# Integration of Fog Computing and Internet of Things: An Useful Overview

**G. Rekha, Amit Kumar Tyagi and Nandula Anuradha**

**Abstract** In the past decade, the evolution of computing has moved from distributed, parallel, grid, cloud, and now to fog computing. The massive amount of data generated by Internet of Things (IoT) devices is growing up exponentially. The flood of information (generated by those IoT/Internet-connected devices) becomes troublesome for data processing and analytical prediction functionality using cloud computation. Several problems have been investigated with cloud computing with respect to latency, limited bandwidth, low Internet connectivity, etc. Here, solution to such problems can be solved by introducing fog computing with powerful functionality of cloud framework, i.e., based on the deployment of fog nodes called microclouds at nearest edge of data sources. Fog computing for big data/IoT data analytics is in evolving phase and requires extensive research to produce more knowledge and smart decisions. This article discusses several basic facts related to fog commuting, challenges in fog computing and opportunities in the near future, in the context of fog big IoT data analytics. In addition, this work also emphasizes the key characteristics in some proposed research works, those make the fog computing as a suitable (useful) platform for new proliferating IoT devices, services, and applications. Most significant fog applications (e.g. healthcare monitoring, smart cities, connected vehicles, and smart grid, etc.) will be discussed here to create a well-organized green and quantum computing paradigm to support the next generation of IoT applications.

**Keywords** Internet of Things · Cloud computing · Fog computing · Big data · Data analytics

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## 1 Introduction

Fog computing is a pushing edge for processing computer applications, data, and services in close proximity of end-user. Fog Computing or Fog Networking or Edge Computing, and it is also known as Fogging, provides computing facilities away from centralized cloud to the logical stream of the network edge. Fog computing is started with the word 'fog', means 'closer to someone'. Fog computing is closed to cloud and nearer to end-users. It extends the traditional cloud computing architecture to the edge of the network architecture. The fog extends the basic building block of the cloud like compute, storage, and networking services to the edge of the network so-called fog nodes, near the end devices (like IoTs, smartphones, GPS, wearable devices, etc.). Fog offers distributed points for assembling data generated by the end devices via proxies, access points, and routers placed at the network edge, near the source devices. Though now days cloud computing is widely used a backbone to Internet of Things, and provide resource utilizations (accessing) from anywhere, anytime. But still cloud computing has some limitations. The fundamental limitation of cloud computing is the connectivity between the cloud and the end devices. Such connectivity is set over the Internet, not suitable for a large set of cloud-based applications [1], such as connected vehicles, smart grid [2], re-detection [3], and content delivery [4]. Further, the distribution-based cloud application made up of multiple components, sometimes deployed separately over multiple clouds, may deteriorate the latency due to the overhead induced by inter-cloud communications [5]. Yet, as another limitation of cloud computing is, the regulations may suggest processing at locations where the cloud provider may have no data centre [6]. In literature [7], it is widely recognized that cloud computing is not feasible for most of the Internet of Things (IoT) applications and fog could be used as an alternative solution to solve this problem (feasibility with IoTs). Nowadays, IoT becomes an important and essential device that promises a smart, easier, longer life to human beings. IoT-enabled devices allow communication between the machines (or devices), objects, and everything connecting together with people. The need to build that IoT is to dig up, access, and analyse the information that provides valuable insight. The information generates digital data by connecting the IoT devices over the Internet (or World Wide Web), for example, online transaction, downloading of applications, retail, etc.

The IoT systems consist of things or devices in the real world and sensors are embedded with devices which are communicated to the Internet (via wired or wireless networks as a medium). The variety of powerful devices like servers, smart access devices such as smartphone, tablets, smart sensors, smart appliances in home, and many more. Therefore, all connecting things together formulate an IoT ecosystem, used to solve real-world applications. The various types of connections used by IoT sensors are RFID, Wi-Fi, Bluetooth, and ZigBee, and for wide area connectivity, GSM, GPRS, 3G, and LTE are used. As reported by Ovum and CISCO [1] in March and June 2017, respectively, at present the main areas of investment are the Industrial Internet of Things (IIoT) [8], by deployment of IoT devices in industries include manufacturing operations, transportation, smart grid technologies, smart buildings and increasingly, consumer IoT, and smart home automation. Moreover, in general, some applications of fog computing are connected cars, smart cities and smart grids, real-time analytics (e.g. mobile big data analytics, etc.), water pressure at dams, health data, and any other smart utility services. Hence, an architecture of fog computing or fog network with consist cloud environment is depicted as Fig. 1. Irrespective of cloud computing, fog computing provides a better-analysed experience to the end-user by generating some real-time network information (because it is nearer much to end-users than cloud with a high Internet connectivity, i.e., with a low latency, refer Fig. 2). Hence, big IoT data analytics with fog computing provides better, efficient insights by enabling devices to make smart and intelligence-based decisions without the interaction of human. These data or information analyses by big data can be used in solving or predicting several real-world problems in the near future.

Hence, the rest of this paper is organized as follows: Sect. 2 deals with the overview of fog computing and its related work. Further, Sect. 3 discusses the interfacing fog, with fog, cloud, IoT devices/end-user devices and Sect. 4 presents the salient features of fog computing. Real-time use cases are discussed in Sect. 5. Further, some challenges with respect to fog computing have been discussed in Sect. 7, and in last, this work is concluded with some future remarks/enhancements in Sect. 7.

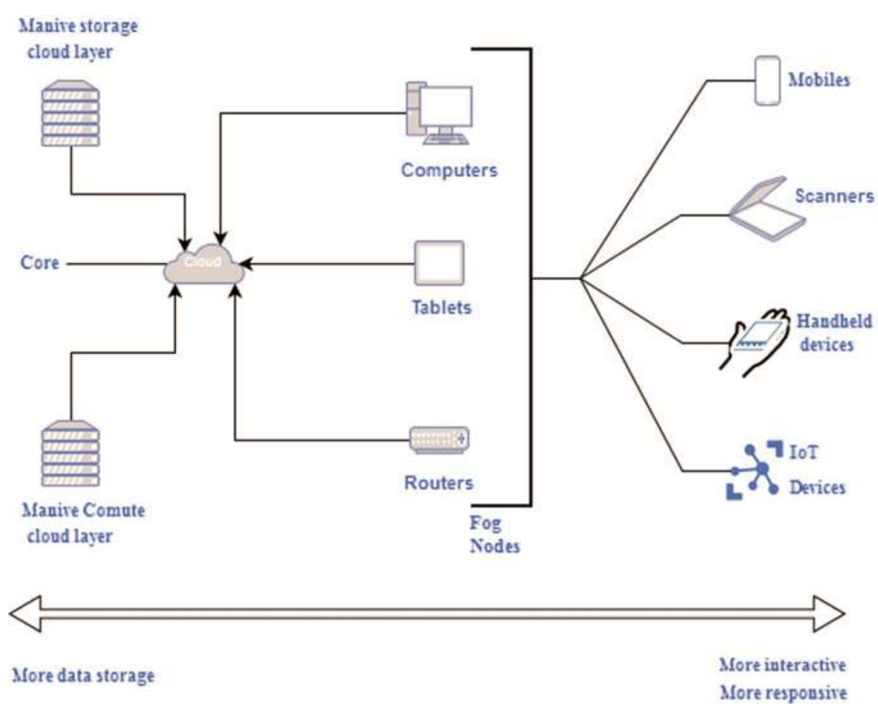


**Fig. 1** Architecture of fog computing

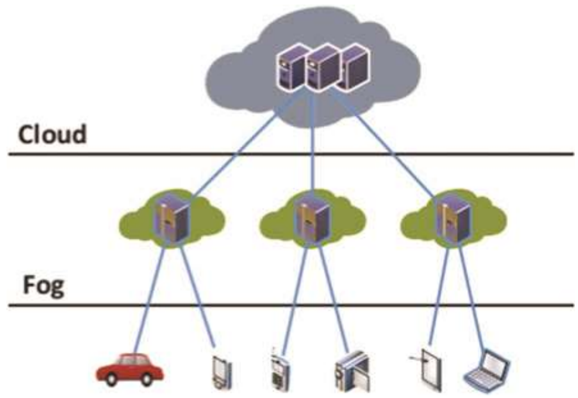


**Fig. 2** A generic convergence of IoT devices and fog devices [2]

## 2 Related Work

As data is increasingly generated by the IoT devices at the core network end, to efficiently process all data at the close proximity of IoT, CISCO in 2012 introduced a concept called fog computing. It is an extension of cloud computing architecture from the cloud to the edge of the network. This section provides an overview of fog definition and discusses the similarities and differences between the related concepts and its interface with cloud, IoT, and other fog nodes in brief.

### *2.1 Fog Computing—Definition*

Fog computing is an extension of cloud computing paradigm by enabling computation at the edge of the network, closer to IoTs and/or the end-user devices (i.e. to provide reliable and efficient services to users). It (i.e. fog computing) presents a distributed hierarchical architecture, offering more flexibility to the system. It supports integration with various technological components and services like smart cities, smart homes, and smart grid system [7]. Fog computing provides pool of resources with one or more decentralized nodes which cooperate and communicate with each other or in a group at the edge of the network. Figure 2 shows a fog system with three-tier architecture consisting of IoT/end-user devices, edge-level nodes or fog nodes and the cloud-level nodes. Fog computing provides services at the edge of IoT devices and the communication happens via local area network (LAN). The main focus of the nodes at the edge is to sense the collection of raw data, process, and control of end-user or IoT devices as shown in Fig. 2.

**Table 1** A brief description of cloud computing, cloudlets, mobile edge computing

| | Cloud computing | Cloudlets | MEC |
|---|---|---|---|
| Definition | It includes software and applications running on a central server having built-in local networks with big data centres | It provides a small cloud computing architecture by inheriting the features from centralized cloud computing | MEC enables technologies to be available for cloud computing to provide QoS at the edge of the network |
| Uses | SaaS, PaaS, IaaS | Time-sensitive and limited bandwidth applications | Mobile applications |
| Mode of operation | Connected | Stand-alone or connected to cloud | Stand-alone |
| Applications | Any application | Mobile offloading application | Mobile offloading application |
| Difference | Mainly driven by R and D | Mainly driven by R and D | Mainly driven by industry |

### *2.2 Similarities and Differences with Cloud Computing, Cloudlets, and Mobile Edge Computing*

There are some similar terms that come along with fog computing called cloud computing, cloudlets, and mobile edge computing (MEC). Even though cloud computing, cloudlets, and MEC aim at computing at the edge, few differences exist in each new technology. Table 1 illustrates the definition and the difference among all three.

Hence, this section discusses the related work to fog computing, like definition of fog computing, similarities, and difference in fog computing technology/environment with existing (new) technologies like cloud computing, cloudlets, and mobile edge computing. Now, the next section will discuss some interacting scenarios, i.e., with cloud, and IoT devices, or as cloud based IoT/ IoT based Cloud.

## 3 Interfacing Fog with Fog, Cloud, Internet of Things Devices/End-User Devices

As discussed in Sect. 2, fog computing develops from cloud computing, and this term was coined in 2012 to provide flexible, reliable services to end-users. It provides functionality with more flexibility for computation at the edge of the network and shared same processing strategies, visualization, and multi-tendency features. The more significant features support by fog computing are: (a) supports high-speed moving applications like smart connected rail, smart vehicles, etc., (b) low latency, (c) provide distributed environment in large scale, (d) supports geographically distributed applications using sensor networks to monitor the different environment. The

**Table 2** Interfacing of fog to cloud, fog to fog, fog to IoT

| Interface | | | |
|---|---|---|---|
| Fog to cloud and vice versa | It is considered compulsory to support collaboration between fog to cloud and cloud to fog services | It also supports functionalities like supervision at fog end | It also transfers data for processing, comparing between each other |
| Fog to fog | It must have pool of resources to support processing with each other | Multiple fog nodes act together to support backups for each other | All the fog nodes deployed can share their data, computation, and processing for one or several applications |
| Fog to IoT | Fog computing provides services to widely distributed IoT devices like smart devices and sensors | It provides IoT devices to access fog services in a user-friendly environment | Fog computing provides high QoS to the IoT devices or end-users |

most fundamental components in fog computing architecture are called fog nodes. They are set of hardware and software elements that can be configured together to perform specific functions like providing resources for services such as cloudlet. Generally, cloudlet is a cloud data centre located at the edge of the Internet. As fog computing is an emerging technology and in infant stage (i.e. just started, not developed completely). Therefore, further research is needed in this area/domain. The architecture of fog computing allows processing, networking and storage services to dynamically allocate at the fog nodes, cloud, or IoT systems. However, the interface of fog with other devices is must to enable well-suited end-user assessment and also to provide effective QoS management. Table 2 illustrates the different interfacing between the fog, cloud, and IoT.

Hence, this section discusses the interfacing of fog with fog, cloud, IoT devices, or end-user devices. Now, the next section will deal with the salient features of fog computing in brief.

## 4 Salient Features or Characteristics of Fog Computing

The movement of computational load to fog networking from cloud enables the development of IoT structure for diversity of applications and services. The fog computing characteristics are as follows:

(a) Cognition: Cognition means thinking and perceiving the client's intentions. Fog-based data processing offers a more lucid picture about the client's interests.

For example, getting insight into how to store, control, and transfer data from cloud to IoT and vice versa. The devices at the edge respond more quickly to the client's requests as they are at the ground level than the remote cloud-based services.

(b) Heterogeneity: Fog computing is an integration of various computing platforms offering a variety of computing infrastructure. It bridges the cloud server and the senor enabled devices. Fog computing servers utilize federation of clouds in a distributed environment.

(c) Geographical environment distribution: Fog computing has the capability of providing Quality of Service (QoS) in both mobile and stationery environments by distributing the fog nodes so that they can communicate with the nearest gateways. E-heath, m-health, traffic monitoring are some examples of location-aware services.

(d) Edge location with low latency: Fog nodes (existed in a fog computing environment/fog network) give quick response than the cloud, thus improving the Quality of Service (QoS) in terms of low latency. This is an important requirement of any application that involves streaming of data.

(e) Real-time interaction: Real-time interaction is the most crucial aspect in fog applications where the edge devices should transmit real-time information such as airflow inside mines, radiation levels in nuclear power plants, leakage of poisonous gases inside chemical factories, etc.

(f) Support for mobility: Multiple geographically distributed fog nodes can communicate with the mobile devices in applications such as vehicle networks and efficient logistic management.

(g) Large-scale sensor network: Fog computing has the capability of forming a hierarchical network architecture by combining data from multiple gateways for global data processing.

(h) Widespread wireless access: In fog computing, Wireless Application Protocol (WAP) and mobile gateways enable users to connect to the closest fog nodes.

(i) Interoperable Technology: Fog computing infrastructure can be considered as an interoperable system which can be physical, virtual, or a hybrid consisting of a collection of sensor devices, cloud services, communication protocols that facilitates dissimilar components to generate solutions to specific issues.

Hence, this section discusses several characteristics that make the fog computing essential to end-users and non-trivial extension of the cloud computing, that is, fog computing provides service to users like edge location, location awareness, low latency, providing hierarchical organization and proximity of data to end-users, dense geographical distribution, large-scale sensor networks, large number of nodes, support for mobility, real-time interactions, predominance of wireless access, heterogeneity, federation and interoperability, and integration with the cloud and support for online analytic. Now, the next section will discuss some real-time uses cases in brief.

## 5 Real-Time Use Cases with Fog Computing

In this section, we discuss the role the fog computing plays in IoT environment or IoT ecosystem with explaining four interesting scenarios, i.e. video streaming data, healthcare monitoring systems, gaming, and smart traffic light (STL) system. Hence, each use case/scenario is discussed as follows:

(a) Video streaming data: The characteristic features such as low response time, mobility, position awareness and real-time data processing capabilities of fog nodes benefit the real-time video streaming applications. Aqua computing is a mobile edge network that enables the computing resources to be integrated with communication resources, thereby improving the connected users' experience. It also optimizes the computing resources. Here, the fog nodes act as clones at the edge and as buffers at the user's desktop. Also, systematic deployment of fog nodes enhances real-time on-demand video streaming.

(b) Healthcare monitoring systems: Many health and fitness applications are built to continuously monitor individual's health. The captured data is analysed and diagnostic predictions can be made to take appropriate decisions by healthcare applications. This can be achieved with the integration of massive number of fog nodes that can create a real-time transmitting system than a cloud which has high response latency. Cao et al. [9] have proposed a real-time monitoring application, U-Fall, which can be separated into three major sections, front-end, back-end, and communication module, where front-end and back-end both make independently detections results. Thus, eliminating the false alarm rates and improving the detection accuracy. The other significant factor of U-Fall application is that it discovers the exhaustive fall using data of mild strokes. Hence, the experimental findings showed an increased sensitivity. It can be understood that the application of fog computing gateway improves complex techniques such as data mining and priority-based storing. FAST [10] is a distributed data analytics application with fog sensors that monitor cardiac strokes. It was shown that a fog-based edge network offered enhanced QoS by identifying the location of the patients quickly.

(c) Gaming: Cloud computing has increased the popularity of online multiple player computer games without any kind of hardware infrastructure. Wang and Dey [11] described mobile gaming application framework based on the cloud servers, where centralized server works on all possessing load of the game. But due to inherent latency of the cloud computing, the gaming commands issued by the server take much time, thereby disrupting the game. Hence, the application of fog computing in online gaming enhances the Quality of Service (QoS) and Quality of Experience (QoE). The experiment showed that the collected data encoding improves the playback consistency and end-time-driven buffer forecast approach.

(d) Smart traffic light (STL) System: Traffic lights are equipped with sensors that can sense, process, and communicate. These STLs can monitor the ongoing traffic. This data can be analysed and sent to traffic controller to avoid accidents and traffic congestions. Also, it helps an ambulance to find a traffic-free route or clears the route for ambulance. Thus, STLS requires high data transmission rates from one fog node to another fog node for making quick decisions for choosing alternative routes.

Hence, this section discusses several real-time use cases of fog computing in IoT. Now, the next section will briefly explain the challenges of fog computing for IoT.

## 6 Challenges in Fog Computing with Internet of Things

Fog nodes (in a fog networking) mostly provide localization, therefore enabling low latency and context awareness, the cloud provides global centralization. Many applications require both fog localization and cloud globalization, particularly for analysing the data generated by IoT devices. Hence, some challenges have been investigated with fog computing, which are included as follows:

(a) Security: As fog nodes are distributed throughout heterogeneous networks and platforms, adhering to a specific set of security protocols is not feasible. So, the fog nodes at the gateways may be compromised. Security is also not the first topic in the current IoT discussions and is still largely treated as a compulsory yet secondary subject. Such disregard can be attributed to the lack of organizational policies and the ambiguities in government laws [12].
(b) Data processing, integrity, and quality: Huge number of interconnected IoT devices transmits continuous streams of data. The data collected is not only huge, but generated at various rates and dynamic in nature. The quality of data collected determines QoS. Error in data collection, noise, and error in measurement will affect the quality of services. SLAs play an important role in achieving the required QoS. Also, in a distributed environment data integrity is an important consequence. Data integration provides a single view of the data arriving from different sources and combines the view of data [13].
(c) Real-time data analytics: As discussed in [14], Internet of Things produces a lot of data (called big data), which need to be analysed smartly with more meaningful and useful information, which requires algorithms that are capable of analysing continuous streams of data generated by various sources in real time. Choosing a specific algorithm for a specific IoT application is crucial to make real-time decisions. Big data implementations must perform analytics with real-time queries to help organizations obtain insights quickly, rapidly make decisions, and interact with people and other devices in real [8].
(d) Privacy: Preserving network privacy, data privacy, location privacy, and identity privacy is a biggest challenge (or concern) in fog computing (due to connected via wireless). The leakage of private data or information from fog node is receiving attention from many malicious users while using networks. As solution to this problem to preserve privacy, encryption methods like HAN (Home-Area Network) can be used to counter these issue/challenges.

(e) Resource management: As discussed above, fog servers and data storage facilities require in a fog computing environment (at the edge of the network, to increase processing). The management of large number of fog nodes and providing storage to each fog node increase additional computing a fog computing environment, i.e. increase management costs. We (i.e. researchers) need to provide properly analysed services, effective management to fog servers in the near future.
(f) Heterogeneity: Several types of IoT devices, sensors, etc., are communicating in fog environment (i.e. with fog servers). To handle all devices, sensors, etc. (they have different protocols, storage capabilities, sensor characteristics, etc.), will create a massive problem, i.e., to provide a reliable coordination between these devices and fog server is a big challenge.
(g) Latency: Latency is an essential parameter in fog computing. It was a reason why it (fog computing) was used over cloud computing, but again latency (in fog computing) is not improved till end user's expectation level. Hence, if latency requirement is not satisfied, the performance would be degraded resulting in user dissatisfaction, and interest of users will be decreased.
(h) Complexity: In fog computing, large number of sensors and IoT devices are connected together to provide flexible service to end-users. But, providing such services with an optimized route/device is really a critical issue/challenging task. Sometimes, used software and hardware in IoTs may also increase complexity in fog environment, i.e. decrease performance.

In fog computing environments, nodes are higher and making communication continuously, and then computation is distributed among all nodes (in parallel) and can be less energy-efficient. Note that energy consumption or battery is a big issue with IoT Devices. Fog computing is closer to end-user with IoT devices, so improving battery power and saving energy in IoTs (during making a communication with devices or human being) is an essential work, it is a bigger challenge to overcome in the near future. The next section will conclude this work with some future enhancements in brief.

## 7 Conclusion with Future Research Directions

Fog computing performs some computing and storage at the edge of the network rather than relying entirely on cloud. This paper presents a few application areas such as health care, smart traffic light system (STLS), real-time gaming, etc., where fog computing and cloud computing go together. The key-enabling technologies underlying the fog computing are computation offloading, latency management, communication interfaces such as network function virtualization (NFV), software-defined networking (SDN), 5G, etc., and pre-cache system storage and storage expansion. The computation offloading can be achieved by provisioning live VM migration. SDN and NFV offer network scalability. Although there are many favourable areas for the application of fog computing, there are still challenges such as safety and security risks, energy-efficiency issues to be resolved. This work discussed cloud and fog computing in detail. Cloud computing offers massive data handling capability, scalability and flexibility, whereas fog computing offers user-centric services with low latency, location awareness, mobility, real-time response. This work provides a general overview to understand more about fog computing, and also some other new technologies like cloudlet, mobile edge computing, etc. (i.e. with similarities and dissimilarities). As future work with fog computing, we can try to build a smart gateway between networks to realize cloud with fog computing. Also, reduction of energy consumption in fog computing (including IoT devices) is always an essential and mandatory issue to overcome.

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