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Fog Computing and its Current Research Trends

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ABSTRACT
The Internet of Everything (IoE) solutions gradually bring every object online, and processing data in a centralized cloud does not scale to the requirements of such an environment. This is because there are applications such as health monitoring and emergency response that require low latency and delay caused by transferring data to the cloud and then back to the application can seriously impact the performance. To this end, Fog computing has emerged, where cloud computing is extended to the edge of the network to decrease latency and network congestion. Fog computing is a paradigm for managing a highly distributed and possibly virtualized environment that provides compute and network services between sensors and cloud data centers. The computing world has seen a paradigm shift from traditional personal computing to present-day client-server computing with the advancements in computer networking. Client-server computing has completely evolved into cloud computing, which provides flexibility, low-cost deployment, fault tolerance, and high availability, to build virtualized services. Currently, with the proliferation of the Internet of Things (IoT) devices, computing needs latency-sensitive support, which a cloud cannot provide. In the year of 2012, a group of researchers from Cisco presented a new computing paradigm, called fog computing, where IoT devices can be given effective and enhanced support by bringing back a part of the computation from the cloud to the edge or near-edge devices. Fog computing is a computing paradigm where some of the computations take place in the edge devices, and these fog devices interplay with the cloud server to provide a better quality of service (QoS) to the end-users.
KEYWORDS: Fog Computing; IoT; Edge Computing; Cloud Computing

I. INTRODUCTION

Fog computing is a decentralized computing infrastructure in which data, computing, storage, and applications are located somewhere between the data source and the cloud. Like edge computing, fog computing brings the advantages and power of the cloud closer to where data is created and acted upon. Many people use the terms fog computing and edge computing interchangeably because both involve bringing intelligence and processing closer to where the data is created. This is often done to improve efficiency, though it may also be used for security and compliance reasons.

The fog extends the cloud to be closer to the things that produce and act on IoT data. These devices, called fog nodes, can be deployed anywhere with a network connection: on a factory floor, on top of a power pole, alongside a railway track, in a vehicle, or on an oil rig. Any device with computing, storage, and network connectivity can be a fog node. Examples include industrial controllers, switches, routers, embedded servers, and video surveillance cameras.

II. CHARACTERIZATION OF FOG COMPUTING

Fog Computing is a highly virtualized platform that provides computing, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of the network. Figure 1 presents the idealized information and computing architecture supporting future IoT applications and illustrates the role of Fog Computing.

Compute, storage, and networking resources are the building blocks of both the Cloud and the Fog. “Edge of the Network”, however, implies several characteristics that make the Fog a non-trivial extension of the Cloud. Let us list them with pointers to motivating examples.

Edge location, location awareness, and low latency. The origins of the Fog can be traced to early proposals to support endpoints with rich services at the edge of the network, including applications with low latency requirements (e.g. gaming, video streaming, augmented reality).

Analyzing IoT data close to where it is collected minimizes latency. It offloads the gigabytes of network traffic from the core network. And it keeps sensitive data inside the network.

IoT environments consist of loosely connected devices that are connected through heterogeneous networks. In general, the purpose of building such environments is to collect and process data from IoT devices to mine and detect patterns, perform predictive analysis or optimization, and finally make smarter decisions promptly. Data in such an environment can be classified into two categories [10]

- Little Data or Big Stream: transient data that is captured constantly from IoT smart devices.
- Big data: persistent data and knowledge stored and archived in centralized cloud storage fog computing also have the potential of providing services as follows.

1) Location awareness: The fog device of a particular location can better know its context information.
2) Wide-spread-geographical distribution: The fog nodes are distributed around large geography.
3) Mobility-based services: Mobile devices can move with uninterrupted fog-enabled services.
4) Supporting a very large number of nodes: A large number of end devices can be served in the fog architecture.
5) Omnipotent role of wireless access: Wireless network has provided the advantage of accessing the fog services.
6) Device heterogeneity: Different heterogeneous devices can reside and participate in the fog computation with minimal effort.

III. FOG COMPUTING ARCHITECTURE

The concept of fog computing [4] emerged from the concept that part of the computing can be brought back near the edge devices. The term fog computing has been proposed by Cisco [2] in 2012

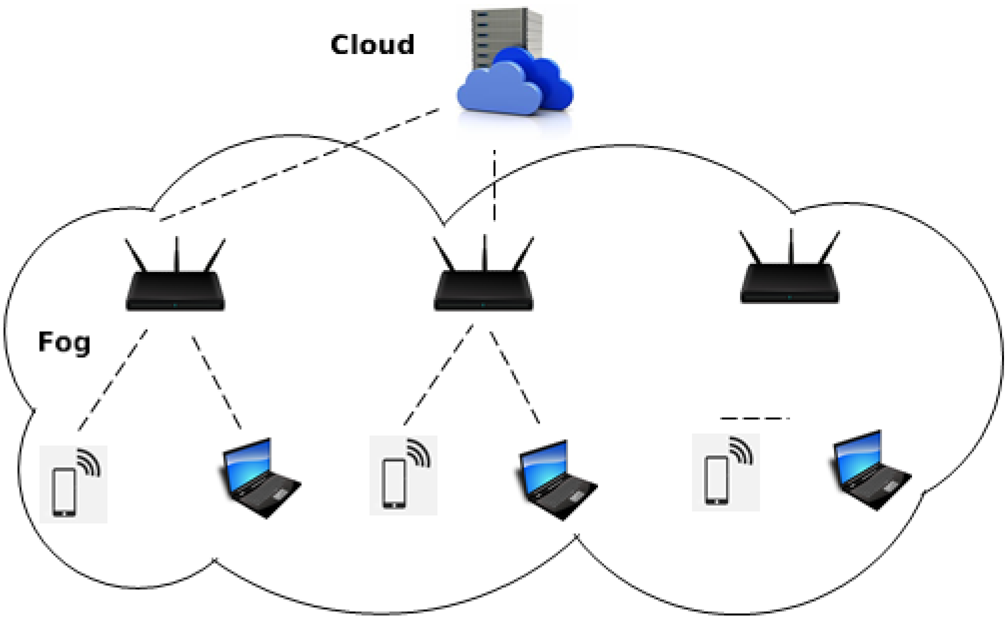

Fig. 1. Typical Components of a Fog Architecture

The fog computing architecture has been shown in fig. 1. It refers to extend the cloud computing paradigm to the edge of the network. The edge devices (i.e. routers, gateways, etc.) can be used as the computing nodes along with the existing cloud data centers. Fog computing has been envisioned to provide computation from the network edge, through the network core, and to the cloud data centers. The different services are hosted in the fog nodes, which are using its resources through the hypervisor, the management software for virtualizing the computing environment. Fog computing does the proper interplay of the services with the cloud. The applications which require real-time response and context-aware computing rely on the fog computing framework. Further, there are situations where there is a need for supporting a huge amount of data generated from IoT devices. Cloud computing alone is not sufficient in these situations as there is a requirement for real-time service provisioning. The typical applications of the fog computing paradigm can be in real-time healthcare monitoring systems, smart cities, smart grids, vehicular ad-hoc networks (VANET), etc. Being loosely coupled and highly distributed, QoS management and dynamic adaptability are the key challenges faced by the fog computing domain which need to be solved.

IV. FOG COMPUTING: RESEARCH CHALLENGE

Fog computing is a domain that emerged from the success of the cloud computing framework as a commercial and commodity solution for providing a computing resource to the end-users. However, with the development of low-cost computing hardware and devices like IoT sensors and smartphones, the research community realized that a part of the computation can be brought back to the devices near the edge, which can reduce the cost of data offloading at the cloud, as well as can provide privacy and security solution to the user data. However, computation at the edge also has challenges that the researchers are currently exploring for the end-to-end development of the fog computing framework. Consequently, several research outcomes have come out recently. In this section, we briefly discuss the general challenges for the development of a fog computing solution and accordingly classify the existing works into different groups for further discussion.

4.1. Challenges in Fog Computing Research

As mentioned earlier, fog computing is a distributed computing architecture that involves network-related challenges, computing-related research directions, security-related challenges, as well as management-related challenges. Being highly distributed, it makes the system more vulnerable to computation correctness. Here, we discuss these issues of a fog computing system.

Network and Device-Related Challenges: The various network and device-related challenges that the fog computing framework faces are as follows.

Distributed architecture: The distributed architecture makes fog computing more prone to having a redundant system. The same code is replicated in several locations in the edge devices of the network[3]. Therefore, the computing framework should have sufficient sophistication to reduce redundancy in the distributed environment.

Network resource distribution: The networking resources are scattered in the edge or near-to-edge devices in the fog architecture. This makes the system more complex in terms of the network connectivity aspects. A common network middleware is required to be developed, which can manage the common pool of resources over the edge or near-to-edge devices, and accordingly should be able to allocate resources to the application workloads.

Heterogeneity of devices: The fog environment has several heterogeneous end devices. This heterogeneity of the devices has made the system more diverse[5]. The computing platform should consider this device and network heterogeneity while developing fog applications.

Computing Challenges: The computation over a fog environment is challenging because of the following reasons.

Computation hierarchy development: The fog computing system always communicates with distant cloud servers. There is a trade-off between the response time and computation power in the fog computing system. The fog computing devices, that is the edge as well as the end devices, perform computations and should respond to the users within a time guarantee. At the same time, some computations are also offloaded to the cloud, and these computations at the cloud may take higher time compared to the time required to execute the computation at the edge devices but with a less computation cost. Therefore, it is always a challenge to identify what parts of the computations have to be offloaded to the cloud, and what fractions of the computations have to be performed at the fog devices. This also has the trade-off in accuracy-interoperability that needs to be addressed by the application developer.

Computation resource distribution: Computation of different applications needs proper resources. The edge devices may not always have all the resources deployed in them. Some of the resources have to be used from other fog nodes. This requirement has generated the need to distribute the computation resources among the edge devices. Therefore, there is a requirement for developing a converged framework to integrate the computation, memory as well as networking resources for building up the common pool. Applications can reserve resources from this common pool. The current research in this direction is exploring whether container technology [9] can be used to develop a common pool of resources over the edge devices for computation.

Distributed computation: The distributed computation in the fog has created the need to verify the computation's correctness. Fog applications need to be designed and developed in such a way that there are few inconsistencies in computation, and also such inconsistencies should be verifiable [3].

Mobility: With the advent of mobile and hand-held devices, the current computing framework demands computation over anywhere, anytime and anything connectivity, and therefore a pervasive computing framework needs to have emerged over the fog computing framework. The edge nodes may be mobile in the fog computing environment. This mobility is another barrier to computing in the fog domain. Therefore, the researchers need to develop integrated, pervasive, and ubiquitous solutions for handling the mobility of fog-enabled computing frameworks [8].

Security-Related Challenges: The fog computing system, being distributed with different heterogeneous devices, is vulnerable to various security attacks. The existing literature discusses man-in-the-middle attacks in the fog computing domain [8]. Data and network security are the main issues in fog. Further, as the fog computing framework also depends on the services from the cloud servers, the computation framework becomes vulnerable to trust and authentication issues. The privacy of the data is another concern in this highly distributed fog computing architecture[8].Another security vulnerability is that fog devices are not deployed in highly secure data centers, but in locations that may be easy to have physical access for attackers[8]. Hence, the system software itself may not be trusted. Therefore, there is a requirement to securely execute the edge functionalities over the fog.

Management Challenges: The fog computing framework, being a distributed system architecture, poses several challenges related to system management.

Service-oriented computing: In the fog computing framework, user service is divided into multiple micro-level services and these micro-services are distributed across the edge devices and the cloud. This particular distribution of services over fog devices is a mode of service-oriented computation over edge devices. However, executing micro-services over the fog nodes has its challenges. The proper management of the architecture to get the services is one of the prime challenges in the fog computing domain. There are several challenges in micro-service management. These are service placement, service combination, tracking of execution steps, etc. We need a proper orchestration system so that the services are provided to the end-users within a very less amount of time over the fog framework [8].

Resource management: The different networking, as well as computation resources, are distributed in the fog computing domain [8]. Fog computing has to be flexible and adaptive (like the cloud) to respond to issues like transient failures or resource shortages. The failure of fog nodes makes the whole system down as the resource would not be available from that fog node. Again, the resources are virtualized in the fog network. The virtualization of resources creates many challenges. These challenges are the latency, initiation, placement, migration of virtual network devices in a fog network, etc. In these cases, we need to properly manage the resources so that downtime can be avoided ensuring high availability. This is primarily because a fog computing system deals with latency-sensitive applications, such as smart homes, smart healthcare monitoring systems, etc. [3] [8]. Modern technologies like software-defined networking can be utilized for resource management [7] over the fog nodes which poses several research directions.

Orchestration between fog nodes and the cloud: Another challenge is the end-to-end orchestration of the fog-cloud resource ecosystem to provide QoS guarantees for various user-level services [8]. The fog computing system consists of the edge network as well as the cloud infrastructure. The integration of heterogeneous edge devices needs to be taken care of in the fog environment. Also, the cloud infrastructure should be properly handled to perform distributed computation and storage. Thus, there is a requirement for end-to-end orchestration of cloud servers and heterogeneous fog devices so that the resources can be allocated dynamically.

Based on these diverse challenges to develop an end-to-end fog framework, the researchers and industrial developers have targeted to solve various aspects of the fog computing framework. Accordingly, we classify the existing literature on fog computing, as discussed next.

The following are a few of the applications using fog computing.

Healthcare: An analytics system assisted by fog computing called FAST was proposed by Cao [6] can monitor fall conditions for stroke patients. They developed a set of fall detection algorithms, which uses data like measurements of acceleration and time series analysis methods along with data noise-reducing algorithms to allow an increase in efficiency in detecting fall conditions. It detects fall conditions in real-time and it was based on a distributed network of fog computing.

Augmented Reality: Applications based on augmented reality cannot allow even minor latency as even very small delays in response can potentially damage the user experience. Fog computing will be one of the major players in the augmented reality domain due to its distributed computing capabilities. The augmented Brain-Computer Interaction Game proposed by Zao [7] is based on Fog Computing and Linked Data, it will collect raw streams of data created by EEG sensors and then it will be classified to detect the brain state of the user while playing a game, which uses augmented reality [11]. Brain state classification is one of the most computationally heavy signal processing tasks, which needs to be carried out in real-time.

Caching and Preprocessing: Zhu[1] improves website performance by using edge servers where users used to connect with the internet by "fog boxes" where each user's HTTP request goes through a fog device. The fog device on user's page loading requests, to reduce its amount of time, performs various optimizations. It will have some general time-saving techniques like caching HTML components, reorganizing the composition of webpages as well as reducing the size of elements in the web. The edge devices could also perform different optimizations that will analyze the user's behavior and internet conditions. For example, when there is congestion in the network, the device at the edge then sends low-resolution graphics and photos to the user so that response time can be under an acceptable limit. Also, the performance of the client machines is monitored by the edge device which sends graphics of appropriate resolution taking care of the rendering time required by the browser.

4.2. Software-Defined Networks (SDN): SDN is an important concept based on computing and networking. SDN along with fog computing together will be capable to resolve some of the main issues related to networks of vehicles, intermittent nature of connectivity, high collision rate, and high rate of packet losses. Augmenting the vehicle-to-vehicle as well as vehicle-to-infrastructure communications along with main control supported by the SDN does this. It would split the control and communication layers where controlling will be done by the central server and the server would decide the communication path for nodes.

V. COMPARISON OF FOG COMPUTING AND CLOUD COMPUTING OVER IOT

Even though fog computing gives great advantages to the IoT infrastructure, however, cloud computing is one of the emerging solutions and it is already in use in many different areas. Also, a lot of research and development had already happened into cloud computing compared to fog computing. Fog and cloud are both good solutions but they are the complement of each other in the form of providing service. Table 1 shows a comparison of Fog and cloud computing.

Table 1- Comparison of Fog and cloud

Areas[8]	**Cloud**	**Fog**
Location and Model of Computing	Centralized in a small number of data centers	Distributed along large Geo-graphical areas and it is closer to the user. Fog nodes and systems can be controlled by a centralized node or in a distributed manner.
Size	High Each cloud data center is very large in size consisting of at least thousands of servers.	Each fog node can be equivalent to a single server machine. It's designed to meet user demands.
Deployment	Require sophisticated deployment planning	Depends on the environment. The majority of them don't require intense planning.
Operation	Operated in a fully controlled environment with technical expert teams by large companies.	Operated in an environment where it primarily depends on user demands. They are not operated directly by a person. It can be operated by any size of the company.
Applicatio-ns	It can support predominantly cyber-domain applications. The applications mainly suffer high latency.	Can support cyber-domain, and cyber-physical applications. It suffers very less latency and is hence useful for time-critical applications.
Network requireme-nts	Require clients to have network connectivity until the user wants to access its services. Bandwidth requirement grows with the increase in the total amount of data generated by all the clients.	Can operate autonomously to provide uninterrupted network services even with no or intermittent network connectivity. Bandwidth requirement depends on the total amount of data that needs to be sent to the cloud after filtering by fog.

VI. CONCLUSION

Fog computing has benefits in many domains and provides solutions for security problems in the current paradigm. Future research can expand the paradigm of fog computing in smart grids. This provides us a vision for the fog to be a platform of unification made enough for a brand new breed of rising services and modify the development of the latest devices and applications. However, this study suggests that with the emergence of fog, cloud computing can not become an obsolete concept. As it was seen, even if fog computing continues to develop in the future, it has to go hand-in-hand with cloud computing. Fog computing is just a bridge that connects the gap between the demands of IoT infrastructure and the computational capabilities of the cloud could provide. By creating harmony between these two complementary techniques of remote computing, various targets can be achieved, which are once just a dream for us.

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