la Torre Díez, I, “MAFC: Multi-Agent Fog Computing Model for Healthcare Critical Tasks Management,” in *Sensors* 2020, 20, 1853.

[87] Jain, R., Gupta, M., Nayyar, A., Sharma, N., “Adoption of Fog Computing in Healthcare 4.0,” in *Tanwar, S. (eds) Fog Computing for Healthcare 4.0* Environments. Signals and Communication Technology. Springer, Cham. 2021.

[88] "Cisco Visual Networking Index: Forecast and Methodology 2016-2021", White Paper Available: www.cisco.comlc/en/us/solutions/collaterallservice-provider/visual-networking-index-vnilcomplete-white-paper-cll-481360.html#Toc484813971

[89] V. Veillon, C. Denninnart and M. A. Salehi, "F-FDN: Federation of Fog Computing Systems for Low Latency Video Streaming," in *IEEE 3rd International Conference on Fog and Edge Computing (ICFEC)*, Larnaca, Cyprus, 2019, pp. 1-9.

[90] E. S. Gama, R. Immich and L. F. Bittencourt, "Towards a Multi-Tier Fog/Cloud Architecture for Video Streaming," in *IEEE/ACM International Conference on Utility and Cloud Computing Companion (UCC Companion),* Zurich, Switzerland, 2018, pp. 13-14

[91] I. Ledakis, T. Bouras, G. Kioumourtzis and M. Skitsas, "Adaptive Edge and Fog Computing Paradigm for Wide Area Video and Audio Surveillance," in *9th International Conference on Information, Intelligence, Systems and Applications (IISA),* Zakynthos, Greece, 2018, pp. 1-5.

[92] C. -F. Lai, D. -Y. Song, R. -H. Hwang and Y. -X. Lai, "A QoS-aware streaming service over fog computing infrastructures," in *Digital Media Industry & Academic Forum (DMIAF),* Santorini, Greece, 2016, pp. 94-98.

[93] L. Ait-Oucheggou, M. I. Naas, Y. Hadjadj-Aoul and J. Boukhobza, "When IoT Data Meets Streaming in the Fog," in *IEEE 6th International Conference on Fog and Edge Computing (ICFEC)*, Messina, Italy, 2022, pp. 50-57

[94] E. Baccarelli, M. Scarpiniti and A. Momenzadeh, "EcoMobiFog–Design and Dynamic Optimization of a 5G Mobile-Fog-Cloud Multi-Tier Ecosystem for the Real-Time Distributed Execution of Stream Applications," in *IEEE Access*, vol. 7, pp. 55565-55608, 2019.

[95] N. Chen, Y. Chen, Y. You, H. Ling, P. Liang and R. Zimmermann, "Dynamic Urban Surveillance Video Stream Processing Using Fog Computing," in *IEEE Second International Conference on Multimedia Big Data (BigMM),* Taipei, Taiwan, 2016, pp. 105-112

[96] K. Bilal and A. Erbad, "Edge computing for interactive media and video streaming," in *Second International Conference on Fog and Mobile Edge Computing (FMEC)*, Valencia, Spain, 2017, pp. 68-73.

[97] M. H. Ashraf, N. Javaid, S. H. Abbasi, M. Rehman, M. U. Sharif and F. Saeed, "Smart Grid Management Using Cloud and Fog Computing" in *Advances in Network-Based Information Systems*, Cham: Springer, pp. 624-636, 2018.

[98] A. Mohanty, S. Samantaray, S. S. Patra, M. A. Ahmad and R. K. Barik, "An Efficient Resource Management Scheme for Smart Grid Using GBO Algorithm," in *International Conference on Emerging Smart Computing and Informatics (ESCI),* Pune, India, 2021, pp. 593-598.

[99] R. K. Barik et al., "FogGrid: Leveraging Fog Computing for Enhanced Smart Grid Network," in *14th IEEE India Council International Conference (INDICON)*, Roorkee, India, 2017, pp. 1-6.

[100] R. P. Díaz Redondo and A. Fernández Vilas, "Smart Grids Monitoring: A fog-computing strategy to detect anomalies," in *IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)*, Riga, Latvia, 2018, pp. 1-5

[101] S. Chouikhi, M. Esseghir and L. Merghem-Boulahia, "Energy Consumption Scheduling as a Fog Computing Service in Smart Grid," in *IEEE Transactions on Services Computing,* vol. 16, no. 2, pp. 1144-1157, 2023.

[102] W. Zheng, W. Wang, G. Wu, C. Xue and Y. Wei, "Fog Computing enabled Smart Grid Blockchain Architecture and Performance Optimization with DRL Approach," in *IEEE 8th International Conference on Computer Science and Network Technology (ICCSNT)*, Dalian, China, 2020, pp. 41-45.

[103] L. Zhu et al., "Privacy-Preserving Authentication and Data Aggregation for Fog-Based Smart Grid," in *IEEE Communications Magazine*, vol. 57, no. 6, pp. 80-85, June 2019.

[104] S. R. Ullah Kakakhel, A. Kondoro, T. Westerlund, I. Ben Dhaou and J. Plosila, "Enhancing Smart Grids via Advanced Metering Infrastructure and Fog Computing Fusion," in *IEEE 6th World Forum on Internet of Things (WF-IoT*), New Orleans, LA, USA, 2020.

[105] J. Akram, Z. Najam and A. Rafi, "Efficient Resource Utilization in Cloud-Fog Environment Integrated with Smart Grids," in *International Conference on Frontiers of Information Technology (FIT),* Islamabad, Pakistan, 2018, pp. 188-193.

[106] Y. Boloorchi and S. Azizi, "An IoT-Fog-Cloud Framework for Demand Side Management in Smart Grid," in *5th International Conference on Internet of Things and Applications (IoT),* Isfahan, Iran, 2021, pp. 1-6.