Connecting Fog and Cloud Computing

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Abstract - *Cloud computing has several innate advantages with respect to its three key dimensions, Infrastructure-as-a-Service, Platform-as-a-Service, and Software-as-a-Service, but still face some challenges pertaining to the stretch between the end devices and the cloud. Since the cloud is not physically located near the data source, data Transfer takes more time. This poses a problem for the performance of latency sensitive applications and services. Service level agreements (SLAs) may also foist processing at locations where the cloud provider does not have data centers. Fog computing outstretches cloud computing to end user devices, to better support and enhance the performance of time dependent, location dependent, massive scale, and latency sensitive applications. Fog computing is a complement for cloud computing, it allows rigging resources and services outside the cloud, at the edge of the network, closer to end devices, it enables processing at the edge while still offering the capability to interact with the cloud. This paper presents a compendious survey on fog computing. It captiously reviews the connection between fog and cloud computing. it covers the architecture and characteristics of fog computing, whilst also discussing its similarities and differences with cloud computing. It also discusses the benefits that escort cloud computing and also its challenges. Additionally, it subtly explores the relationship of fog computing with the internet of things.*

***Key Words*: Fog Computing, Cloud Computing, Cloud models, Fog nodes, Cloudlet, Edge computing, Latency**

1. INTRODUCTION

With the passage of time there have been a significant evolution in computing paradigms from distributed, parallel, and grid to cloud computing. Cloud Computing has several intrinsic capabilities such as on-demand resource allocation, scalability, flexible pricing model, easy applications and reduced management efforts. It encompasses three fundamental service models: Platform-as-a-Service (PaaS), Infrastructure-as-a-Service (IaaS), and Software-as-a-Service (SaaS).The PaaS dispenses software environments for the development, deployment, and management of applications. IaaS dispenses the virtualized resources, such as compute, storage, and networking. The SaaS dispenses software applications and composite services to end-users and other applications. Cloud computing is being used extensively, however it still has some challenges, the most fundamental being the distance between the cloud and the end user devices. This distance increases latency in cloud computing. This distance proves to be problematic for latency sensitive application and services. For example, disaster management applications, content delivery applications, fire detection and firefighting. Fog computing is a paradigm introduced to overcome the latency related problems of cloud computing. Fog computing outstretches cloud computing to end user

devices, to better support and enhance the performance of time dependent, location dependent, massive scale, and latency sensitive applications. Fog computing is a supplement for cloud computing, it allows rigging resources and services outside the cloud, at the edge of the network, closer to end devices, it enables processing at the edge while still offering the capability to interact with the cloud. The fog computing architecture outstretches the traditional cloud computing architecture to the edge of the network. Fog computing is closer to end-users and has wider geographical dispensation. Fog computing expedites the operation of storage, compute, and networking services between cloud computing data centres and end devices. This paradigm supports vertically-isolated, latency-sensitive applications by providing omnipresent, scalable, layered, federated, distributed computing, storage, and network connectivity. In the literature it is widely accosted that cloud computing is not workable for most of Internet of Things (IoT) applications and fog could be used as a substitute. A lot of extensive and comprehensive research has been carried out on fog computing in the past. The following subsections reviews the connections between cloud and fog computing, similarities and differences between these two paradigms, architecture of fog computing, its benefits and challenges and its relationship with the subject of internet of things.

2. LITERATURE REVIEW

Fog computing is the middle section of internet of things and cloud computing. It is a critical part for creation of several projects like smart cities which apply internet of things. These projects are increasing by the day and managing them is a final issue. Traditional cloud computing systems are not enough, thus fog computing plays a vital role in providing real time services being decentralized. Internet of Things comprises different kinds of sensors and devices that are connected to internet. Internet of things are low memory devices. So, data processing is not possible within these devices. Data processing is performed outside cloud computing. The cloud load increasing day by day and the traditional cloud is not efficient. Thus, additionally an architecture is required for handling this large data and process the same. Fog Computing is a medium for storage that holds between the cloud computing layer and internet of things layer. It is a distributed system. It mainly provides real time services to the end user and also provide location awareness to the user devices. Fog computing is an outstretch of cloud computing. This is an important advancement of the cloud computing paradigm. The cloud computing architecture is improvised by fog computing which provides more functionalities and features to the architecture. Fog computing increases the reach of the connectivity and has more focus on local processing as compared to the large data centers of cloud computing.

3. CLOUD COMPUTING

Cloud computing is the on-demand availability of huge computing resources, particularly data storage (cloud storage) and computing power, while not direct active management by the user. The term is mostly accustomed to describe data centers offered to several users over the web. Cloud Computing is cost friendly and it also provides solution for data recovery and fast service. Massive clouds nowadays have functions over multiple locations of central servers.

The Main Characteristics of Cloud Computing are:

1. On-Demand Self Service: Cloud computing resources can be provisioned without human interaction from the service supplier. In other words, a producing organization will provision further computing resources as needed without surfing additional cloud service suppliers. The cloud could be a space for storing, virtual machine instances, information instances, and so on.
2. Resource Pooling: Public cloud providers trust multitenant architectures to accommodate a lot of users at the same time. Customers' workloads measures are abstracted from the hardware and underlying software system that serve multiple customers on an equivalent host. Cloud providers more and more trust custom hardware and abstraction layers to enhance security and speed of users' access to resources.

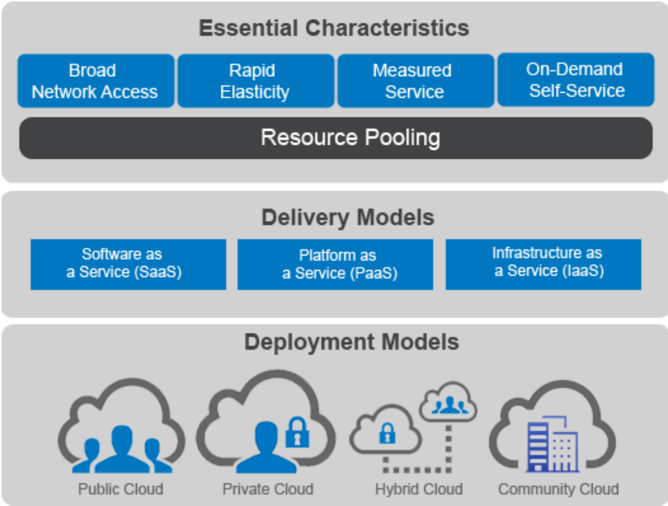

Fig -1: Cloud Computing

3. Scalability and rapid elasticity: Resource pooling permits quantifiability for cloud suppliers and users as storage, networking and alternative assets will be added or removed as needed. This helps the enterprises to optimize their cloud workloads and to avoid the end user bottlenecks. Clouds will scale vertically or horizontally and repair suppliers supply automation code to handle dynamic scaling for users. Traditional, on-premises architectures cannot scale as simply as cloud. Typically, enterprises ought to arrange for peak capability by getting servers and alternative infrastructure assets, those further resources sit idle throughout inactivity. This is avoided in Cloud Computing.
4. Metered Service: Measuring service usage is helpful for both cloud providers and their customers. The supplier and also the client monitor and report on the utilization of resources and services, like VMs, storage, process and information measure. Then the data is used to find the customer's usage of cloud resources and sends it into the pay-per-use model.
5. Reliability and Availability: Cloud providers use a variety of techniques to protect against time periods, like minimizing regional dependencies to avoid single points of failure. Users can even extend their workloads across available zones that have redundant networks connecting multiple information centers in comparatively shut proximity. Some higher-level services mechanically distribute workloads across all availability zones.

Cloud Computing is mostly separated into two distinct sets of models: Deployment Models and Service Models

A. Deployment Models:

Based on the location and management of the cloud's infrastructure.

1. Public Cloud: Public clouds are units owned and operated by third parties and deliver superior economies of scale to customers. Public Cloud permits systems and services to be simply accessible to the public. The public cloud could also be less secure attributable to its openness, E.g. E-Mail.
2. Private Cloud: Private Cloud is accessible within an organization. It offers high security because of its private nature. Private clouds are generally built for a single enterprise. E.g. HP Data Centres.
3. Community Cloud: The Community Cloud allows systems and services to be accessible by a group of organizations, E.g. Google Apps for Government
4. Hybrid Cloud: The Hybrid Cloud is a mixture of public and private clouds. The security critical activities are mostly performed using private while the non-critical activities are performed using the public cloud. The pool of hardware resources is taken from multiple servers and networks sometimes distributed across varied centres.

E.g. Azure Stack

B. Service Models:

The Service models are categorized into three models which are: Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS):

1. Infrastructure-as-a-Service (IaaS): IaaS provides a layer of virtualized hardware that delivers the computing power and knowledge centers needed for applications to run and resources such as physical machines, virtual machines, virtual storage, etc. Eg. Amazon EC2
2. Platform-as-a-Service (PaaS): PaaS enable application developers to build, test, debug, deploy and host their services. It saves the developers from the complexities of maintaining the infrastructure, it also provides runtime environment for applications, development and deployment tools, etc. Eg. Microsoft Azure
3. Software-as-a-Service (SaaS): The SaaS model allows the cloud providers to provide software applications as a service to end-users over the internet using a thin client like web browser. Eg. Gmail, Google Drive.

4. FOG COMPUTING

Fog computing consists of networking elements which acts as intermediary between IoT applications. The networking elements such as routers, gateways, switches etc. It is a powerful complement but not a substitute for cloud computing. We can see a fast growth of interest in people with respect to fog computing over a few years. Different concepts like cyber foraging, cloudlets, and Multi-access Edge Computing (MEC) are also related to Fog computing. Placing a fog server in between edge devices and cloud layers, it can flare up the IoT services systematically.

Fig -2: Fog Architecture

1. *Fog Architecture:*

This contains mainly 3 layers:

- Layer 1: Terminal Layer

This is the basic layer in fog architecture where it contains devices like phones, sensors to collect the data, readers etc. It deals with the sensors and capturing the data from different devices.

- Layer 2: Fog Layer

It includes devices like routers, gateways, base stations which are also called fog nodes. These nodes are located in-between Terminal and Cloud Layers. Fog nodes can be either static or moving. It can transfer, store as well as compute the data temporarily.

- Layer 3: Cloud Layer

These are basically the data centres as these provide large storage capacity and it also includes machines with high performance rate. It stores data permanently which is used later for back-up and is accessed by the user later on. This layer has high storage capacity with great computing power. The data centres are scalable and are available to users at any time.

B. Characteristics of Fog Computing:

1. Low Latency: Low latency is very important for time sensitive applications such as video streaming, live surveillance, and online data analytics. Fog computing allows the emergence of the latency-sensitive IoT network to support real-time applications.
2. Diversity: Fog computing is heterogeneous in nature as it collects data from multiple sources. It acts as an intermediary between terminal layer and cloud computing.

3. Mobility: Fog computing has to communicate with different terminal devices which makes them conducive to mobility techniques.
4. Scalability: It can support major functions like computation, data load changes and network variations.
5. Wireless: It is appropriate for wireless IoT access networks. The wireless sensors are widely spread in areas where IoT devices are in great demand which are related to analytics.

5. CONNECTING FOG TO CLOUD COMPUTING

Emerging technologies in the IoT and IT developments require more efficient ways to manage data transmission and processing. Fog computing can satisfy the ever increasing demand of devices by making the processing local rather than cloud-based. Fog computing and Cloud computing are interconnected. Similar to nature, fog computing is closer to the end-users, bringing cloud computing capabilities closer to the users. Fog computing comes in place considering the large amount of data generated by the increasing number of Internet-Of-Things (IOT) devices. It extends the cloud to be closer to the things that produce and act on IoT data. Fog computing tender's substantial business capabilities through profound and faster insights, detailed security and lower costs. When considering cloud computing, only the central nodes have the capability to perform processing. Fog computing is an apt fit for projects that need to process data from several sources as well as one which requires minimal latency. Based on these characteristics, fog computing is preferred over the cloud computing systems.

A. *Similarities:*

Cloud and fog computing are complementary in nature. They are meant to work together and to add advantages of one to nullify the disadvantages of the other. Similar to a Cloud computing architecture, the fog computing architecture comprises multiple edge nodes that are connected to physical devices. The concept of cloud computing houses on-demand provision of computational resources, rapid flexibility and a unified management interface alongside virtualization. It comes out to have a similar infrastructure to that of the cloud computing setup. Herein the computing resources are placed between the data sources and cloud or any data centres. Fogging creates a decentralized environment similar to the cloud computing paradigm, it is able to provide storage, data, applications and computations. The design model makes sure that the time-sensitive data can be processed at the fog node without having to be sent to the cloud. The data that remains can be sent to the cloud for further processing and analysis where it can be stored.

B. *Differences:*

- The major difference between the two architectures is that cloud computing is centralized with large data centres as compared to fog computing being distributive and consisting of several nodes bringing the cloud closer to the user.
- The major difference between the two architectures is that cloud computing is centralized with large data centres as compared to fog computing being distributive and consisting of several nodes bringing the cloud closer to the user.
- The fog is the medium between the data centers and the hardware, making it closer to the end-users. This decreases latency as compared to the cloud communicating directly with the users.
- Cloud computing has remote data centers where the data processing takes place. In case of fog computing, the same is performed on the edge, close to the source for time control.
- Cloud computing architecture has more computational capabilities and storage provision as compared to fog computing. Fog provides greater security compared to Cloud systems due to the distributed architecture.
- Fog has less latency issues relative to Cloud processing.
- Cloud system infrastructure has several large nodes and Fog has millions of small nodes spread across the network.

6. RELATION BETWEEN INTERNET OF THINGS, FOG COMPUTING AND CLOUD COMPUTING

The term Fog Computing was invented by Cisco 2012. In this paper, we want to highlight the importance of using fog computing alongside cloud computing. Traditional cloud computing is centralized and this is time consuming for real time services. Fog computing isn't permanent storage. It is a decentralized method. If we tend to delete unessential information into fog process storage, then load is minimized into cloud layer. Here, additionally cost will be reduced. Due to the increase of smart cities, fog computing platform is helpful.

The solution to the current distance drawback are often that we tend to bring the process work nearer to the edge network so that we are able to reduce the number of information that's sent to the cloud for process and to analysis. By doing this we are able to give the necessity of real time and latency application. Transferring the computing power and application services nearer to the edge network is fog computing. Fog computing is really a mixture of hardware and software system solutions that decentralizes the cloud and has the flexibility to watch and analyse information at period with terribly low latency. Fog reduces the time taken for the information analysis from minutes to seconds. Any service that need low latency service and while not that any accident could occur. For example: Within the medical sector wherever the treatment for patient wants fast response or within the auto-mobile sector wherever autonomous cars wants real time information to avoid any collision on the road.

7. BENEFITS OF FOG COMPUTING

1. Latency Reduction: Increased latency is a challenge in cloud computing Fog computing has a primarily reduced latency, coupled with the ability to extend the overall reach of the cloud service nearer the data source. It is not necessary for the data to be sent to cloud for processing, for time sensitive services some of the compute can be done near the data source.
2. Improved Response Time: Reduced Latency improves response time. Real time applications benefits from improved response time and greater overall user experience.
3. Enhanced Compliance: With fog computing, it is possible for data to reside locally. Data that can reside locally rather than moving to the cloud can increase compliance for specific business sectors.
4. Enhanced Security: As it is possible for data to reside locally, there is no need for sensitive data to move to the cloud for processing. Sensitive data residing locally will improve the security.
5. Data Confidentiality: Since sensitive data can reside locally and there is no need for it to be sent to the cloud for processing, it is processed locally. Only a subset if the data is sent to the cloud for further additional analysis.
6. Reduced bandwidth Cost: Since certain data can processed locally and there is no need for it to be sent to the cloud, less network bandwidth is required, thus reducing the bandwidth cost.
7. Increased Speed and efficiency: If local processing is allowed between numbers of devices that share data, rather the utilising cloud services, it will increase the speed and efficiency of the service.
8. Greater Uptime for critical systems: Critical Systems that use fog computing has a greater uptime as the reliance on remote cloud services for data compute, analytics and storage is reduced.

8. CHALLENGES IN FOG COMPUTING

1. Increased design complexity: The use of fog nodes on your network will increase the complexity and support requirements
2. Security: The main security issue is the authentication of the devices involved in fog computing at different gateways. Each appliance has its own IP address. A malicious user may use a fake IP address to access information stored on the particular fog node. To overcome this access control an intrusion detection system has to be applied at all layers of the platform
3. Network management: Network management becomes an issue as so many heterogeneous devices are connected, management of fog nodes, the network, connection between each node etc
4. Placement of fog servers: Placing a group of fog servers in such a way that they deliver maximum service to the local requirements is an issue.
5. Delay in computing: Delays due to Data aggregation, Resource over usage reduces the effectiveness of services provided by the fog servers, causing delay in computing data. Data Aggregation should take place before data processing, Resource limited fog nodes should be designed scheduling by using priority and mobility model.
6. Energy consumption: Since fog environments use large number of fog nodes, the computation is distributed and can be less energy efficient.

9. CONCLUSION

This paper surveys the literature on fog computing and its connection with cloud computing. It gives a detailed description of cloud computing and how and when fog computing comes into picture along with its architecture, its relationship with cloud computing, similarities and differences between cloud computing. Benefits of fog computing and its challenges are critically discussed. In addition, we have discussed relationship of fog computing with IOT.

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