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Improving Latency with Edge Computing and IoT in Health Applications: A Review

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Abstract: World is developing at a quick pace as is data. The boom of smart phones and Internet of Things (IoT) enable more users to access data as well as computation power in real-time. The constraints of current distributed computing is a subject of more prevalent concern. In response to these rising difficulties in computing, as new requirements and challenges spring up day by day, especially in cloud computing scenario, computing paradigms that can meet these challenges are sought after. In order to expand the efficiency and to decrease the quantity of the data to be sent to the cloud for processing, numerous solutions have been proposed for the edge-centric network. In this paper, an elaborate study of computing architectures proposed for edge paradigms is carried out and application areas in the Internet of Things are ascertained.
Keywords: Edge Computing; Fog Computing; Internet of Things; Mobile edge computing;

I. INTRODUCTION

Computing architectures have gone through quite a few changes between centralized and decentralized models in the recent past. Cloud being the present centralized paradigm, majority of web content is served through a main data center and researchers rent their private servers from cloud for testing or experimenting. In addition Cloud offers an expedient way for both small and big businesses to obtain computing sources from a service provider instead of putting up their own data center. Usage of Cloud services like Google Cloud, AWS, Azure and VMware have become so popular in recent past. However, the new trend towards a soaring emphasis on edge devices and edge computing paradigms cannot go unnoticed.

On the other side, many research organizations have given a startling prediction about the future computing scenario , that is, more than 20 billions of devices will be connected to the Internet by 2020. Thus more and more internet-enabled devices will result in generating huge amounts of data than ever. The Cisco white paper states that, IoT devices will generate 600 zettabytes of data by 2020[46] . Even though Cloud computing can be utilized in a pay-per-usage way through centrally managed resources, high latency and privacy issues are seen as solemn challenges. Hence, there is an inclination towards a decentralized solution of Cloud computing framework and the recent trend of computing paradigms lead to realization of shifting computing to the edge of the network. Since the connected devices prove to be potent in terms of computational capabilities and also battery power, they can be used for IoT applications. The requirements of low latencies and less bandwidth utilization of the data-intensive applications in the Internet of Things (IoT) are met.

Most of the Cloud datacenters are centralized and located far from the nearness of the edge devices, and the latency-sensitive real-time service requests suffer due to large round-trip delays, degradation in service quality and network congestion. Such issues can be resolved efficiently by means of latest edge computing paradigms. Although the notions of edge and fog computing have been conceptualized before now, a universal understanding of these paradigms in practice is lacking . The rest of this paper is organized as follows: Section II highlights the earlier work found in literature. Section III discusses about the various edge paradigms based on their architectures. Section IV presents a comparison scenario of edge computing, fog computing and Mobile Cloud Computing (MCC) derived from an analysis of performance parameters. Section V identifies application areas for edge paradigms in the field of IoT and highlights unresolved deployment issues. Finally, Section VI concludes the paper.

II. RELATED WORK

In recent times quite a lot of researchers and authors have endeavored to throw more light on the cloud-based computing paradigms by reviewing existing frameworks and applications. A detailed study of existing architectures based on complete taxonomy is made by Mahmud *et al.* [1]. The architectures as well as applications related to MCC have been examined elaborately in [2] and [3]. An overview of fog computing literature along with diverse application scenarios are outlined in [4]. Surveys on Mobile Edge Computing (MEC) have been made recently [5], [6].

The security aspects of fog computing, MCC, and MEC are reviewed by Roman *et al.* [7]. Dolui *et al.* [8] and Yi *et al.* [9] have surveyed a wider range of features, however, they have not mentioned the architectures anticipated for each structure. Similarly Li *et al.* [10] have reviewed various fog and edge computing methods; nevertheless no classification of the paradigms has been made. Wang *et al.* identified some unresolved issues like the necessity to devise policies for optimal selection of edge servers for mobility management [11]. Hence to facilitate the closure of this research gap, an analysis of different architectures proposed for each edge paradigm is being attempted in this paper.

III. EDGE PARADIGMS

Clouds that can be accessed over the wireless network. Thus mobile devices are allowed to perform computationally intensive tasks at centralized cloud servers [26]. Nowadays MCC tasks are delegated to small servers positioned at the edge of network. Obviously, there are two likely forms of realization of MCC as an edge paradigm:

As regards to the acceptable vocabulary of edge paradigms, there seems to be a slight confusion existing among authors who use the terms, edge computing, fog computing and Mobile Cloud Computing (MCC) interchangeably [12], [13]. Hence, this section emphasizes the distinguishing elements of the prevailing edge paradigms.

1) *Edge Computing:* Edge computing is presumably used as a generic term that covers all edge paradigms. Recently published researches [14]–[16] place edge computing as a separate paradigm but the perception of the term was initially introduced in 2014 by Vaquero *et al.* [17] where edge computing is outlined as a distributed setting with networking devices, ubiquitous end-user devices and edge servers forming a mini-cloud closer to the user. Processing data of the connected IoT devices depends more on the cooperation among end-user devices than with more powerful networking components [18] while there is no interaction with the cloud [19]. Edge Computing restricted to mobile networks [11], is christened as Mobile Edge Computing (MEC) in which edge servers are endowed with cloud services within the Radio Access Network (RAN) nearer to connected sensors and mobile devices [20]. Servers can be deployed at cell aggregation sites or base stations according to the framework suggested by the European Telecommunications Standards Institute (ETSI) or afar in a decentralized core network of the operator. User requests can be processed either directly by MEC servers or by forwarding them to a remote data center. In addition, devices can also be connected to each other directly in Radio Access Network [21]–[23].
2) *Fog Computing:* The notion of fog computing was first brought in by Cisco Systems in 2012 [24]. It can be characterized as a greatly virtualized platform that offers storage, compute and networking services among end-user devices and cloud computing data centers located at the edge of the network thus expanding cloud computing services to the devices at the network edge. Fog computing, therefore, refers to distributing or extending cloud computing resources and services to the edge of network. A three-layer architecture for fog computing suits the accepted perception which matches the simple software architecture that has been proposed in [25]. Fog organization is visualized as a layered one as shown in figure 1 with IoT nodes, fog nodes, and cloud in three levels. The first layer has IoT devices through either 3G/4G or Wi-Fi connection that produce data and send them to the nearby fog node.

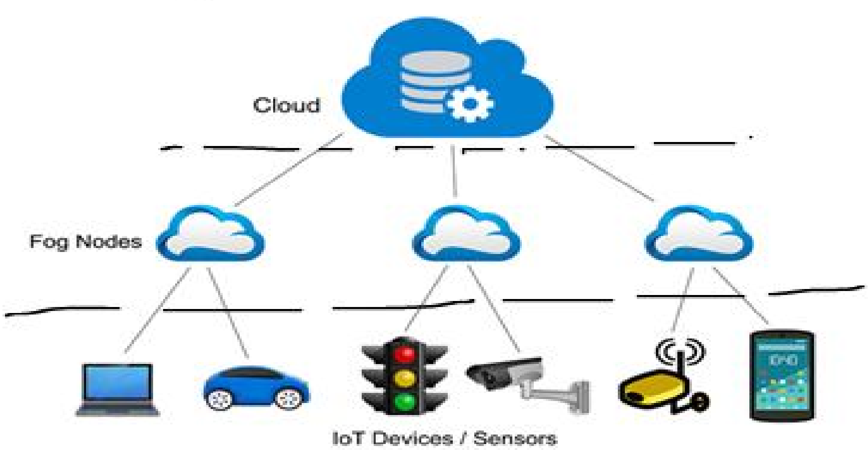

Figure 1. Three-layer architecture for fog computing

The second layer comprises of the fog nodes, which are responsible for allocation of resources and processing data. The third layer represents the cloud. The different architectures proposed in literature differ primarily in composition of fog nodes, fog organization and resource coordination. While the tasks which are latency-sensitive are processed directly at the nearest fog node, those tasks which are latency-tolerant are sent to higher-level nodes.

Regarding resource coordination, a P2P arrangement managed by a central controller or one fog node acting as master node is opted for. Concerning the composition of fog nodes, Cisco's definition describing a fog node as any device (sensors, mobile phones, etc.) connected to the network and networking components with computational facilites (switches, routers, access points, gateways etc.) holds good.

3) Mobile Cloud Computing (MCC): It refers to an infrastructure where both data processing and data storage take place exterior to the mobile device. In mobile cloud applications, computing power and data storage are shifted away from the mobile devices into centralized powerful computing platforms located in

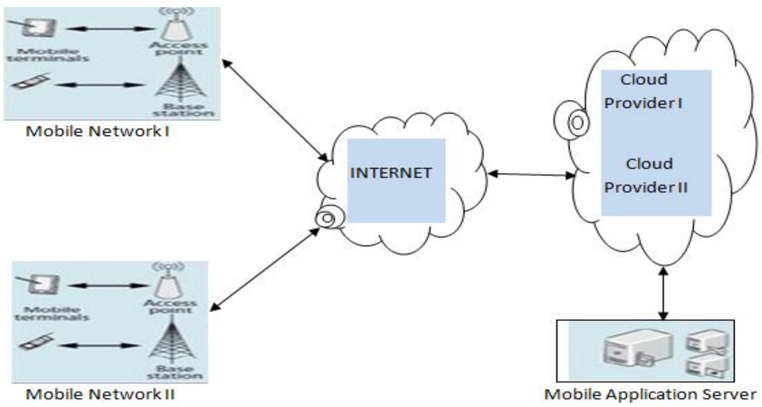

Figure 2. Architecture of Mobile cloud computing

One form is that of cloudlet referred to as 'data center in a box' [27] , which is developed as a framework for MCC and accessed over Wi-Fi or mobile networks [28]. Although cloudlets are powerful clusters of computers connected to the Internet and rigidly positioned at the edge of network and relieve the centralized datacenters to a great extent, they show certain inadequacies contrasted to fog computing. The main drawback is limited mobility support [6]; Other restraints such as less resourcefulness, scalability being applicable only on geographical expansion [29] and the use of cloudlets in merely getting cloud resources nearer to the edge but not interacting with the cloud [30], need attention. In order to address these limitations, Satyanarayanan *et al.* [31] extend the framework into three-layer architecture of interconnected end user devices, the cloud and cloudlets in between. Thus, cloudlets function as fog nodes.

Another form of implementation of MCC is that of Ad-hoc Clouds. Based on a common objective , mobile devices in close proximity form a cluster and their resources can be shared over an ad-hoc network [32].

IV. PERFORMANCE PARAMETERS

In order to meet the requirements of IoT applications, bandwidth and energy consumption issues need to be addressed. The following parameters are studied and compared to that of cloud servers deployed in major data centers. Table I gives an outline of these paradigms and the performance parameters.

1) *Low Latency:* Cloud computing may not suit processing of IoT applications incessantly because of requirement of prompt responses in a few milliseconds [16]. Moreover queuing and routing delays account for end-to-end latency[34]. On the other hand, edge paradigms are capable of processing latency-sensitive data in close physical and logical proximity to the source, thus avoiding these issues[8].
2) *Geo-distribution:* In order to provide continuous low-latency services to the widely distributed IoT devices, computing nodes need to offer dense geographic coverage. Cloud computing deploys centralized servers, whereas edge servers are geographically dispersed [5], [24], [33]. The widespread availability of cloudlets has yet to be achieved through the creation of an open ecosystem [28].

3) *Bandwidth Savings:* Due to the enormous increase in the number of connected devices and the proportionate rise in bandwidth demand, there is a possibility of network infrastructures failing to meet the demand. [15]. The benefits of edge paradigms are threefold: First, edge servers can preprocess data and forward only the meta data [34]; second, similar content can be aggregated; third, the resolution of audiovisual content can be reduced [35].
4) *Mobility Support:* Offloaded tasks should be made accessible even as the offloading device moves. Being dependent on stable Internet connection, the cloud may not be able to fulfill this requirement [36]. Isolated cloudlets cannot solve the issue either [8], whereas the other edge paradigms can transfer tasks from one computing node to another as the device moves through the network.
5) *Energy-efficiency:* Offloading computation-intensive tasks saves resources at the offloading device, but the wire-less transmission also consumes energy [35]. Multi-hop transmission of data to remote cloud servers is therefore expensive in terms of energy consumption [15], and cloud data centers consume enormous amounts of energy [12].

Paradigms \ Parameters	Low Latency	Geo-distribution	Bandwidth saving	Mobility support	Energy efficiency
Edge computing	Yes	Yes	Yes	Yes	Yes
Fog computing	Yes	Yes	Yes	Yes	Yes
Mobile Cloud computing	Yes	No	Yes	Yes	Yes
Cloud computing	No	No	No	No	No

TABLE 1: Comparison of performance parameters with Edge paradigms

Considering other factors like scalability [37] and context-awareness, edge servers perform well compared to remote cloud servers. Total energy consumption is also reduced by processing tasks on edge servers [38]. Regarding reliability, even though cloud servers offer 99.9% availability [17], they can be accessed over the core network alone. In edge computing, fault tolerance is achievable due to its geographic distribution ; however the problem of node churn has to be prevailed over.

V. IOT APPLICATIONS AND DEPLOYMENT ISSUES

Lately, the connected devices have entered every facet of our life, from health to smart home, smart agriculture , smart cities and whatnot. Owing to the time restraints of highly reactive IoT applications and large amount of data generated, edge paradigms which meet the above requirements more effectively appear as optimal solution.

A few of the real time scenarios of IoT applications that gain advantage of edge and fog computing environments are discussed below.

1) *Smart Healthcare:* Sensor data from wearable devices connected over body sensor networks facilitate advanced health services. But high latencies are observed while processing these real time data in the cloud and such delays in sending critical data to the doctors may be unfavorable. A solution using fog nodes is presented by Nazmudeen et al. [39] which analyze ECG sensor data to recognize abnormal heartbeats. In the same manner, detecting fall of a stroke patient and notifying an emergency contact

from smart phone accelerometer data is proposed by Cao et al. [40]. In [41], a decentralized fall detection algorithm is introduced that learns the sensor position at runtime. The classification of the current position should be offloaded to nearby resources instead of running directly on the wearable device. One main advantage of processing health data on fog nodes is privacy protection. In [42], an innovative health fog is proposed which combines user data with hospital data for providing personalized treatments. Here security can be integrated in Fog nodes which preprocess the data in order to remove any identifiable patient data.

2) *Smart Traffic and Surveillance Systems:* Vehicular networks forming ad-hoc networks of vehicles and edge servers collectively, deploy Fog architectures [43] and MEC [21]. Vehicles which draw near can collect content from edge servers or nearby base stations thus exploiting the mobile edge network infrastructure for content delivery. Real-time warnings to vehicles can be issued by edge servers in accident-prone areas. In the traffic light systems proposed in [25], Fog nodes perform analysis of sensor data of approaching vehicles as well as pedestrians and send real-time warnings to vehicles while adjusting traffic light sequence. Likewise, surveillance systems detect unusual situations and issue alerts based on video streamed to the nearby edge server[9]. In such applications, only the end results along with meta data are sent to the cloud for modified searches and further analysis after aggregating the video streams.
3) *Smart Home:* Management and remote control of home appliances, and systems in a residence that has internet-connected devices realizes a smart home. As appliances can communicate among themselves and with outside entities such as a Smart Grid, network congestion may result [37]; but fog servers can detect any abnormality in sensor data, and also adjust actuators to change conditions or send requests to an appropriate place or person for safeguarding[4]. Mounted surveillance cameras, actuators and sensor devices collaborate to identify intrusions and other hazards
4) *Smart Power Grids:* Real-time data on energy consumption in households recorded in the embedded metering devices require to be analyzed to know energy consumed [5] . An apt fog platform for this purpose is proposed in [24] since a lot of bandwidth is needed . Thus smart meters at the edge of the network are good at processing latency-sensitive sensor data, and issue control signals to actuators in real-time whereas latency-tolerant data can be transmitted to cloud for analysis and subsequent reporting.
5) *Smart Agriculture:* The application of IoT solutions in agriculture has been introduced with the aim of enhancing food production , monitoring crops and protecting stored products. Data collected by agriculture sensors can be used to track soil quality, weather conditions, growth of crops, etc.[45]. In addition remote farm monitoring and pest management capabilities allow end-to-end farm management.
6) *Smart City:* According to Gartner's prediction on swift urban growth, around 70 percent of the world's population is supposed to live in cities by 2050. To handle this demand on cities, IoT technology makes it easier for buildings to save energy and improve sustainability. Moreover IoT has the prospective of transforming the cities by providing other smart facilities such as enhanced water supply, improved communication and reliable transportation.
7) *Smart Tourism:* Interactive guide systems help in automating tourism industry, as the one presented in [44] where visitors can stream video and audio information about scenic sights from edge servers as they roam about. Edge servers are capable of computing user's position, and providing neighborhood content directly without any inherent delay [20], [30].

There are a lot more application scenarios where IoT penetration has become visible. Yet, quite a few issues need to be addressed for an extensive deployment of edge paradigms in IoT.

First and foremost thing lies in defining the responsibilities of cloud service providers, network operators, and users of IoT applications [9]. Next, the Interoperable system architectures required to connect and manage heterogeneous IoT devices use Software Defined Networks (SDN) and Network Function Virtualization (NFV) which are not void of security challenges [7] since they provide programming environments and abstractions with common interfaces[25]. Furthermore as several IoT applications are in need of adding new devices recurrently, such systems should be tolerant to node churn, and failure . Hence mobility management solutions, reliability-aware scheduling, security mechanisms and other unresolved issues, like the need to devise policies for the best possible selection of edge servers are of concern.

VI. CONCLUSION

In this paper, the most promising edge-centric computing approaches for distributed and decentralized environment have been discussed in length and the various paradigms are compared based on their performance parameters. The proliferation of IoT applications which benefit us greatly are studied with a focus on smart systems. Yet, further research on interoperability, robustness, security and privacy of edge-centric systems is indispensable.

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