A Survey of Fog Computing Paradigm: Concept, Applications and Challenges

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Abstract: Due to limited storage and processing power, IoT (Internet of Things) devices utilize the concept of cloud computing by offload their work to the cloud servers. With the increasing functions and daily usage of the smart IoT and devices, demand for high quality, low latency, real time services have increased. With the inability of the cloud computing to fulfill these demands, a new paradigm is introduced by the Cisco named as fog computing. It extends cloud computing by offering location based services and virtualized resources at the edge of the network. In this paper, I am presenting the basic concept, characteristics, challenges and applications of the fog computing.

***Index Terms* – Fog Computing, Cloud Computing, Mobile Computing, Latency-Sensitive, Fog Nodes.**

I. Introduction

IoT (Internet of Things) has always been considered as an area with vast possibilities; and with the recent advancement in areas of wearable gadgets, smart house/city, smart metering and bulky wireless sensor networks, it has now been regarded as the future of computation. Though IoT devices' hardware limits the computation and storage on these devices, Cloud Computing comes here to the rescue. Cloud Computing paradigm is an alternative to managing and owning private data centers, its pay-as-you-go [4] model provides flexibility to the enterprises in terms of hardware and software specifications, those can be changed anytime on the fly.

IoT enabled applications requires, IoT device/sensors to be highly distributed across the network, and have use cases of Real-time processing with minimal latencies. Since Cloud datacenters follow centralized infrastructures, they usually fail to cope up with the processing and storage requirements of billions of geographically distributed IoT devices. This results in network congestion and latencies, which defeat the core concept of IoT enabled services - Real time processing, and provides a poor Quality of Service [2].

Therefore, IoT needs geographical distribution with low latency, mobility support and location awareness. To handle these use cases, Fog computing has emerged as a more reliable and practical approach. The word 'fog computing' was coined in 2012 by Cisco [5] in context with the limitations of the cloud computing in IoT applications [3]. From the perception of Cisco, fog computing paradigm is deliberated as an extension of the cloud computing from the core of network to the verge of the network. That is why; the Fog is inferred as "the cloud close to the ground". It's highly virtualized infrastructure delivers networking, storage, and computation facilities between traditional cloud servers and IoT devices. It extends cloud computing by offering light-weight devices with location based services and virtualized resources at the edge of the network [1]. It extends cloud's two-tier cloud-mobile architecture into a three-tier hierarchy of cloud-fog-mobile by inserting a middle layer Fog between the cloud and mobile devices. The middle Fog layer is made up of geographically distributed devices termed as fog nodes which are installed at the local sites of the mobile users. A fog node can be an existing networking device like WiFi access point, set top box or router or can be an improvised networking device with added storage and processing power. The upcoming section will explain fog nodes in detail.

This paper is structured as follows. The second section outlines the characteristics of the fog computing paradigm. The next section introduces different types of devices that can act as fog nodes in order to create a fog network. In the fourth section, a comparison between fog and cloud computing is made with day-to-day example to further clarify the basic concept. Fifth division introduces several services and applications that favor the need of fog computing for the support for the Internet of Things and next section briefly explain the challenges that need to keep in mind while implementing fog computing. The last section concludes the fog paradigm.

II. Characteristics of Fog Computing

Fig. 1 presents the brief architecture of fog computing that supports the IoT applications. The fog and the cloud are made up of resources - networking, storage and computing. There are many characteristics of fog computing that make it a useful extension of the cloud computing. Some of which are listed below:

- Geographical Distribution: According to a published white paper [6], "The world will have 50 billion connected IoT devices by 2020." These connected and geographically distributed devices require a widely distributed arrangement of resources in contrast to centralized services provided by the cloud. The fog environment meets this criterion by placing several fog nodes in proximity to the IoT devices, thus providing superior quality video streaming to the mobile vehicles by utilizing access points and proxies situated along roads and highways.

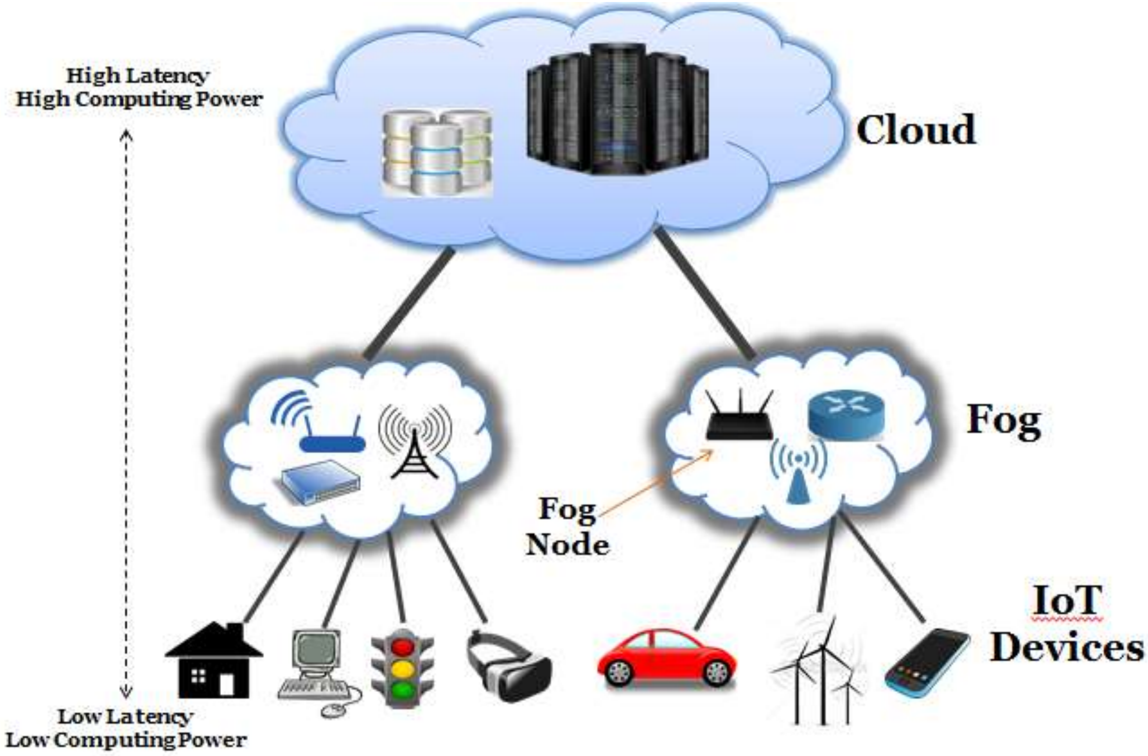

Fig. 1 Fog Computing Environment

- Low Latency: This is the key driving feature of the fog paradigm. Low latency is critical for the time bound real-time applications such as augmented reality, gaming and live streaming. The requirement of these delay-sensitive applications i.e. low latency is sustained by fog computing.
- Mobility Support: Numerous IoT devices support mobility feature. These mobile devices will communicate directly with the fog nodes for storage and computation purpose. Therefore, it is a necessity to support mobility techniques, for instance the LISP protocol [7].
- Large number of nodes: Since fog nodes are widely distributed, there are a very large number of fog nodes used in large scale sensor networks that require distributed computing and storage resources.
- Heterogeneity: Fog nodes are deployed in different environments such as air quality monitoring in cities, smart agriculture or traffic light system. The fog nodes differ from router to base station to proxy server and many more.

III. FOG NODES

Devices that are placed on the fog network are called fog nodes. They provide resources like storage, computation, etc. to the end user devices. Connected fog nodes form a fog network. There can be millions of fog networks serving billions of IoT devices and sensors. Different types of fog nodes are:

- Networking Devices: Despite their networking functions such as packet forwarding, routing, signal conversions, etc., all networking devices such as switches, smart hubs, set-top boxes, routers, etc. can perform as possible arrangements for the fog computing.
- Servers: The fog servers provide storage, networking and computing services. These are geographically dispersed at public areas like gardens, shopping complexes, streets, buildings, etc.
- Base Stations: For signal processing and smooth communication in mobile and wireless networks, base stations play an important role. If we can enhance computing and storage abilities of these base stations [9, 10], they can act as the fog nodes.
- Vehicles: Parked or moving vehicles with computation abilities can function as fog nodes [11, 12]. They will form a highly scalable and distributed fog environment.

IV. WHICH IS BETTER CLOUD OR FOG COMPUTING?

In comparison to the customary desktop consumers, mobile consumers have foreseeable demands for resources subject to their positions [8]. For example, a tourist visiting a new place would search for the information regarding the tourist locations for sightseeing, surrounding climate, and news of that particular place, diversifying it from other places.

Cloud computing offers a centralized infrastructure with high storage and computing facilities and end user devices directly access cloud server, however it does not support location-awareness. The fog computing paradigm solves this problem by delivering localized facilities subject to the particular positioning sites. The inspiration behind Fog computing is to place services and resources as near as possible to their user's applications.

However, we cannot completely rely upon fog paradigm as it cannot handle storage and computation intensive applications. Because fog nodes have restricted resources, their sole purpose is to fulfill requests with low load. Therefore, we require an environment that supports both cloud as well as fog computing; fog for a limited resource requirement such as for localized processing of data, monitoring temperature in a building, etc. and cloud computing for applications that require great amount of computing or with huge data to store, like data warehouse and data mining applications.

V. APPLICATIONS

In this section, various applications and scenarios are presented in which fog computing can play a crucial role to improve the performance and deliver real time quality of services. Fig. 2 illustrates the applications of the fog computing paradigm.

5.1 Smart Grid

Applications with energy load balancing may execute on micro grids and smart meters [15]. They automatically shift to substitute source of energy such as wind and solar, if required. The generated data is processes by the fog collectors which, in turn, generate control instructions to the actuator [1]. They also perform filtration of data to decide which data to send to the upper layer (cloud) for storage and analysis and which one to process locally.

5.2 Smart Traffic Light System

Bikers and pedestrian are identified by intelligent street lights using sensors, and distance and speed of coming vehicle is measured. These smart lights act as fog nodes. Synchronization of adjacent fog nodes produce a green traffic wave [1] and generate cautionary indicators to upcoming vehicles. On sensing an ambulance blinking light, fog nodes can spontaneously switch traffic lights to green to allow vehicles to clear that lane.

5.3 Transport Hub

Fog nodes can be deployed at different transport hubs to provide multiple services to the commuters such as arrival and departure time, number of seats available, leisure activities like gaming, video streaming, social networking etc. By using computing capability, utility data can be collected and processed by the fog nodes and sent to cloud. The fog nodes deployed on buses can be used to monitor and measure the air pollution in the city. "BLUE" [14] an on-board entertainment system based on fog computing was launched by Greyhound for its intercity bus services.

5.4 Smart Buildings

Thousands of sensors can be deployed in a building to measure numerous functional parameters such as vacant parking space, keycard readers, humidity, lighting, and temperature. The data generated by these sensors must be examined to check whether any action is needed such as activating temperature controlling devices if a change in temperature is sensed. In this scenario, fog nodes can be placed on every block, floor or even in each room and perform sensing and response functionalities. All fog nodes form a fog network. These nodes can communicate with each other and outcome of distributed shared information can be used to take necessary decision. Therefore, the entire system can work together to control climate, open windows or insert fresh air, can provide a storage and compute infrastructure to its users to add-on the restricted abilities of tablets and smartphones. Sensors can sense movement and turn off or on the lights accordingly. All the computing and short term limited storage is done locally at the fog nodes; however, cloud is used to store the collected logs of history of building's functionality and control activities to analyze for further optimization. In this way, smart buildings preserve their internal and external environments in the most efficient manner.

5.5 Wireless Sensor and Actuator Networks

Wireless sensor network comprises of resource constrained nodes. They have limited battery, low bandwidth, and low processing capabilities. They collect and forward data towards the sink node which consumes the data. These sensor nodes do not perform any physical actions. In the scenarios where more than tracking and sensing is needed, these sensor networks fail. In these cases, wireless sensor and actuator networks (WSAN) are used, in which the actuator acts as fog node and takes necessary actions. For example, in an automatic fire alarming system in a building, smoke / heat detectors detect smoke or heat and warn people through audio or visual devices and open emergency exits automatically.

5.6 Smart Agriculture

Phenonet [22] a real-world project is developed by CSIRO for case study on smart agriculture. In this, multiple smart sensors are deployed to collect data over an area of experimental crops. This network of smart sensors monitors conditions of climate, growth of plant, and performance information. Reasoning and fusing techniques are applied on the data collected by sensors to better understand the growth of plants. Time and location sensitivity play a vital role in agriculture.

For example, fusing humidity data, soil temperature, and air temperature can detect a frost event. However, if due to breakdown, air temperature sensor halts working; it is useless to carry on sensing humidity as it is not possible to detect frost events without temperature. In this case, putting a humidity sensor on sleep mode until the temperature sensor starts working again is the ideal solution [16]. Thus, by minimizing useless sensing and communication, energy can be conserved. Therefore, fog computing paradigm is required, to deploy such a smart (re-)structure.

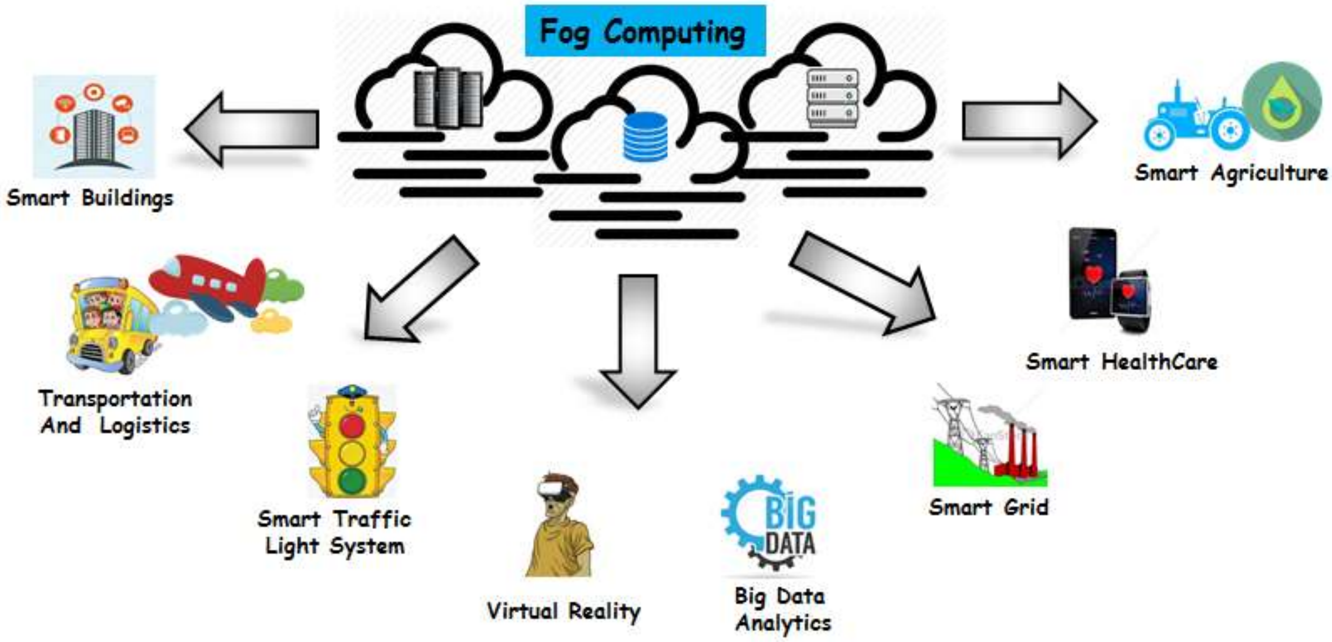

Fig. 2 Applications of Fog Computing

5.7 Smart Healthcare

Nowadays, multiple companies provide smart healthcare monitoring devices [17] that automatically monitor the well-being of the patients and thus increase the workflow organization of the patients. For example, sensors on wearable smart watches can monitor number of parameters like blood pressure level, weight, heart rate, number of steps while walking, running, cycling, number of calories burned, etc. The sensors on the device gather the data and send it to the user's smartphone for local processing. Here, the smartphone acts as the fog node. Furthermore, the data can be sent to the cloud server to maintain health history of the user for future references. In another example, a Brain computer interaction application [18] is developed with the capabilities of the fog computing paradigm. The Health Care Originals (HCO) developed a wearable smart respiratory monitoring device named ADAMM [19] to aid people with asthma. ADAMM acts as proactive and intelligent system, which eases the life of care provider and patients by increasing adherence, automating processes (reports/vaccination reminders, etc.) and advance warnings. The smart healthcare industry is undoubtedly an area that will grow exponentially over time.

5.8 Big Data Analytics

Big data processing on the cloud server [21] is a broad and current interest of researchers. A large storage, computation, data transportation, and processing power is needed in the acquisition, accumulation, and preprocessing of the big data. The cloud computing paradigm [20] is used to solve the problem of big data, however, it suffers from the downside of high latency. Therefore, an amalgamation of cloud and fog computing can be applied to resolve the issue. Consider an Environment monitoring structure. For example, in which data(regional and local) can be collected and extracted at fog nodes, that can be used to deliver timely responses and recommendations like in the case of high level of pollution, while cloud infrastructure can be utilized for in-depth analysis and computation demanding jobs.

5.9 Augmented and Virtual Reality Applications

Nowadays, augmented and virtual reality applications are the new trend used on tablets, smart glasses, and phones by overlapping an informative outlook on the display of the system. Popular products in this category are Google Glass, Magic Leap Lightwear, HTC Vive, Pokemon Go, and Microsoft Hololens. These applications require high bandwidth and a lot of computation for video streaming and data transmission. The usage of fog nodes with applications and cloud server can reduce latency and increase throughput in both communication and data computing. Many companies are looking forward to this technology to maximize the efficiency of their smart devices.

5.10 Tourists Places

Tourist Places: The fog network can be set up to offer localized tourism facilities. Multiple fog nodes can be positioned at significant locations such as an entrance gate to provide pre-cache information like traveler guide and map, at different sites within tourist places to provide navigation and important facts, and at exits to provide information regarding cab/bus services and other nearby places to visit.

5.11 Smart Cities

Centralized infrastructure is used to build the smart cities applications. Cloud is used to store all the gathered data which is not efficient system. Therefore, the fog computing paradigm is making its way in all the areas which include agriculture, transportation, health, water, and waste management. Fog computing will ensure stability and sustainability in building smart cities.

5.12 Shopping Malls

In a multi-floor shopping mall, multiple fog nodes can be positioned on different floors to form a unified localized fog network. These fog nodes can store information specific to each floor, such as layout of stores on current floor, opening and closing times, discounts (if any) and reviews. Customers can access information on his/her cell phone through WiFi and give feedback on their recent purchase.

VI. CHALLENGES

As shown in Fig. 1, a fog node is connected to three other devices: adjacent fog nodes through wireless / wired connection, IoT devices through wireless connections and to the cloud. This section presents potential challenges during the implementation of the fog computing paradigm.

- Communications between adjacent Fog nodes: Different fog nodes with different capabilities are placed at different locations. Therefore, Communication between these nodes is very important to improve the performance of the system. Centralized or distributed routing algorithm can be used for data transfer. Distributed fog nodes can be owned by different companies; therefore, they may follow different policies so routing requires maintaining diverse service policies. The adjacent fog nodes can be connected in wired or wireless manner.
- Communications between IoT devices and Fog nodes: A fog node can utilize Bluetooth and WiFi wireless interfaces to communicate with the end device. A fog node can also implement cross-layer design to deliver the best service quality to its users.
- Communications between Cloud and fog node: The cloud plays the role of the centralized hub of all the information and the controller of the widely deployed fog nodes. The fog nodes cache the selected content from the information pool located at cloud and then provide the replicas to the user.
- Incorporating with Emerging Technologies: The key challenge for fog computing is its incorporation with the existing and emerging technologies such as Software defined networking, 5G technology etc.
- Security: One of the major issues is the security threats such as denial of service, man in the middle, privacy leakage, misuse of resources, etc.

VII. CONCLUSION

With the increasing number of connected IoT devices, there is a major requirement of a concept like fog computing which provides resources at the edge of the network instead at far centered cloud server. Fog computing brings the cloud nearer to the customer devices to fulfill their requirement of resources in a location aware, timely manner. This survey discusses the basic concept of fog paradigm with comparison to the cloud computing, key characteristics, provides illustrative applications with challenges. It is clear that fog computing better fulfills the IoT devices and applications requirements in comparison to the cloud computing and it has a bright future.

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