Emerging Trends in Internet of Things

Yash Agarwal and K. A. Nethravathi

Abstract Recent technological eco-space has observed an exponential increase in the number of devices connected to the Internet. The data generated by these devices has reached astronomical figures. Due to this, there exists a need for managing and processing the big data, at the same time maintaining the reasonable latency. This requirement of today's world in the field of Internet of things has given rise to technologies like fog computing, edge computing, mist computing, etc. This paper focuses on new technologies which are improvements of existing cloud computing. A computational analysis of fog computing is performed using iFogSim and cloud-Analyst simulator to carry out latency and cost comparisons between fog and cloud computing. As simulation results conclude fog has a lower latency of 159 ms, but at the same time, it has a higher total network implementation cost of $2.39, while the data transfer cost remains the same.

Keywords Big data · Fog computing · Edge computing · Applications · IoT (internet of things)

1 Introduction

Internet is expanding like never before. Each and every day, new devices are becoming the part of it. Today, there are about 5 billion active mobile subscribers in the world. The total number of devices connected to the Internet is expected to be 50 billion by the year 2020 from 8.7 billion in 2012 [1]. Such a drastic increase is mainly due to two reasons—firstly, the need to make everything a part of a network to facilitate communication among various devices or entities which may be far apart or not physically accessible—secondly the quest to make every device **SMART** like smart televisions, phones, machines, home appliances, cities, etc. with the motive of improving the general standards of living of the people [2]. All these smart or network-connected devices generate huge amounts of data. This data is expected to

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R. M. Singari et al. (eds.), *Advances in Manufacturing and Industrial Engineering*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-15-8542-5_67

reach 4.4 ZB by 2020 from just 0.1 ZB in 2013. Such an explosion in produced data has given rise to scope of technologies like big data analysis or analytics. This big data can be stored and processed by means of machine learning algorithms and neural networks to make sense out of it and calculate certain statistical parameters known as key performance indicators (KPIs). These KPIs can prove to be extremely beneficial for various firms and institutions to take crucial decisions [3]. In today's world, data is being considered as the most important asset. It is set to become a trillion dollar industry. The annual revenue from IOT sales is expected to hit $1.6 trillion by 2025.

Traditionally, the data gathered from IoT devices is sent to a cloud-based platform where it is processed by using various algorithms to perform the necessary prediction or to make some decision. As the number of IoT devices has increased, the associated data traffic has also increased. Therefore, the cloud platforms should be capable of storing and processing such huge traffic and should have required computational capacity. But this kind of system has some drawbacks. The bandwidth requirement is extremely huge to send the data from large number of devices to the cloud. The computationally extensive cloud platform will lead to higher costs and power consumption. Also there might be a latency problem in case of time sensitive data which needs to be responded with some action quickly but has to travel long distances to reach and get processed by a remotely located cloud data center. This problem can be very well held by fog and edge computing techniques. The term fog computing was first used by CISCO in the year 2014. It focuses on moving the operations of storage, processing and network services between the end user and the cloud data center. Edge computing involves processing of data locally at the edges or as close as possible to the edges [4]. This reduces the latency and improves the response time.

2 Why Fog Computing?

The existence of gigantic number of IoT devices and the huge data produced by them when integrated with the cloud computing can pose several problems. This huge data creates a lot of traffic on the network, and it can become really troublesome to handle it. Also the bandwidth consumption will be large. Apart from this, there is a problem of high latency or response time. The data from these devices can be identified into three broad categories depending upon the response time requirements.

- Time-sensitive data
- Less time-sensitive data
- Non-time-sensitive data

In case of time-sensitive data and applications, the latency problem will be exacerbated. In regular cloud computing systems all the data has to be sent to a centralized cloud data center, which can be located at a large distance from the device generating data. This is not a desirable condition in case of time sensitive data which require quick response and might result in unwanted results. Figure 1 illustrates the latency

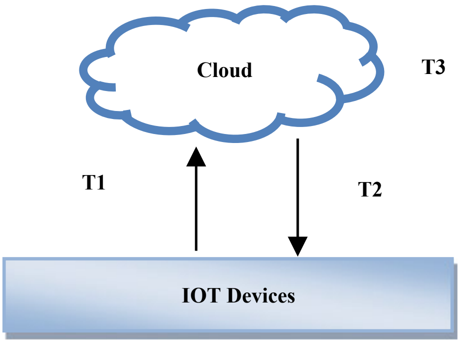

Fig. 1 Latency problem

problem.

T1 Time from devices to cloud.
T2 Time from cloud to device.
T3 Cloud processing time.

Latency = T1 + T2 + T3

In case of huge volumes of data, the processing time T3 will be large which will give longer response time and larger latency. This problem led to the development of modified cloud models like fog and edge computing.

3 Fog Computing

3.1 Basics

The conventional cloud model faces many issues while handling big data and large number of devices. To overcome these issues, fog computing came into picture. The basic idea of fog is to extend the cloud capabilities closer to IoT devices. It acts as an intermediary layer between the cloud data center and the end IoT devices (Fig. 2).

The fog performs processing before sending it to the cloud which improves the response time and latency. The fog layer consists of various fog nodes which can be routers, embedded servers, switches, etc. These nodes are virtual instances of IoT devices and provide enhanced processing, storage and networking. Each node is associated with the aggregate fog node [5]. Unlike the cloud data center, the fog layer provides transient data storage. A fog node also provides the connection with IoT devices, other fog nodes and the centralized cloud.

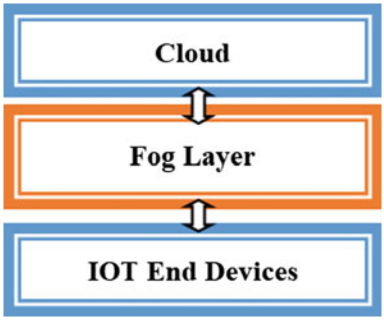

Fig. 2 Basic fog model

3.2 *Fog Architecture*

A fog layer cannot exist independently. It is not a substitute of cloud computing and works in conjunction with it. Figure 3 illustrates the detailed fog architecture.

1. Non-time-sensitive data
2. Summary for historical analysis and storage
3. Ingestion of time sensitive data
4. Immediate response
5. Less time-sensitive data
6. Response to less time-sensitive data

The fog architecture operates on the basis of type of data generated by devices. If the data is time sensitive, it is sent to the nearest fog node which processes the data

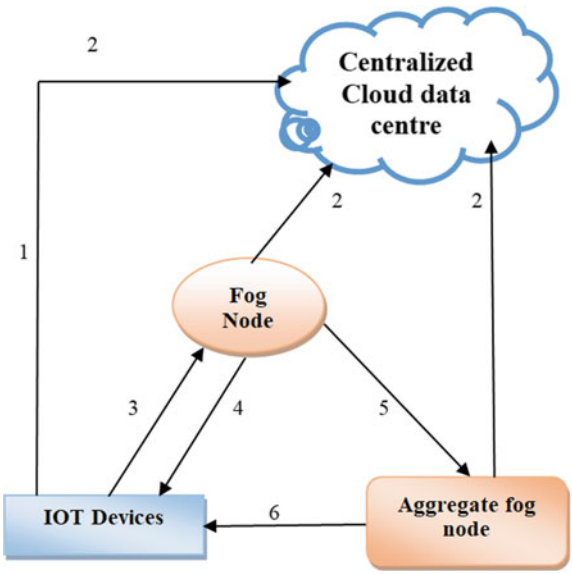

Fig. 3 Fog architecture

and responds with an immediate action. This data is also sent to the cloud by the node as summary for analysis and historical storage. In case of less time-sensitive data, the data is forwarded to the aggregate fog node which performs the required processing and performs the necessary action. From here, the data is forwarded to the cloud as summary. In case of non-time-sensitive data, the data is directly forwarded to cloud for processing and storage [6].

3.3 Fog Computing Versus Edge Computing

Fog computing enables the storage, networking and processing operations nearer to the end IoT devices (Edge). On the other hand, edge computing enables processing of data locally at the edge or as close as possible to the IoT device. It occurs directly on the devices to which sensors are connected by means of Programmable Automation Controllers (PAC's) [7]. It does not involve sending of data to centralized remote data centers. This reduces the distances and time to send data to cloud which improves speed (latency) and performance of data transport. Edge computing in fact is a concept, and fog computing is a standard that defines how it should operate or work. Fog acts as a jumping off point for edge computing [4]. There is another term mist computing which is generally used synonymously with edge computing. The difference between the two is that mist uses lightweight computing objects with microchips and microcontrollers [7].

3.4 Latency Comparisons with Cloud Computing

As mentioned earlier, the latency in a centralized cloud data center is higher than fog architecture. In a system without a fog, data from all the devices has to travel to a centralized cloud data center for processing. This leads to increased latency because of time taken to reach the remotely located cloud and processing time taken at the cloud. Unlike this fog architecture does the processing part near the device and reduces latency.

Figure 4 shows a cloud topology which is having six user bases (consisting of ten devices or users each) and one centralized cloud data center. This topology is created using a Java-based iFogSim simulator and is simulated with cloud analyst tool to obtain Fig. 5 which shows average, maximum and minimum response times for each user base with respect to the centralized data center [8]. The cloud analyst allows us to select a server broker policy, which in this case is closest data center. But it will not have an impact on the response times since there is only one centralized cloud data center. Figures 6 and 7 show the simulation results of the fog architecture with multiple fog nodes apart from a cloud data center.

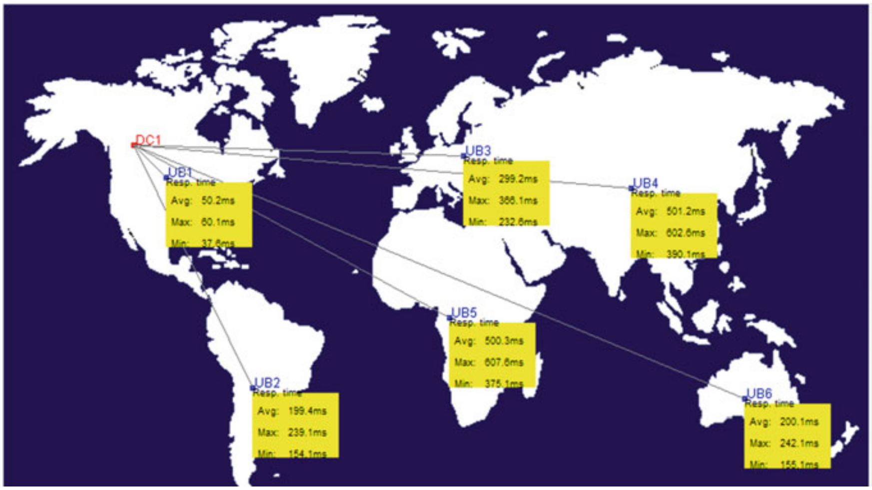

Fig. 4 Cloud topology

Overall Response Time Summary

	Average (ms)	Minimum (ms)	Maximum (ms)
Overall Response Time:	292.10	37.61	607.62
Data Center Processing Time:	0.28	0.02	0.86

Export Results

Response Time By Region

Userbase	Avg (ms)	Min (ms)	Max (ms)
UB1	50.173	37.606	60.107
UB2	199.446	154.112	239.114
UB3	299.227	232.616	366.059
UB4	501.173	390.116	602.614
UB5	500.337	375.116	607.617
UB6	200.115	155.112	242.114

Fig. 5 Overall response time of cloud topology

DC Data center.
UB User base.

Figure 6 shows fog cloud topology with six user bases, one centralized cloud data center (DC1) and three fog nodes (fogcloud1, fogcloud2 and fogcloud3). Figure 7 shows the results of the simulation of this topology in the cloud analyst in terms of response times. As it is clearly evident from the simulation results, the average overall response time of fog cloud topology (159 ms) is lesser than the cloud topology (292.10 ms). The same trend can be observed in response times of individual user bases. This is because of the presence of multiple fog nodes in the fog cloud topology. When we select the server broker policy as closest data center, the data from the user bases is sent to the nearest fog node and not without any decision making to the centralized cloud. This reduces the response time and thus latency. The above simulation results clearly show how fog architecture is an improvement of regular

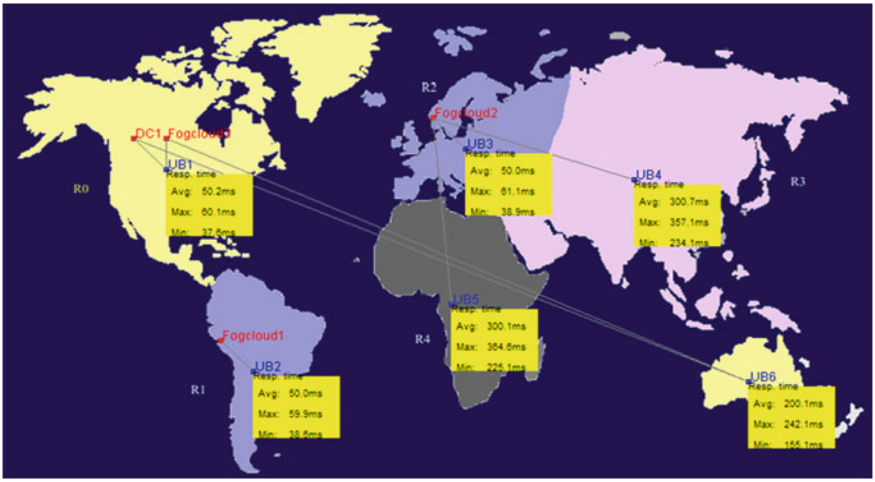

Fig. 6 Fog cloud topology

Overall Response Time Summary

Export Results

	Average (ms)	Minimum (ms)	Maximum (ms)
Overall Response Time:	159.00	37.61	364.65
Data Center Processing Time:	0.39	0.02	0.89

Response Time By Region

Userbase	Avg (ms)	Min (ms)	Max (ms)
UB1	50.207	37.606	60.107
UB2	49.974	38.641	59.893
UB3	49.989	38.881	61.058
UB4	300.726	234.141	357.146
UB5	300.098	225.141	364.648
UB6	200.137	155.137	242.142

Fig. 7 Overall response times of fog cloud topology

cloud computing in terms of latency or response time. But the same cannot be said regarding the cost of the network. The following figures illustrate the simulation of cost analysis of the two topologies.

From Figs. 8 and 9, it is clearly evident that the total cost of implementation of a cloud topology ($0.89) is lesser than that of fog topology ($2.39). This is because fog involves setting up of multiple fog nodes (fogcloud1, fogcloud2 and fogcloud3) rather than a single centralized data center. This accounts for additional costs in fog. However, total data transfer cost is same in both the cases since the same data is transferred, with the difference that the total data transfer cost is distributed among various fog nodes in fog topology instead of being aggregated in case of regular cloud.

Cost

Total Virtual Machine Cost: $0.50

Total Data Transfer Cost: $0.38

Grand Total: $0.89

Data Center	VM Cost	Data Transfer Cost	Total
DC1	0.502	0.385	0.886

Fig. 8 Cost table for cloud topology

Cost

Total Virtual Machine Cost: $2.01

Total Data Transfer Cost: $0.38

Grand Total: $2.39

Data Center	VM Cost	Data Transfer Cost	Total
DC1	0.502	0.064	0.566
Fogcloud1	0.502	0.065	0.567
Fogcloud2	0.502	0.192	0.693
Fogcloud3	0.502	0.064	0.566

Fig. 9 Cost table for fog topology

3.5 Advantages of Fog Architecture

The fog architecture is a significant improvement over the regular cloud computing. Some of its major advantages are mentioned below.

- It provides better data security, and all the fog nodes can use the same security policy [5].
- Bandwidth consumption and data traffic is significantly reduced, since not all the data is being sent to cloud.
- It provides better privacy as the confidential data of an organization can be stored on the local servers.
- It facilitates quicker decision making, owing to less latency.
- Fog architecture provides a lot of flexibility as the fog nodes can join and leave the network at any time.
- Every industry can analyze their data locally using fog architecture.
- It allows deployment in remote or harsh environmental conditions.
- The operation costs are lesser than cloud computing.

3.6 Challenges Faced by Fog Architecture

Despite its many benefits, fog architecture also faces some challenges which need to be worked on. Some of the major challenges are mentioned below.

- Fog uses multiple fog nodes which increase the power consumption, and in fact, the power consumption of the fog is even higher than cloud.
- Since the data producing nodes are distributed and not centralized, providing authentication and authorization to the whole system of nodes is not an easy task [5].
- Maintenance of data integrity and ensuring availability of millions of nodes is extremely difficult.
- Fog nodes may be mobile, and they can join or leave the network at any time. But many data processing frameworks might be statically configured. Therefore, these frameworks will not be able to provide required scalability and flexibility [5].

4 Mobile Cloud Computing

Nowadays, mobile devices are used for hosting and processing various types of services in entertainment, social media, news, business, games, health, etc. However, the increased demand for these services has led to certain problems with mobile devices like low energy, poor resources and low connectivity. This created the concept of mobile cloud computing, where a resource rich cloud server can be used by a thin mobile client for running a service. It allows the mobile nodes to play the role of resource provider in case of peer-to-peer network. But this type of computing may also face issues faced regular cloud computing like latency, bandwidth and connectivity issues. This led to the concept of cloudlets which later on leads to mobile edge computing. A cloudlet is very much similar to fog architecture. It is connected to a centralized cloud and aims at bringing the cloud services nearer to the end mobile user.

In the cloudlet concept, the mobile device offloads its workload to a resource-rich local cloudlet. These cloudlets situated in common areas like libraries, coffee shops, universities, etc. which allows the mobile devices to connect and function as thin clients to the cloudlet. It can be considered to be the first hop node at the edge of the network.

The cloudlet is considered to be as the central tier of a three-tier cloudlet architecture, which consists of mobile devices, local cloudlet and distant cloud [9].

A cloudlet has four key attributes as follows:

- It has only soft state.
- It should be resource rich and well connected.
- It should have low end to end latency.
- It should have a certain standard for workload offloading like virtual machine migration.

All these attributes together define a local cloudlet in mobile cloud computing.

5 Applications

The multiple advantages of fog computing make it useful in a wide number of applications. It can also be used for existing cloud applications to achieve better performance. Some of the popular applications are:

- Real-time health analysis—It involves real-time monitoring of patients suffering from chronic diseases by monitoring multiple body parameters. Due to reduced latency of fog, the doctors can be intimated quickly in case of emergency situations. The collected historical data can be used for predicting any future dangers to the patients.
- Pipeline optimization—Oil and gas pipelines require the monitoring of parameters like pressure and flow rate. In case of very long pipelines, terabytes of data could be generated. In such situation, fog computing is preferable [5].
- Supply chain and inventory management—Cloud computing is extensively used in warehouses and departmental stores for keeping a track of the inventory using radio frequency identification (RFID) tags. There could be millions of such tags sending data, which could not be efficiently managed by cloud and thus will require fog architecture [10].

6 Potential Applications (Case Study)

Agriculture is a domain which is attracting a lot of attention for research in recent times. Over use of fertilizers, poor yield, deteriorating quality and forever reducing area available for cultivation are some of the main reasons. There has been an idea for growing the crops in artificially created eco-systems with complete control over growth parameters. The soilless farming techniques like aeroponics, aquaponics, hydroponics and techniques prevalent in urban landscapes like vertical faming can be a part of such system. Such kind of a setup will require a large number of sensors, actuators and other data generating devices to monitor and control the growth parameters. Such systems on commercially viable scale will generate big data and a lot of traffic. This makes it an excellent potential application for fog computing. The following is an example of a smart agriculture setup, to which fog computing could be applied—Smart Vertical Farm.

Figure 10 shows an abstract view of a smart agriculture farm. Here multiple sensors and actuators are interfaced to a microcontroller to monitor and control essential growth parameters like soil moisture content, soil pH, light intensity and gas concentration. A similar setup can be used in urban landscapes in the form of vertical farms where such sensor–actuator setups can be implemented in multiple stacks for better area utilization. Such a setting on commercial scale will require a large number of sensors. To give an idea of the number of sensors required, an instance of a vertical farm of 3000 ft^2, with five stacks providing an effective area of 15,000 ft^2, is considered in Table 1.

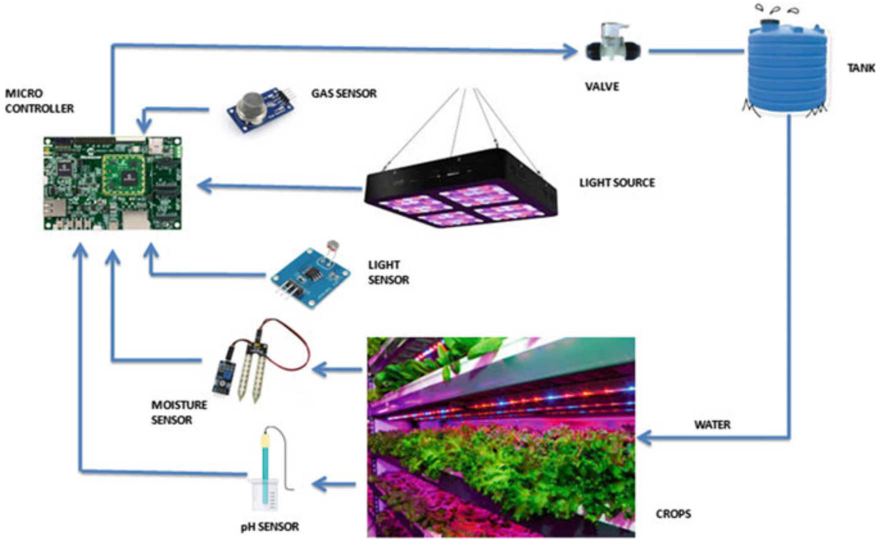

Fig. 10 Abstract view of a small agriculture

Table 1 Sensor requirements

Entity	Number of units
Microcontrollers	200
pH sensors	200
Soil moisture sensor	200
Gas sensor	1
Light intensity sensor	5
Total	606

As evident from the table, a 15,000 ft^2 vertical farm will require approximately 600 sensors. The data generated from them will be huge and a computationally extensive cloud data center will be required to process such data. These sensors will keep sending the growth parameter data to the cloud. But in case if some sort actuation is required to control or change a parameter, it might take a lot time for the necessary action to happen due to large volumes of data being sent and processed by the cloud. There might be a situation where the ultraviolet wavelength light sources used in such systems need to be switched off when there is human interference in otherwise isolated setups for the purpose of biological safety. All these applications require low latency which can be achieved by deploying fog nodes. These nodes will process the data from the sensors depending upon which node is closest to a sensor. This will facilitate quicker decision making and immediate action. The fog nodes can forward this data to the centralized cloud data center for permanent storage and historical analysis.

7 Conclusion

The conventional cloud computing used for IoT applications is proving to be insufficient for handling big data traffic. This provides for alternative technologies for supporting cloud and IoT. Comparisons between fog and cloud computing are performed using iFogSim simulator and cloud analyst tool, in terms of average response times and total network cost. Mobile cloud computing makes use of the concept of cloudlets for offloading the workload from mobile devices and sending data to centralized cloud. A potential application of fog technology can be in upcoming smart agriculture farms, where multiple sensors and actuators are deployed, generating huge amounts of real-time data.

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