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A Survey of Fog Computing: Architecture and Research Challenges

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***Abstract*—The use of Internet of Things (IoT) devices/sensors has increased dramatically. As a result, an enormous data volume is generated and needs to be processed regarding the Quality of Services (QoS) requirements such as security, response time, bandwidth, energy consumption, …etc [1]. In cloud computing architecture, the physical distance between data centers and data sources in IoT devices increases latency in the response and decreases the quality of services for the end-users, especially, in real-time services that require sensitive responses and low latency, such as video streaming and health care systems. An extension to the existing cloud architecture, fog computing has emerged. Generally, fog computing is closer to IoT devices. The key challenge in fog computing is the workload scheduling considering the energy consumption of the fog node. Also, when a fog node lost connection to its fog domain, becomes overloaded, or when energy power is low, the workload of this node needs to be offloaded to another fog node.**

The objective of this paper is to present a comprehensive survey on fog computing architecture, challenges, and analyse the current research in the fog computing field.

***Index terms* — Cloud Computing, Internet of Things (IoT), Fog Computing, Scheduling, Load Balancing, Energy Consumption.**

I. INTRODUCTION

Today, highly competitive business corporates try to find means for cutting costs and maximizing profits. Instead of purchasing computer resources and applications, an alternative model, "pay-as-you-go", has emerged. This is the concept of cloud computing.
According to the US National Institute of Standards and Technology (NIST), cloud computing is
"… a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." [2]

Permitting organizations to focus on core business rather than infrastructure and IT issues which has become the responsibility of the cloud service provider, is a powerful benefit offered by cloud computing.

Despite the popularity of the cloud, there are a lot of challenges like single-point-of-failure, scalability, lack of resources, vulnerability to attack, and downtime issues [3][4]. As cloud data centers are geographically centralized, network congestion, poor Quality of Services (QoS), and latency issues with real-time applications are experienced. This makes cloud insufficient for time-sensitive applications in the Internet-of-Things (IoT) environment [5].

As a result, new technologies have appeared to extend the cloud platform to achieve latency reduction and location awareness. One of the key important and popular models is fog computing.
Fog computing (FC), first introduced by Cisco in January 2014, is a distributed computing model that is placed in the edge network with additional computing processing power and storage resources. It is not a solo application and does not replace cloud computing, but it serves to make the data processing and analysis more efficient [6][7]. FC is a middle layer between cloud computing data centers and the IoT layer and it is located near to the IoT layer.

The main idea of FC is the "smart front-end" concept which adds intelligence to the edge layer. By increasing the storage and processing capabilities, the amount of data being transmitted to/from the cloud has reduced, as a result, network congestion, data storage bottleneck has been eliminated [8][9]. It uses the available resources at the edge nodes to do the computation instead of reducing the load on the cloud data centers.

Despite all the benefits gained from the FC paradigm, researchers face many challenges such as heterogeneity, scalability, latency, complexity, security, and dynamicity [10] [11]. Moreover, energy consumption, resource allocation, and management are the most significant challenge and needs more research.

This survey presents the definition of fog computing focusing on its architecture, characteristics. Moreover, the challenges encountered while designing or implementing fog computing system is discussed.

This paper is organized as follows: Section II introduces fog computing background. Section III presents the challenges in the fog computing. Section IV discuss the existing research methods in the fog computing paradigm. Section V describe the significance of the fog computing field. Section VI provides a conclusion and future research.

II. FOG COMPUTING BACKGROUND

1. *From cloud to fog*

IoT nowadays becomes the most important technology that provides a lot of benefits and services which make life better. Sensors are used in IoT for collecting data from the environment without human intervention.

Shortage in IoT appeared in performance, reliability, security, and limited computations. So, integration with cloud computing will be a better solution to overcome these limitations [12].

But this integration introduces new challenges. IoT applications collect a huge amount of data from devices or sensors, these data need to be analyzed for real-time actions. Sending all these data to the cloud requires high network bandwidth and stability in the connection [13]. Moreover, the geographically centralized structure of the cloud is not suitable for a lot of IoT applications such as health care and vehicle-to-vehicle communications which is time-sensitive for taking decisions. Therefore, fog computing appeared to overcome these issues [14]. Basic differences between cloud computing and fog computing are indicated in table [1].

TABLE 1
Comparison between cloud computing and fog computing [15].

	Cloud	Fog
Deployment	Centralized.	Distributed in regional areas; related to specific locations.
Distance to Users	Faraway. Users connect to it through IP networks.	In the proximity. Users often connect through single hop connections.
Target User	General internet users.	Mainly mobile users.
Hardware	Scalable storage space and computing power.	Limited storage, computing power, and wireless interface.
Latency	High.	Low.
Service Type	Global information collected worldwide.	Limited localized information services related to specific deployment locations.

2. *Definition*

Fog computing is an extension of the cloud computing paradigm with limited services but closer to the IoT devices. These devices are called fog nodes.

Many researchers have defined fog computing from multiple perspectives.

Yi et al. [16] defined FC as:

“*Fog Computing is a geographically distributed computing architecture with a resource pool which consists of one or more ubiquitously connected heterogeneous devices (including edge devices) at the edge of the network and not exclusively seamlessly backed by Cloud services, to collaboratively provide elastic computation, storage and communication (and many other new services and tasks) in isolated environments to a large scale of clients in proximity*”.

Whilst, Vaquero and Rodero-Merino [17] definition of FC is:

“a scenario where a huge number of heterogeneous (wireless and sometimes autonomous) ubiquitous and decentralized devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks without the intervention of third parties.

These tasks can be for supporting basic network functions or new services and applications that run in a sandboxed environment. Users leasing part of their devices to host these services get incentives for doing so”.

And the OpenFog Consortium [18] definition is:

“*a system-level horizontal architecture that distributes resources and services of computing,* *storage, control and networking anywhere along the continuum from Cloud to Things*".

3. Architecture

Fog computing architecture is a new paradigm that complements cloud computing. FC architecture is variant from other computational models. The main feature of this architecture is its decentralization. A lot of designs have been proposed for FC, but they mostly relied on three-tiers architecture as shown in figure 1.

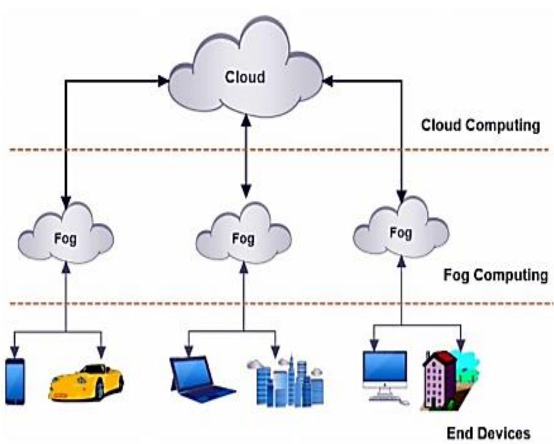


Fig. 1. Fog Computing Architecture [19].

FC hierarchal architecture consists of the following three tiers [20][21][22]:

- *Terminal Tier*

This is the nearest tier to the end-users and physical devices. These devices can be sensors, smartwatches, smart vehicles smart cards, … etc. all these devices are being used for collecting data only, neglecting their storage and computational power capabilities. These devices sense and collect data and then transmit the collected data to the upper layer, which is the FC layer, for processing and storage.

- *Fog Computing Tier*

This tier is located at the edge of the network. This tier consists of many fog nodes (FN) which include routers, base stations, switches, gateway, …etc. FN is distributed between terminal tier or end devices and cloud tier. In this tier, the collected data from the terminal tier can be processed and temporarily stored. Real-time sensitive applications can be served in the FC tier. Moreover, FN can be connected to the cloud tier for enhancing their abilities of processing and storage.

- *Cloud Tier*

This tier consists of more powerful servers and storage devices. Permanent storage and extensive processing capabilities are provided by this tier. However, not all the computational and storage tasks go through the cloud, which makes this tier different from traditional cloud computing.

The scenario in this architecture is that, end devices are connected to one of the FN through wireless technology such as Wi-Fi, 3G, 4G, ZigBee, ...etc or wired connection. FN also can be connected through wired or wireless communication technologies to contact each other. Each FN is connected to the cloud by an IP core network.

4. Characteristics

Fog computing architecture is characterized by [23][24][25][26][27]:

- Low latency- as the fog is geographically closer to the user, the delay during the transfer between one point to another is ignorable.
- High security- as the fog is geographically distributed and connected by many numbers of nodes, data is processed and maintained by higher security.
- Real-time interaction- as the fog is closer to the end-users, it provides real-time responses to the time-sensitive applications.
- Good user experience- as the users get an immediate response while the data is transmitted, they tend to use fog computing.
- Bandwidth reduction- as the amount of data being transmitted to/from the cloud is being reduced, fog computing reduces bandwidth utilization.
- Interoperability- as fog nodes are self-customized according to the computation requirements by end-users heterogeneous devices, the architecture of these nodes is interoperable.

III. FOG COMPUTING CHALLENGES

In this section, we address challenges in fog computing architecture. Some of these challenges are workload scheduling, load balancing, energy consumption, fog nodes management, as well as failure recovery, just to name a few [28].

As mentioned, scheduling tasks between fog nodes is a challenge, as the tasks are real-time sensitive and affect the efficiency and the execution of the system.

Furthermore, load balancing between fog nodes is critical to avoid a situation where some nodes are overloaded, and others are underloaded.

Another challenge is the energy consumption of the fog nodes. As fog nodes are dependant on battery life, researchers recently have been investigating the energy consumption of the fog nodes. The challenge comes from the trade-off between minimizing energy consumption and guaranteeing the quality of service (e.g., latency requirements) of end-users [29] [30].

Also, management of fog nodes is critical as there is a very large number of heterogeneous and dynamic nature of nodes.

Moreover, as the decentralized nature of fog computing architecture, failure of any of the fog nodes can split the fog computing system into disjoint clusters. However, transferring computations to neighboring nodes, which is called task offloading, or to the cloud when node failure is detected can also affect the system performance and reliability [31].

IV. EXISTING RESEARCH

As previously stated in the last section, challenges in the fog computing field motivated the researchers to make efforts and provide a solution for tackling these challenges. In this section, we select some of these researches and provide a summary of them as stated in table [2].

V. DISCUSSION

Since the fog computing paradigm is still in its infancy, an intensive analysis for this new technology is expected. This paradigm is worthy of attention to the IoT especially for time-sensitive applications for response time improvements it offers. After integrating fog computing technology into IoT applications, the device can react in milliseconds. [37].

Fog computing is used nowadays in applications such as smart cities, self-driven cars, health care systems, Augmented Reality (AR), and traffic control systems [38].

VI. CONCLUSION

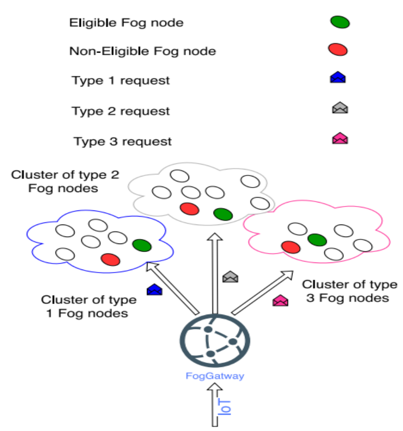
This survey presents definitions of fog computing and its architecture. Challenges in the fog computing is also introduced. We also discuss the existing research work and provide a criticize of them. From the shortages of these research works, we can conclude that the most promising challenges that need more investigations is workload scheduling and energy consumption.

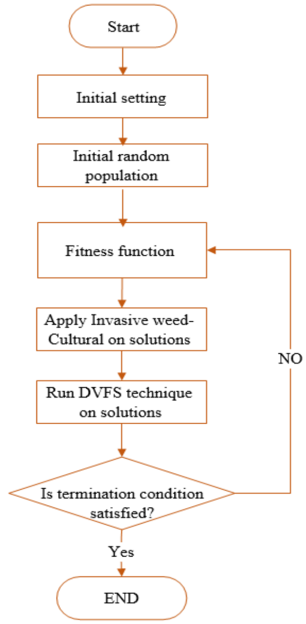
Scheduling the incoming workload efficiently leads to the proper use of the available fog nodes and achieve the latency awareness goal for the real-time applications.

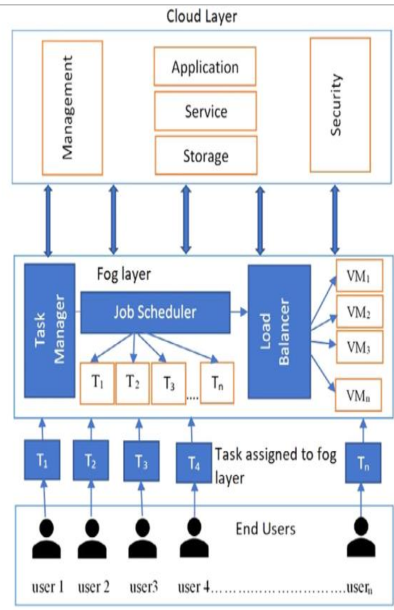
Moreover, this proper use of the available fog nodes can improve the energy consumption which is critical as the battery-life nature of these nodes.

Future work could lead towards better scheduling approaches, which can enhance the efficiency of the whole system.

TABLE 2
Summary of Existing Work in Fog Computing

Author/Year	**Research Goal (Paper Title)**	**Recommender Algorithm (Methodology)**	**Contribution**	**Shortcomings**
Muzammil Hussain Shahid, Ahmad Raza Hameed, Saif ul Islam, Hasan Ali Khattak, Ikram Ud Din and Joel J.P.C. Rodrigues 2020	Energy and delay efficient fog computing using caching mechanism [32].	The proposed algorithm using caching method as follows: • Classify files as (high, medium, or less) popular. • Select active nodes based on their number of connections with other nodes. • Use the filtration method to select only those nodes which have the computational and power capability to process that file. • Replicate the popular file to the selected active nodes. 	The proposed algorithm enhances the energy consumption by 92.6% less than the “without caching” mechanisms. Also, latency improved by 85.29% against the “without caching” mechanisms.	• It takes a long time to get the updated nodes information as this process is repeated every 30 min. • The proposed algorithm doesn’t consider the dynamic nature of fog nodes (assuming all nodes statically work with 0.75% of their power). • There is no balancing between fog nodes and cloud nodes requests.
P. Hosseinioun, M. Kheirabadi, S.R.K. Tabbakh et al 2020	A new energy-aware tasks scheduling approach in fog computing using hybrid metaheuristic algorithm [33].	The proposed algorithm has two steps: 1. Create a priority queue for the tasks in the directed acyclic graph (DAG) by using the IWC-CEA algorithm. 2. Find the appropriate voltage and frequency supply for the available resources by using the DVFS technique. The flowchart for the proposed algorithm:	• Reducing energy consumption of fog nodes by applying the Dynamic Voltage and Frequency Scaling (DVFS) technique. • Evaluating energy of task scheduling approach by a hybrid invasive weed optimization (IWO) and cultural evolution algorithm (CEA). • Maximizing resource utilization for the proposed task scheduling approach.	• There is no load balancing strategy between the available recourses.

				
Masoumeh Etemadi, Mostafa Ghobaei-Arani & Ali Shahidinejad 2020	A learning-based resource provisioning approach in the fog computing environment [34].	The Automatic Scalable Resource Provisioning (ASRP) algorithm consists of four modules and one shared database. • The control module receives the IoT workloads sent by the sensors and determines whether the workload is processed in the fog layer or sent to the cloud layer. • Fog devices specification such as CPU usage, storage and memory usage are collected by the monitor module and stored in the shared DB. • The prediction module uses a nonlinear autoregressive (NAR) neural network to predict the future workload. • In the decision module, the number of fog devices needed is decided.	• The Hidden Markov Model (HMM) is used as a decision-maker to identify resource provisioning actions. • Proposing a learning-based resource provisioning mechanism to handle the time-varying workloads of IoT applications.	• Load balancing between fog devices is not applicable. • Energy-saving strategy while scaling up or down the number of fog devices is not considered.
Kaur M., and Aron R.,	Energy-aware load balancing in fog cloud computing [35].	In the proposed algorithm the tasks are assigned to the task scheduler based on first-come-first-served as follows: - The task scheduler selects the nearby active fog nodes. - Get the energy state and the computation capacity of the selected active nodes. - If the required capacity is less than the available capacity, then assign the tasks one by one to the selected active nodes. - If the active node is overloaded, then the scheduler transfers the task to the nearby neighbor nodes.	• The proposed algorithm tries to reduce energy consumption by fog resources and tries to utilize the resources at the fog layer. • The proposed algorithm compared with the existing Tabu search method, and the results indicate an improvement in the execution time and reduction in cost and energy	• The proposed algorithm allocates all the incoming takas to only the nearby fog node till it is overloaded and neglecting the remaining fog nodes in the task allocation process.

			consumption in the fog computing environment.	
Jung-Yeon Baek **, Georges Kaddoum** **, Sahil Garg** **, Kuljeet Kaur** **, and Vivianne Gravel.** **2019**	Managing Fog Networks using Reinforcement Learning Based Load Balancing Algorithm [36].	- The proposed algorithm is used for making offloading decisions between fog nodes. - The proposed algorithm uses Markov Decision Process (MDP) to find the optimal actions for selecting the optimal neighboring node to which it can offload the workload. - The proposed algorithm also uses Reinforcement Learning (RL) to address the limitation of the system when it cannot predict the reward transitions by using the previous observations.	• The proposed offloading algorithm lets the controller decides the action according to the reward function. • The proposed algorithm improves the system performance by predicting the offloading decisions. • Balancing load between the fog nodes using reinforcement learning.	• The proposed algorithm does not consider the power consumption of the fog nodes.

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