International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 6, June-2018

Fog Computing: Architectural Framework, Applications and Open Research Issues

Anjum Mohd Aslam[1], Mantripatjit Kaur[2]
[1]Assistant Professor, Deptt. Of CSE, Chandigarh University, anjum151993@gmail.com
[2] Assistant Professor, Deptt. Of CSE-IBM, Chandigarh University, mantripat63@gmail.com

Abstract*—The present decade has seen a wide implementation of Internet of Things (IoT) innovation in different application areas, and its extensive role will keep on increasing in the future. With the fast development of Internet of Things (IoT) applications, the cloud computing worldview faces a few challenges i.e. latency, network failure, least performance. For managing countless gadgets and the huge information produced by them, a proficient computing technique is required. Thus, Fog computing has been proposed as an efficient solution to bring the cloud nearer to the IoT devices and to give productive and secure services to the numerous IoT clients. It is a model extending cloud services to the edge of the network, and thus reducing the latency and improving the performance in a dynamic real-time environment. The fog computing supply the services with good response time and high quality as opposed to cloud. This paper reviews the architecture of fog computing model, its characteristics, applications and its related works in Fog and IoT technology.

Keywords— Fog computing, IoT(Internet of Things), Cloud computing, Edge computing, Latency, QoS(Quality of Service).

I. INTRODUCTION

Fog computing is a rising technology used for the Internet of Things (IoT). It is a model that extends the cloud computing and other services to the edge of the network [1]. Cloud computing is an efficient model which provides on-demand access to shared pool of resources such as storage, power, network on " pay-as-you" basis. Thus, it helps to meet the need of users, scale the requirements of IoT and is effective for clients that require to have web and mobile applications instead of operating private data centers. As similar to cloud computing, fog computing also gives information, storage, computation, and applications to the end-users. The main differentiation of fog computing with the cloud is closeness to end-clients, mobility, and dense geographical distribution of services [2].

Thus, fog computing concept has emerged because of the delay between cloud and end-user devices while transferring data, mainly in applications which requires high response time and performance. Even, dense geographical distribution and mobility support is also needed in today's application.[1]. Fog computing is a decentralized computing architecture which was initially and formally introduced by Cisco[3] that uses edge devices to store, compute and process the data between the source of origin and cloud framework. It comprises of edge nodes which perform input and output by taking input from sensors and then displays the output. Instead of using centralized clouds, it uses cloudlets i.e. small edge clouds for computation. Thus, it minimizes the overhead of data transmission and enhances the performance of cloud by diminishing the prerequisite to processing and storing substantial volumes of unnecessary information. The model of fog computing has emerged because of the high continuous rise of Internet of Things(IoT) devices which is generating an increasing amount of data in terms of volume, velocity and variety [4]. IoT provides rich services by connecting every device to internet and to each other and exchanges data. These devices further require fast decision processes to manage the data, but this can present some issues such as reliability, scalability when utilized with the traditional client-server architecture.

In the research surveys, it has been widely acknowledged that cloud model is not suitable for most of the IoT applications and for that fog computing could be used as an alternative. Thus, fog computing model has evolved as an efficient solution to provide a scalable decentralised solution and to tackle the challenges by creating a distributed platform between cloud and end-user devices[5].It will also save time and communication resources by filtering, combining, analyzing, processing and transmitting the data. As discussed that cloud computing provides us numerous benefits[6] to the users, but the services provided by cloud is not suitable for the applications such as IoT, Smart grids, Fire detection, wearable computing etc which are latency- sensitive, requires high response time, and portability. Moreover, these types of applications generate a huge volume of data and till the time it reaches for analysis to cloud and then to inform the IoT device, the delay gets occurred. For, any real-time life critical application this latency can have adverse effects.

The paper is organized as follow. Section 2 gives an overview of the Fog computing architecture and how it works. Section 3 describes the various characteristics of Fog computing and its importance and role in IoT. Section 4 describes the Applications of Fog Computing, Section 5 discusses some of the Open research issues and Challenges and Finally, Section 6 concludes with the conclusion.

II. OVERVIEW OF FOG COMPUTING

Bonomi et al.[7] has introduced fog computing as a new technology for IoT in 2012. This computing model incorporates the idea of providing computation and storage functionality closer to IoT devices at the edge of the network. This functionality can decrease the distance between the processing unit and the end devices by introducing an additional layer called as fog layer [8]. This fog layer acquires its own computation and storage ability to process the jobs, filter it, and store the data. It even provides high geographical distribution of the devices for reliable execution of its service, even while moving it maintains the strong connection to the connected moving devices, such as mobile phones, smart cars etc [9].

The Fig. 1 describes a three-level fog-cloud system hierarchy where the fog cells are located at the edge of the network. The fog cells are located between the cloud service provider and the terminal devices. These cells receive the service request for the tasks from the connected IoT devices such as sensors, actuators. Then these fog cells decide to process the requests and all the communication occurs inside the fog layer framework [10]. This fog layer can also be connected to the multiple cloud providers or a private cloud can be used inside fog environment. At the top cloud providers are there which are connected to the fog layer and then this fog layer is connected to the IoT devices located at the bottom [11]. Thus, the different tasks from various regions can be executed by the fog devices which enhance the efficiency.

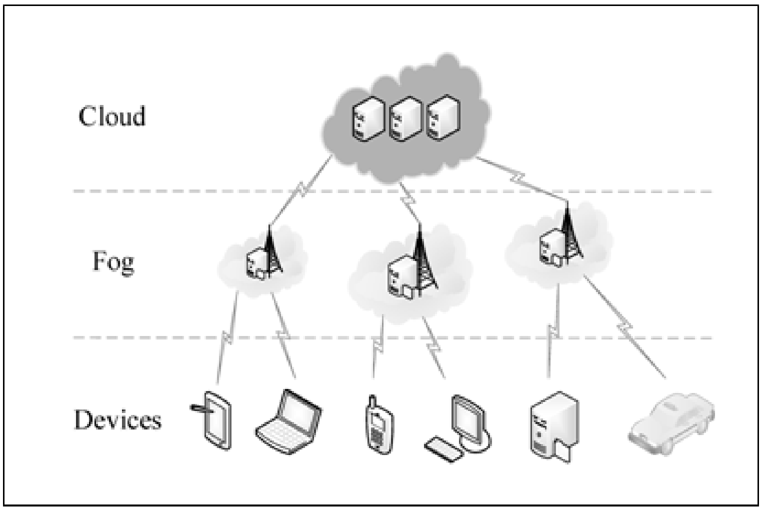

Figure 1. Fog computing environment model

The architecture of a fog computing network is shown in Fig. 2. The fog cells are located in the hierarchical layers between cloud and IoT(Internet of Things) at the bottom. The main idea of this computing model is to provide computing and storage capabilities closer to the end nodes and provides efficient functionalities for the applications [12]. Using, the paradigm of fog computing, better quality of service is achieved with low latency. This low latency is achieved because the data analysis occurs at the fog layer which is a lightweight process and then further processing is done at the cloud layer. The applications which require real-time computation is performed by the fog layer, but for some applications which don't require the real-time computation but need high processing power, then it can be performed at the cloud layer [13].

The hierarchical architecture of fog computing comprises three following layers:

1) Terminal layer: This layer is located at the bottom and is close to the end users. It contains various IoT devices such as sensors, actuators, smart devices, smart vehicles, mobile phones, etc. These devices are widely geographically distributed and these devices sense the data of any physical objects and then transmit this sensed data to the upper layers for further processing and storage.

2) Fog layer: Fog layer comprises of a large number of fog nodes which are located at the edge of the network and are widely distributed between the cloud and the end devices. These fog nodes comprise routers, switches, gateways, access points, fog servers, base stations etc. The end devices are connected with the fog cells to obtain the services and these fog cells compute, transmit and stores the data it receives.It then performs the real-time analysis on the received sensed data and thus provides high-quality service to the latency-sensitive applications.

These fog cells are also connected with the cloud network and thus it helps to obtain more powerful computing and storage services.

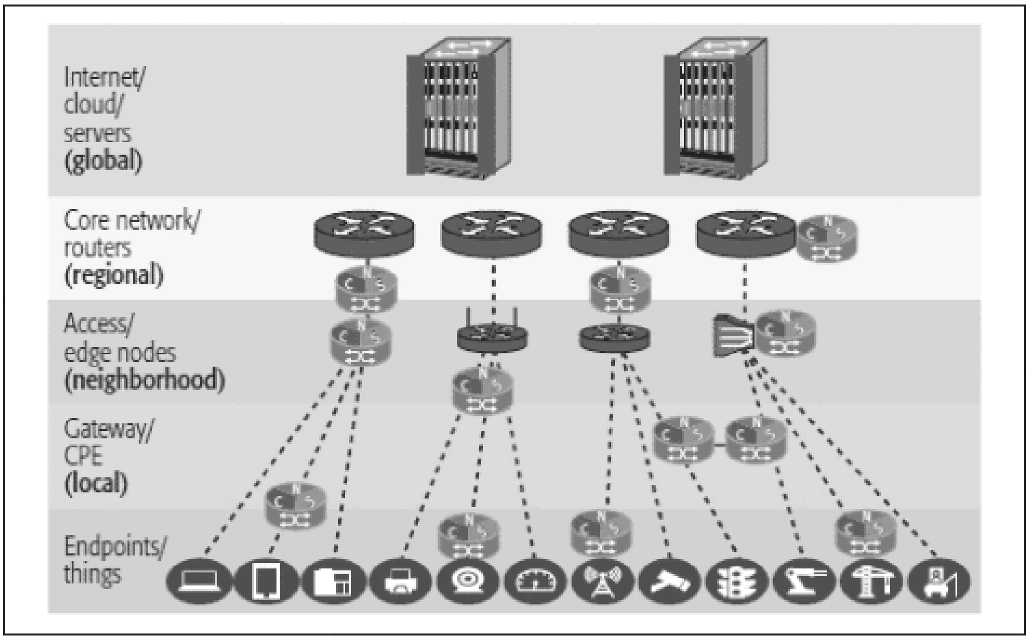

Figure 2. The hierarchal architecture of Fog computing [14]

3) Cloud layer: This layer comprises of servers and various storage devices which provides various application services i.e. smart city, smart transportation, smart vehicle etc[15]. This layer provisions support for substantial computation analysis and processing of a large amount of data by providing strong computation and storage capabilities. In this fog computing architecture, every device is connected with one fog cell by means of wireless access technologies including Wireless local area network(WLAN) , 3G/4G, Wi-Fi, Bluetooth network etc. Then each of these fog nodes are further connected with the cloud network. Thus, this architecture provides the support for IoT applications by providing the capabilities to analyze, compute, process and store huge volumes of data. And then communicate to the network [16].

Thus, the main advantage of including the fog layer in this architecture is to speed up the process, as cloud processing may take a long time depending on the server load and network speed. But, this computing model improves the performance in a mobile environment by providing low-latency services.

III. CHARACTERISTICS OF FOG COMPUTING

Fog computing computes and processes its tasks near to the edge devices and it is the main basic characteristic of the fog computing as compared to the traditional models [17]. Some of the characteristics of the fog computing model are listed below:

1) **Low latency**: In IoT networks, minimizing the latency is the prerequisite that is satisfied by the fog computing techniques. Latency is defined as the delay taken by information processing in a real-time environment which can be one-way or two way as roundtrip [18]. Fog provides low latency for the applications as it acquires the data generated by the sensors at the network edge and then processes and stores that data in a local area network. This further reduces the data movement across the networks and increases the speed of the services supported by the endpoint nodes.

2) **Geographical distribution:** Fog computing provides highly geographical distribution as compared to the centralized cloud environment. It comprises of the large number of nodes which are highly distributed and maintains, tracks the locations of the end devices [19].

3) **Support for mobility:** There are various mobile devices in fog computing environment such as smart devices, smartwatch, and smart vehicles so the spatial mobility at the terminal layer occurs very frequently. The fog nodes can be static or mobile. Thus, using LISP protocols, mobility is provided by fog and thus various mobile devices can communicate with each other freely [20].

4) **Heterogeneity**: Fog nodes can be deployed in a wide variety of environment as a physical or virtual node. These nodes comprise of servers, routers, gateways, switches, etc and thus perform a high level of computation. Thus these nodes are heterogeneous and can be deployed in any environment. Which not only include high-speed network but also wires access technologies [21].

5) **Interoperability:** Fog nodes can interoperate to give a wide range of services to its end user. Due to its heterogeneous nature, these nodes can be deployed in any environment [22]. Thus, it can interoperate with different services providers and support various services such as streaming.

6) **Real-time interactions**: In Fog computing, real-time interactions are required for speedy services.

7) **Enhanced security**: IoT network can carry private data which can be dangerous to the physical systems. Thus, fog computing provides enhanced security and privacy to its users by using encryption algorithms and isolation to protect the data. It even protects from rmware[23].

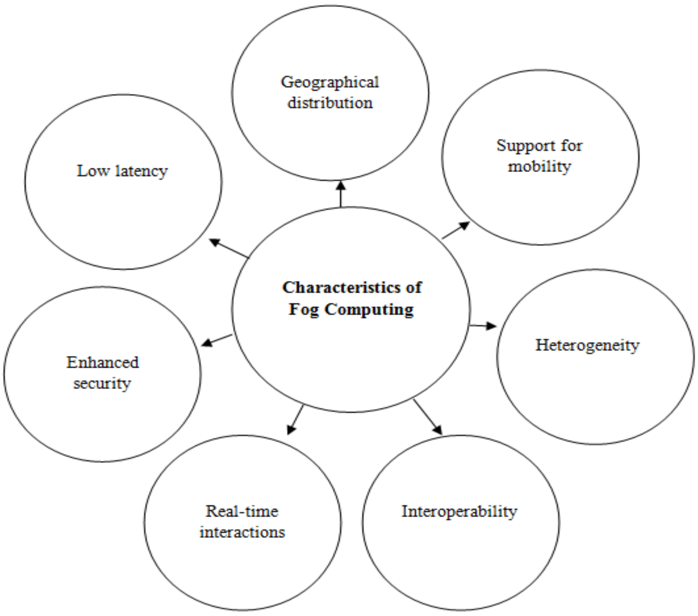

Figure 3. Characteristic of Fog computing

Table 1: Comparison of Cloud computing and Fog computing in terms of Quality of Service

Specifications	Cloud Computing	Fog Computing
Security	Undefined	Can be defined
Latency	High	Low
Delay	High	Low
Location of service	Within the Internet	At the edge of the network
Geographical distribution	Centralized	Decentralized(Distributed)
Mobility Support	Very less	Supported
Number of server nodes	Few	Very large
Connectivity type	Leased line	Wireless

IV. APPLICATIONS OF FOG COMPUTING

This section describes some of the Applications of Fog computing [24].

1. **Smart Cities:**
Huge urban cities confront challenges from traffic jams, water quality, high use of energy, cleanliness, security, the absence of good broadband bandwidth connections etc. By utilizing a network of fog nodes in a single IoT network, these challenges can be addressed. Installing fog computing architecture will enhance the network usage and will provide local processing and storage and will address the major issues and requirements.

2. **Smart Traffic lights**:
With Fog computing architecture, intelligent traffic lights are coming into the picture. These smart traffic lights communicate with sensors and make intelligent decisions in the real-time environment. It uses WiFi, 3G access points for the communication to occur. A video camera installed on the lights can sense the ambulance and then automatically turn the street lights to open the lane to pass the vehicle from the traffic. It keeps on track about the pedestrian, vehicles and sends warning signals in case of any danger situation.

3. **Self-governing cars**:
The self-governing vehicle is the new trend in the market. A company named Tesla is working on it to add automatic features to the vehicle and to connect the cars to the internet. Fog computing here plays a good role for all internet-connected vehicles and to provide them real-time communication. Thus cars, wireless access points; the traffic lights will interact with each other and will set up a new trend to take place on road.

4. **Smart Grids**:
It is one of another application of fog computing, where based on the need of the energy; the smart devices will switch to the renewable sources of energy such as solar, wind etc.
The fog cells collect the data and then edge processes it and pass the control to the actuators. Then this filtered data is processed and passed to the higher layers for further analysis. Here, the fog supports for storing the data locally and for further processing.

5. **Software-defined networks:**
It is one of the growing fields together with fog computing. This collaboration can deal with many of the challenges and issues such as high packet collisions and loss, irregular network connectivity. It will support vehicle to vehicle and vehicle to infrastructure communications and will further provide more security.

V. OPEN RESEARCH CHALLENGES AND ISSUES

The following table describes some of the open challenges and issues in Fog computing environment[25].

Table 2: Open research challenges and issues

Security issues	Fog computing devices may become vulnerable to some of the traditional attacks such as data hijacking, eavesdropping, man-in-the-middle attack, Denial-of-service attack.
Authentication	Authentication and trust issues may be faced by the Fog devices such as gateways. Even relying on central cloud authentication servers is also not a preferable option.
Reliability issues	To analyze the reliability of fog computing model is difficult because of huge size and complexity of the network. Even to detect failures also becomes difficult for such a huge network
Malwares	In Fog environment, the malware infected nodes will decrease the performance of the whole fog computing architecture which can corrupt the data and system completely. Thus, Anti-malware software such as Intrusion Detection System, rigorous data backups, Patching vulnerabilities need to be installed.
Privacy issues	Privacy is always considered as an important issue in distributed computing. It even impacts the latency issue.

VI. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This paper gives the overview of Fog Computing and we have seen the architecture of fog networks. This architecture is a rich canvas with various characteristics and computing requirements. We have seen that fog Computing has the capability to manage a huge amount of data generated by IoT devices. Cloud computing can work along with IoT by providing on-demand services, but the applications require low latency and high quality of service will not be able to perform well because of the congestion in the network. Thus the concept of fog computing has emerged which develops cloud computing to the edge of the networking to overcome the problems identified by cloud computing. It will further help to reduce the burden on the networks by improving latency and performance In this paper, we presented the Architectural framework, characteristics, applications of fog computing. However, fog computing faces many challenges in integrating fully with the IoT domain. We analyzed and categorized some of the open research challenges in this paper.

REFERENCES

[1] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, "Fog computing and its role in the internet of things," in Proceeding of the first edition of the MCC workshop on Mobile cloud computing, 2012, pp. 13-16: ACM.

[2] I. Stojmenovic, "Fog computing: A cloud to the ground support for smart things and machine-to-machine networks," in Telecommunication Networks and Applications Conference (ATNAC), 2014 Australasian, 2014, pp. 117-122: IEEE.

[3] M. Aazam, P. P. Hung, and E.-N. Huh, "Smart gateway based communication for cloud of things," in IntelligentSensors, Sensor Networks and Information Processing (ISSNIP), 2014 IEEE Ninth International Conference on, 2014, pp. 1-6: IEEE.

[4] Cisco System, "The Internet of Things: Extend the Cloud to Where the Things Are," ed, 2016.

[5] S. Yangui *et al.*, “A platform as-a-service for hybrid cloud/fog environments,” in *Proc. IEEE Int. Symp. Local Metropolitan Area Netw. (LANMAN)*, Rome, Italy, 2016, pp. 1–7.

[6] X. Zhu *et al.*, “Improving video performance with edge servers in the fog computing architecture,” *Intel Technol. J.*,vol. 19, no.1,pp. 202–224, Apr. 2015.

[7] S. Yangui and S. Tata, “The SPD approach to deploy service-based applications in the cloud,” *Concurrency Comput. Pract. Exp.*, vol. 27, no. 15, pp. 3943–3960, Oct. 2015.

[8] D. Pop, G. Iuhasz, C. Craciun, and S. Panica, “Support services for applications execution in multi-clouds environments,” in *Proc. IEEE Int. Conf. Auton. Comput. (ICAC)*, Würzburg, Germany, 2016, pp. 343–348.

[9] B. D. Martino, “Applications portability and services interoperability among multiple clouds,” *IEEE Cloud Comput.*, vol. 1, no. 1, pp. 74–77,May 2014.

[10] P. Massonet *et al.*, “A monitoring and audit logging architecture for data location compliance in federated cloud infrastructures,” in *Proc. IEEE Int. Symp. Parallel Distrib. Process. Workshops Ph.D. Forum (IPDPSW)*,China, 2011, pp. 1510–1517.

[11] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, “Fog computing and its role in the Internet of Things,” in *Proc. 1st Ed. MCC Workshop Mobile Cloud Comput.*, Helsinki, Finland, 2012, pp. 13–16.

[12] “OpenFog reference architecture for fog computing,” OpenFog Consortium, Fremont, CA, USA, Tech. Rep. OPFRA001.020817,

[13] Bonomi, F.; Milito, R.; Zhu, J.; Addepalli, S. Fog computing and its role in the internet of things. In Proceedings of the First Edition of the MCCWorkshop on Mobile Cloud Computing, Helsinki, Finland, 17 August 2012; pp. 13–16.

[14] Shojafar, M.; Cordeschi, N.; Baccarelli, E. Energy-efficient adaptive resource management for real-time vehicular cloud services. IEEE Trans. Cloud Comput. **2016**, 99, 1.

[15] Zaghdoudi, B.; Ayed, H.K.B.; Harizi, W. Generic Access Control System for Ad Hoc MCC and Fog Computing. In Proceedings of the International Conference on Cryptology and Network Security, Milan, Italy, 1416 November 2016; pp. 400–415.

[16] Baccarelli, E.; Naranjo, P.G.V.; Scarpiniti, M.; Shojafar, M.; Abawajy, J.H. Fog of Everything: Energy-efficient Networked Computing Architectures, Research Challenges, and a Case Study. IEEE Access **2017**, 5, 9882–9910.

[17] Hajibaba, M.; Gorgin, S. A review on modern distributed computing paradigms: Cloud computing, jungle computing and fog computing. J. Comput. Inf. Technol. **2014**, 22, 69–84.

[18] Aazam, M.; Huh, E.N. Fog Computing and Smart Gateway Based Communication for Cloud of Things. In Proceedings of the International Conference on Future Internet of Things and Cloud IEEE, Barcelona, Spain, 27–29 August 2014; pp. 464–470.

[19] Stojmenovic, I.; Wen, S.; Huang, X.; Luan, H. An overview of Fog computing and its security issues. Concurr. Comput. Pract. Exp. **2015**, 28, 2991–3005.

[20] Yi, S.; Qin, Z.; Li, Q. Security and privacy issues of fog computing: A survey. In Proceedings of the International Conference onWireless Algorithms, Systems, and Applications, Qufu, China, 10–12 August 2015; pp. 685–695.

[21] Lu, R.; Rahulamathavan, Y.; Zhu, H.; Xu, C.;Wang, M. Security and Privacy Challenges in Vehicular Cloud Computing. Mob. Inf. Syst. **2016**, 2016, 1–2.

[22] Lu, R.; Heung, K.; Lashkari, A.H.; Ghorbani, A.A. A Lightweight Privacy-Preserving Data Aggregation Scheme for Fog Computing-Enhanced IoT. IEEE Access **2017**, 5, 3302–3312.

[23] Varalakshmi L, Sudha GF, Jaikishan G (2014) A selective encryption and energy efficient clustering scheme for video streaming in wireless sensor networks. Telecommun Syst 56(3):357–365.

[24] Truong NB, Lee GM, Ghamri-Doudane Y (2015) Software defined networking-based vehicular adhoc network with fog computing. International Symposium on Integrated Network Management (IM). IEEE. pp1202–1207,2015.

[25] Datta SK, Bonnet C, Haerri J (2015) Fog computing architecture to enable consumer centric internet of things services. In: 2015 International Symposium on Consumer Electronics (ISCE). IEEE. pp 1–2.