**Cloud Computing:**

**Bit of history:**

Cloud computing is an evolution in technologies. In 1960s to 1980 we experienced the rise of time sharing, which allowed the user to use the resources more conveniently [1]. And then we experienced the distributed computing at around 1980s [2]. Client server was introduced late 1980s and then the next step towards the evolution was the introduction of cloud computing. The term cloud computing was popularized by Amazon.com around 2006 [3]. After that many big companies started to invest in it.

Cloud computing is the revolution in IT which changed the way we consume computer services. For the past few years cloud computing has made computing to be much more efficient and cost effective. Many companies have saved millions of money by using the services of the cloud computing. Cloud computing leverage the services of the remote systems.

Users don’t need to pay any more than the services that they are using. It helps the companies to minimize the cost for computing and use that capital in other areas.

**Categories:**

By the National Institute for Standards in Technology (NIST) cloud computing has these characteristics:

* On-demand self-service.
* Ubiquitous network access.
* Resource pooling.
* Rapid elasticity.
* Pay-per-use.

Additionally they define these delivery models:

* SaaS (Software as a service).
* PaaS (Platform as a service).
* IaaS (Infrastructure as a service).

Three different deployment model:

* Private Cloud.
* Public Cloud.
* Hybrid Cloud. [4]

**Internet of Things (IOT):**

**Bit of history:**

It was early 1970s when the idea of IOT was began. At that time scientists saw the potential in the field of inter connected things. They used the phrase “pervasive computing”. It was 1999 when Kevin Ashton who was working with radio frequency identification, those were small chips that someone could place to any item or animals, and could track that item. He realized the potential in using RFID. He then used the phrase “Internet of Things”, it was the concept of a huge structure where things on the internet interconnect over sensors.

IOT simply is an extension to the current Internet which is extended into the physical world, into things. IOT has been a buzz word among the industries and researchers since it was officially published in 2005. [5]

IOT is now taking over all the technology departments. The amount of devices are increasing at a huge number. It is estimated that by the year 2020 there will be around 50 billion devices [6]. The global market value of IOT is to reach 7.1 trillion dollar by the year of 2020 [7]. As we can see that this technology is changing the world rapidly. In every sectors of our civilization is now touched by this technology. From medical to transportation and to logistics IOT is used everywhere.

IOT can be fragmented into two sections, B2C- business to consumer IOT and B2B- business to business IOT. B2C is customer IOT, where B2B is commercial IOT. In IOT there are three types of products. Namely- smart, connected, and IOT products. In IOT there is a front end. That is for the users. There is a back end for admin touch points. And in between, we have enabling infrastructure.

**IOT components:**

**People**: People who energies the Internet of Things

**Infrastructure**: It is the backbone of internet.

**Things**: These are sensors, home automation, cameras etc.

**Data**: Other devices receive data after all the data collection.

**Processes**: It bring about the way all these components work together.

**Fog Computing:**

**Bit of history:**

The necessity for extend cloud computing with the help of fog computing appeared around 2012, for coping with increasing number of IOT devices and big data volumes in order to support real-time and low-latency applications [8].

In 2015, Cisco Systems, [Princeton University](https://en.wikipedia.org/wiki/Princeton_University), [Microsoft](https://en.wikipedia.org/wiki/Microsoft), [Intel](https://en.wikipedia.org/wiki/Intel), [ARM Holdings](https://en.wikipedia.org/wiki/ARM_Holdings) and [Dell](https://en.wikipedia.org/wiki/Dell) founded the “[OpenFog Consortium](https://en.wikipedia.org/wiki/OpenFog_Consortium)”, for promoting interests and development in the field of fog computing. [Helder Antunes](https://en.wikipedia.org/wiki/Helder_Antunes), Cisco Sr. Managing-Director is the consortium's chairman and from Intel, its Chief IOT Strategist Jeff Fedders is the first president [9].

The term fog in computer science is an architecture that extends services offered by the cloud to edge devices. Fog is seen as a new cloud and many believe it is here to replace the cloud but really it's just an evolution or an extension of cloud. One thing, the term edge devices these are routers, switches WAN and LAN devices basically these are the entry point into the network. Fog allows us to carry out our storage communication and application services at a distributed level. If we want to put it in simpler terms fog is cloud plus Internet of Things.

In cloud we have some issues like dependency on the internet causing latency, limited bandwidth causing delays, security issues due to failing data protection mechanisms and requirement of high-speed Internet connectivity and that is where fog comes in. Fog doesn't work on a cloud it works on a network edge so it's faster. In cloud architecture devices were directly connected to the data center or cloud. Now we have fog in the middle to bring the

Internet of Things to life by delivering distributed computing capabilities and enabling creation of an intermediate layer between the things and the cloud. Fog basically supports Internet of Things applications and in today's world of cutting edge technology we have integrated Internet of Things into our lives. Every aspect of our lives is now monitored by this technology.

Cloud storage is the backbone of Internet of Things and now we are storing gigantic amount of expanded data, the future of big data is proceeding towards edge computing. Behind this new technology is to build a better operational connectivity between a server core and remote application reader sitting at the farthest point which we call the edge.

Fog supports Internet of Things applications that demand real-time response, especially as fog is closer to the end-user and it supports mobility at the same time. Fog has less demand for internet bandwidth because data is aggregated at certain points instead of sending over cloud channels so it's faster. It has location awareness it supports stability and there's very low delay.

We can also use distribute sensors or activator networks like the ones used for smart cities. Fog also allows for environmental and monitoring control. The best thing about fog is it adds security to the cloud so there is very low probability that an attack on data can occur.

**\*\*\***

Cloud service is a resource somewhere else and the distance is a great disadvantage. Data centers have the ability to process data and also mine large data sets, but the problem is that they are too far away to process data and generate any response in real time. For this distance the cloud model is problematic if we have any critical environment or the internet connection speed is slow.

A solution to this distance problem can be that we bring the processing work closer to the edge network so that we can reduce the amount of data that is sent to the cloud for processing and to analysis. By doing this we can provide the need of real time and latency hungry application. Bringing the computing power and application services closer to the edge network is fog computing.

Fog computing is actually a combination of hardware and software solutions which decentralizes the cloud and has the ability to monitor and analyze data at real-time with very low latency. Fog reduces the time taken for the data analysis from minutes to seconds. Any service which require low latency service and without that any fatal accident may occur, for example: in the medical sector where the treatment for patient needs quick response or in the auto-mobile sector where autonomous cars needs real-time data to avoid any collision on the road.

**Introduction**

Many modern researchers involved in discovering the best uses of the IOT in order to make our live more convenient and comfortable. Cloud computing is wide spread and vastly used in all sorts of platform. Cloud computing made easy to use different kinds of services keeping in mind about the cost that produced by the individual services. Many companies and organizations are now using the cloud services more effectively. Cloud computing system is used with the backbone of a data center which is the center point of all the processing, data analysis and data storage. In a simpler form cloud computing is a data centric networks (DCNs). Every service that user is getting through the cloud is processed through these data centers (DC).

The amount of load that cloud is taking is huge for IOT is expanding at an exponential rate. Global market of IOT reached 598.2 Billion dollar in 2015, it is expected to touch 724.2 Billion dollar by 2023. Globally the IOT market is predicted to register a compound annual growth rate of 13.2% through the period of 2016 to 2023. This is an enormous number.

As for the market in the Asia-Pacific region, in 2015 36% revenue was acquired globally. In the forecast period of 2016 to 2023 it is anticipated that the compound annual growth rate will reach 10.2% [9].

It is projected that by 2025 more than 55 billion of IOT devices will be there, it is an increase of 9 billon devices from 2017. The forecast in investment for IOT devices in period of 2017-2025 is 15 trillion dollar. The investment in the IOT sector is accelerating [10].

\*\*\* not done yet.

**Challenges for the Cloud of Things:**

Cloud of things or CoT is integrating cloud computing to the IoT devices. It can be of many use, like the services that it can give is efficient and cost-effective, it helps to manage IoT resources. It can reduce the flow of IoT data with processing. It is quick in installation in a difficult data processing scenario and deployment.

CoT paradigm is complex and in the IoT system it can face a lot of challenges, simply because the IoT system requires different kind of services and presents new challenges which traditional data center dependent cloud architecture cannot provide, like latency, resource-constrained devices, capacity constraints and enhanced security [11].

Overall, data center (DC) dependent cloud approach is inappropriate for applications which is very time sensitive and when the internet connection is bad, for example telemedicine, patient care and situations like vehicle-to-vehicle communications where a millisecond has great impact in our lives. Cloud approach with centralized data station has higher latency which is not appropriate for real-time applications. For these reason we need some other solution to face these challenges. Cisco had a solution in this regard. They suggested another technology which again is an extension of the cloud computing not an alternative and it was Fog Computing.

Fog computing has the ability to face the challenges that cloud computing couldn’t.

**Fog Computing:**

Fog computing paradigm has limited abilities for example computing, data storage and network service is of a distributed manner. It is very good and efficient for serving the needs of IoT applications with real-time low latency requirement.

For the definition on fog computing we can take the definition of Yi et al [12] It is stated as; “Fog Computing is a geographically distributedcomputing architecture with a resource pool which consists of one or more ubiquitously connected heterogeneousdevices (including edge devices) at the edge of network and not exclusively seamlessly backed by Cloud services,to collaboratively provide elastic computation, storage and communication (and many other new servicesand tasks) in isolated environments to a large scale of clients in proximity” [12].

OpenFog website define fog as *“Fog computing is a system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along the continuum from Cloud to Things.  By extending the cloud to be closer to the things that produce and act on IoT data, fog enables latency sensitive computing to be performed in proximity to the sensors, resulting in more efficient network bandwidth and more functional and efficient IoT solutions. Fog computing also offers greater business agility through deeper and faster insights, increased security and lower operating expenses.”* [13].

**Fog computing characteristics:**

Many consider the fog computing as the building block of cloud computing. From Yi et al [12] and Ai et al [14], some of the characteristics of fog computing:

* Mobility support: For any fog application we need to connect them from the remote location via mobile devices. For example locator id separation protocol needs a system which is distributed.
* Location awareness: Fog supports location awareness. We can position fog devices in remote and different places.
* Low latency: Latency is one of the most useful feature of fog computing as the fog devices are located nearer to end devices.
* Scalability: For monitoring outside, in a long rage of surrounding places we need large-scale sensors. Fog can take on the task of distributed computing and storage capacity which allows to work with large-scale devices.
* Geographical deployment: Huge data center on cloud computing cannot be placed in geographical locations but fog can do this task.
* Diversity: Fog has the capacity to work with different platform as different companies make different fog devices.
* Real-time: Fog allows to work with real-time data and provides response accordingly.
* Acts as intermediary: Fog computing is in between the end devices and the cloud, which makes the fog as an intermediary [18].

**Advantages of fog for the IoT:**

Fog computing works closer to the end devices. For this characteristics fog is a great solution for the IoT devices. Some of the benefits and advantages of the fog are as follows:

* Low latency: Fog can support low latency applications and works great with the IoT devices.
* Business benefits: For the requirement of the customer fog can be deployed and developed accordingly.
* Geographical distribution: Fog computing has the ability to work with distributed end devices and supports the needs of computing and storage.
* Low operating cost: Fog can save the internet bandwidth as it work locally closer to the end devices, no need to send the data to the cloud.
* Scalability: Fog devices are closer to the end devices so we can scale them with the needs accordingly.
* Heterogeneity: Fog computing can collaborate with the different infrastructures and different physical environment [18].
* Security: We can protect our fog devices or nodes by using similar procedures that is used in other sects of our IT areas.
* Privacy control: We can analyze sensitive and private data locally, no need to send the data to the cloud server where privacy might be violated. We can control and monitor the data that is generated.

**Cloud vs Fog:**

If we want to put is simply, difference between the cloud computing and the fog computing is where the processing is done. Cloud computing typically works using remote server and backend data centers, performs data storage and operation in a remote location instead of using the local computer. Cloud computing provides with high level of computation and storage over the internet. There are different types of services that cloud computing provides like storage, servers, software, network etc.

On the other hand fog computing does the processing and store data closer to the end devices. Fog computing is decentralized it can be placed anywhere as the application is needed. Fog computing uses the local computer resources rather than remote computer resources. It provides lower latency and performance is better with the computation closer to the end devices. Fog computing also has the benefit of geographical distribution, lower operating cost, Scalability and heterogeneity. We can discuss further to this regard below: [15]

|  |  |  |
| --- | --- | --- |
| Difference topic: | Cloud computing | Fog computing |
| Latency | Cloud computing has higher latency than the fog computing. | Fog computing has lower latency compare to the cloud. |
| Bandwidth | Cloud computing requires more bandwidth than fog. | Fog consumes less of the bandwidth. |
| size | Cloud computing sends data to the server without data reduction. | Fog computing reduces the data while sending |
| security | Less security compare to the fog. | High security. |
| Real-time | Does not support efficient real-time response. | Supports real-time response. |
| Aware to the location | No. | Yes. |
| Deployment | Centralized. | Distributed. |
| Speed | Less compare to fog. | High. |
| Data integration | Several data sources can integrate. | Several Data Source and devices can integrate. |

**The challenge:**

\*\*\* duplicate, discussed it earlier.

It is projected that by 2025 more than 55 billion of IOT devices will be there, it is an increase of 9 billon devices from 2017. The forecast in investment for IOT devices in period of 2017-2025 is 15 trillion dollar. The investment in the IOT sector is accelerating [10]. \*\*\*

With this kind of enormous devices, needs for data and storage cannot be meet with the traditional cloud computing. The amount of load that cloud has to take is huge. **IoT is going to generate major tensions to the present internet system and data centers.**

This brings another technology architecture called fog computing. It will help reduce the load generated by the IoT devices to the cloud data centers. To demonstrate the load that IoT devices is going to create IDC estimated that “***the amount of data analyzed on devices that are physically close to the Internet of Things is approaching 40 percent***” [16]. This is why we need to use alternative approach to meet this need.

No way fog computing is any replacement of the cloud computing. It exists only to act as an extension of the cloud computing. It mainly has two basic aim one, real-time low latency process and two, to take action for the incoming data. Also the limitation of internet bandwidth and computing power is another driving force behind the need of fog computing.

\*\*\* new. Most of the information and data that is produced through the IoT devices need to be processed in real-time, to do this we need to do our processing closer to the end devices. Fog computing lets us do exactly this task. Now let’s discuss about the solution of the challenges of the IoT devices.

**Solution:**

Fog computing reduces the stress of the cloud data centers from the IoT generated data. Fog takes care of the action-taking decision via the IoT devices, pushes to the main cloud only the relevant information. Cisco coined this term “Fog Computing”, they gave a clear definition for the fog: “*The fog extends the cloud to be closer to the things that produce and act on IoT data. These devices, called fog nodes, can be deployed anywhere with a network connection: on a factory floor, on top of a power pole, alongside a railway track, in a vehicle, or on an oil rig. Any device with computing, storage, and network connectivity can be a fog node. Examples include industrial controllers, switches, routers, embedded servers, and video surveillance cameras*” [17].

Fog computing lets us deploy distributed services and applications. Fog has the ability to deliver real-time and low latency processing near the end devices. Fog computing shines where the applications need low latency and real-time services, for example linked vehicles on the road, live video streaming, augmented reality, gaming [19] etc.

Adding the fog computing to the IoT will bring about many convenience to the IoT applications. In the term of low latency, fog is extremely useful. Time sensitive IoT devices and applications are more efficient using the fog computing. Fog can support large scale sensor network. It is big of a challenge for the fast growing IoT devices. The number is growing exponentially by the days, it is projected that the number will grow to the billions.

Fog computing provides operative solutions to the problem which is faced by the present computing structure relying upon the centralized computing. From T. Zhang and M. Chiang [20], fog computing has the ability to resolve challenges of the IoT, described below: