The Fog Computing Paradigm

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Abstract – Cloud computing is a delivery platform which promises a new way of accessing and storing personal as well as business information. It provides resources to its users through the Internet. But it also has a risk that is the involvement of a third party which makes it difficult to trust that user data is secure enough and will not be misused. To provide security, new technology called Fog computing. Fog computing, also termed edge computing, can address those problems by providing elastic resources and services to end users at the edge of network, while cloud computing are more about providing resources distributed in the core network. Fog computing extends cloud computing by providing virtualized resources and engaged location-based services to the edge of the mobile networks so as to better serve mobile traffics. Therefore, Fog computing is a lubricant of the combination of cloud computing and mobile applications.

Index Terms – Fog Computing, Cloud Computing, NFV, SDN.

1. INTRODUCTION

Fog computing, also known as fog networking, is a decentralized computing infrastructure in which computing resources and application services are distributed in the most logical, efficient place at any point along the continuum from the data source to the cloud. The goal of fog computing is to improve efficiency and reduce the amount of data that needs to be transported to the cloud for data processing, analysis and storage. This is often done for efficiency reasons, but it may also be carried out for security and compliance reasons.

In a fog computing environment, much of the processing takes place in a data hub on a smart mobile device or on the edge of the network in a smart router or other gateway device. This distributed approach is growing in popularity because of the Internet of Things (IoT) and the immense amount of data that sensors generate. It is simply inefficient to transmit all the data a bundle of sensors creates to the cloud for processing and analysis; doing so requires a great deal of bandwidth and all the back-and-forth communication between the sensors and the cloud can negatively impact performance. Although latency may simply be annoying when the sensors are part of a gaming application, delays in data transmission can be life-threatening if the sensors are part of a vehicle-to-vehicle communication system or large-scale distributed control system for rail travel.

Fog computing can be perceived both in large cloud systems and big data structures, making reference to the growing difficulties in accessing information objectively. This results in a lack of quality of the obtained content. The effects of fog computing on cloud computing [1, 2] and big data systems may vary; yet, a common aspect that can be extracted is a limitation in accurate content distribution, an issue that has been tackled with the creation of metrics that attempt to improve accuracy.

CISCO recently delivered the vision of fog computing to enable applications on billions of connected devices, already connected in the Internet of Things (IoT), to run directly at the network edge. Customers can develop, manage and run software applications on Cisco IOx framework of networked devices, including hardened routers, switches and IP video cameras. Cisco IOx brings the open source Linux and Cisco IOS network operating system together in a single networked device (initially in routers). The open application environment encourages more developers to bring their own applications [3] and connectivity interfaces at the edge of the network. Regardless of Cisco's practices, we first answer the questions of what the Fog computing is and what are the differences between Fog and Cloud. In Fog computing [4], services can be hosted at end devices such as set-top-boxes or access points. The infrastructure of this new distributed computing allows applications to run as close as possible to sensed actionable and massive data, coming out of people, processes and thing. Such Fog computing concept, actually a Cloud computing close to the 'ground', creates automated response that drives the value. Both Cloud and Fog provide data, computation, storage and application services to end-users. However, Fog can be distinguished from Cloud by its proximity to end-users, the dense geographical distribution and its support for mobility. We adopt a simple three level hierarchy as in Figure 1.

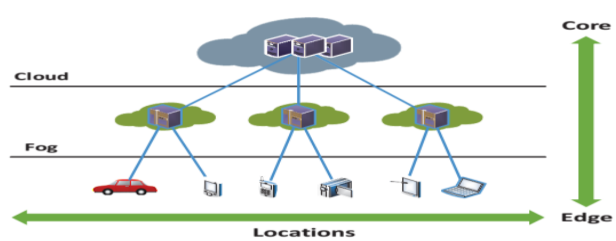

Fig.1 Fog between edge and cloud

2. NEED OF FOG COMPUTING

In the past few years, Cloud computing has provided many opportunities for enterprises by offering their customers a range of computing services. Current "pay-as-you-go" Cloud computing model becomes an efficient alternative to owning and managing private data centers for customers facing Web applications and batch processing .Cloud computing frees the enterprises and their end users from the specification of many details, such as storage resources, computation limitation and network communication cost. However, this bliss becomes a problem for latency-sensitive applications, which require nodes in the vicinity to meet their delay requirements. When techniques and devices of IoT are getting more involved in people's life, current Cloud computing paradigm can hardly satisfy their requirements of mobility support, location awareness and low latency. Fog computing is proposed to address the above problem. As Fog computing is implemented at the edge of the network, it provides low latency, location awareness, and improves quality-of-services (QoS) for streaming and real time applications [2]. Typical examples include industrial automation, transportation, and networks of sensors and actuators. Moreover, this new infrastructure supports heterogeneity as Fog devices include end-user devices, access points, edge routers and switches. The Fog paradigm is well positioned for real time big data analytics, supports densely distributed data collection points, and provides advantages in entertainment, advertising, personal computing and other applications. Fog computing extends the paradigm to the edge of the network. while fog and cloud using same resources(networking, computing, storage) and share many of the same mechanism and attribute(virtualization, multi-tenancy) the extension is a non-trivial one in that there exist some fundamental differences stemming from the reason fog computing developed: to address and services that do not fit the paradigm of cloud [4].

3. ARCHITECTURE OF FOG COMPUTING

The Fog computing extends cloud computing by introducing an intermediate Fog layer between mobile devices and cloud. This accordingly leads to a three-layer Mobile-Fog-Cloud hierarchy. The intermediate Fog layer is composed of geo-distributed Fog servers which are deployed at the local premises of mobile users, *e.g.*, parks, bus terminals, shopping centers, *etc*.. A Fog server is a virtualized device with build-in data storage, computing and communication facility; the purpose of Fog computing is therefore to place a handful of compute, storage and communication resources in the close proximity of mobile users, and accordingly provide fast-rate services to mobile users via the local short-distance [8] high-rate wireless connections.

A Fog server can be adapted from existing network components, *e.g.*, a cellular base station, WiFi access point or router by upgrading the computing and storage resources and reusing the wireless interface. A Fog server can be static at a fixed location, *e.g.*, inside a shop installed similar as a WiFi access point, or mobile placed on a moving vehicle as the Greyhound "BLUE" system. The role of Fog servers is to bridge the mobile users and cloud [9]. On one hand, Fog servers directly communicate with mobile users through single-hop wireless connections using the off-the-shelf wireless interfaces, such as WiFi, cellular or Bluetooth1. With cloud-like resources, a Fog server is able to independently provide pre-defined application services to mobile users in its wireless coverage without the assistances of other Fog servers or remote cloud. On the other hand, the Fog servers can be connected to the cloud over Internet so as to leverage the rich computing and content resources of cloud.

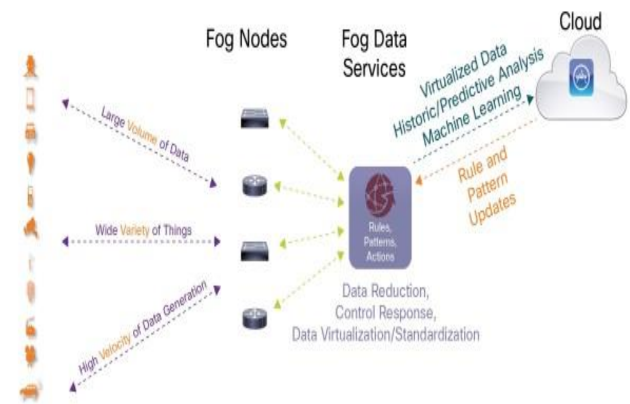

Fig. 2 Fog architecture as proposed by Cisco.

4. ADVANTAGES OF FOG COMPUTING

Fog computing provides- Low latency and location awareness, it has Wide-spread geographical distribution, supports Mobility, is compromised due to the huge number of nodes. The main task of fog is to deliver data and place it closer to the user who is positioned at a location which at the edge of the network. Here the term edge refers to different nodes to which the end user is connected and it is also called edge computing. If we look according to architecture fog is situated below the cloud at the ground level. The term fog computing is given by CISCO as a new technology in which mobile devices interact with one another and support the data communication within the Internet of Things.

4.1 Organizational Benefits

The advantages of the decentralized method of fog computing and IoT analytics extend to both the enterprise and end users. Organizations and those operating in data centers benefit because the majority of computations are performed at the edge of the cloud and closer to the mobile device. Instead of the massive amounts of big data produced by an equipment asset in the industrial Internet continuously being transmitted to a data center, which requires enormous quantities of data, fog computing enables only the results of data computations or analytics that pertain to asset management to be transmitted to the center.

Thus, 90 percent of the data that is transmitted and indicates that the asset is functioning properly is processed at the source and no longer requires any movement. The 10 percent that reveals that an asset is malfunctioning or in need of preventative maintenance is all that is transmitted. This greatly decreases network strain and time to action, and organizations don't need to increase their physical infrastructure and network capacity and can maintain sufficient network availability even with analytics for the IoT.

4.2 End-user Benefits

This approach provides a win both for those monitoring data transmitted by the IoT and mobile computing methods, and for those depending on that data. By facilitating computations near the edge of the cloud and closer to the source of the data, fog computing enables the devices and end users that need the results of those calculations to get them much more quickly than they otherwise could. There is no need to wait for untold amounts of data to travel across the country (or even across the world), to perform analytics at a centralized data center, or to hope the network's availability remains consistently operable. Instead, only the results of analytics undergo that process. And in some instances, everything is processed to produce action at the edge of the cloud by the device itself. The decreased time to action and greater availability of this paradigm can reinforce the trends of mobile computing and the IoT, helping them to gain further traction while satisfying end users in a way that is much more expensive and tenuous to achieve with centralized cloud approaches.

These advantages can be summarized as:

- The detection of masquerade activity.
- The confusion of the attacker and the additional costs incurred to distinguish real from bogus information.
- The deterrence effect which although hard to measure play a significant role in preventing masquerade activity by attackers.
- Edge application services significantly decrease the data volume that must be moved, the consequent traffic, and the distance the data must go, thereby reducing transmission costs, shrinking latency, and improving quality of service (QoS).
- Edge computing eliminates, or at least deemphasizes, the core computing environment, limiting or removing a major bottleneck and a potential point of failure.
- Security is also improved as encrypted data moves further in, toward the network core. As it approaches the enterprise, the data is checked as it passes through protected firewalls and other security points, where viruses, compromised data, and active hackers can be caught early on.
- Finally, the ability to "virtualized" (i.e., logically group CPU capabilities on an as-needed, real-time basis) extends scalability. The edge computing market is generally based on a "charge for network services" model, and it could be argued that typical customers for edge services are organizations desiring linear scale of business application performance to the growth of, e.g., a subscriber base.
- The significant reduction in data movement across the network resulting in reduced congestion, cost and latency, elimination of bottlenecks resulting from centralized computing systems, improved security of encrypted data as it stays closer to the end user reducing exposure to hostile elements and improved scalability arising from virtualized systems.
- Edge computing, in addition to providing subsecond response to end users, it also provides high levels of scalability, reliability and fault tolerance.
- Consumes less amount of bandwidth.

5. DISADVANTAGES

The various disadvantages are:

- Nobody is identified when attack is happen.
- It is complex to detect which user is attack.
- We cannot detect which file was hacking.

Security is the biggest concern when it comes to fog computing. By leveraging a remote cloud based infrastructure, a company essentially gives away private data and information, things that might be sensitive and confidential. It is then up to the fog service provider to manage, protect and retain them, thus the provider's reliability is very critical. A company's existence might be put in jeopardy, so all possible alternatives should be explored before a decision. On the same note, even end users might feel uncomfortable surrendering their data to a third party.

6. APPLICATION AREAS OF FOG COMPUTING

According to CISCO the important areas where fog computing would play a vital role are the following:

6.1 Connected car:

Autonomous vehicle is the new trend taking place on the road. Tesla is working on software to add automatic steering, enabling literal "hands free" operations of the vehicle. Within 2017 all new cars on the road will have the capability to connect to cars nearby and internet. Fog computing will be the best option for all internet connected vehicles why because fog computing gives real time interaction. Cars, access point and traffic lights will be able to interact with each other and so it makes safe for all. At some point in time, the connected car will start saving lives by reducing automobile accidents.

6.2 Smart Grids:

Smart grid is another application where fog computing is been used. Based on demand for energy, its obtainability and low cost, these smart devices can switch to other energies like solar and winds. The edge process the data collected by fog collectors and generate control command to the actuators. The filtered data are consumed locally and the balance to the higher tiers for visualization, real-time reports and transactional analytics. Fog supports semi-permanent storage at the highest tier and momentary storage at the lowest tier.

6.3 Smart Traffic lights:

Fog enables traffic signals to open lanes on sensing flashing lights of the ambulance. It detects presence of pedestrian and bikers, and measures the distance and speed of the close by vehicles. Sensor lighting turns on, on indentifying movements and vice-versa. Smart lights serves as fog devices synchronize to send warning signals to the approaching vehicles. The interactions between vehicle and access points are enhanced with WiFi, 3G, road side units and smart traffic lights.

6.4 Self Maintaining Train:

Another application of fog computing is self maintaining trains. A train ball-bearing monitoring sensor will sense the changes in the temperature level and any disorder will automatically alert the train operator and make maintenance according to. Thus we can avoid major disasters.

6.5 Wireless Sensor and Actuator Networks (WSAN): The real Wireless Sensor Nodes (WSNs) were designed to extend battery life by operating at predominantly low power. Actuator serves as Fog devices which control the measurement process itself, the consistency and the oscillatory behaviors by creating a closed-loop system. For example, in the lifesaving air vents sensors on vents monitor air conditions flowing in and out of mines and automatically change air-flow if conditions become dangerous to miners. Most of these WSNs entail less bandwidth, less energy, very low processing power, operating as a sink in a unidirectional fashion.

6.6 Decentralized Smart Building Control: In decentralized smart building control wireless sensors are installed to measure temperature, humidity, or levels of various gaseous components in the building atmosphere. Thus information can be exchanged among all sensors in the floor and the reading can be combined to form reliable measurements. Using distributed decision making the fog devices react to data. The system gears up to work together to lower the temperature, input fresh air and output moisture from the air or increase humidity. Sensors respond to the movements by switching on or off the lights. Observance of the outlook the fog computing are applied for smart buildings which can maintain basic needs of conserving external and internal energy.

6.7 Mobile computing system:

Fog computing organize highly virtualized computing and communication facilities for mobile users. Fog computing explores the predictable service demand patterns of mobile users and typically provides desirable localized services accordingly. With low-latency and short-distance local connections Fog computing can provide mobile users with the demanded services. This significantly improves the service quality provided to mobile users and, it save bandwidth cost and energy consumptions. Fog computing enable the convergence of cloud based Internet and the mobile computing.

7. RESOURCE ALLOCATION IN FOG COMPUTING

Cloud provisioning and resource management are still interesting topics in fog computing environment. Application-aware provisioning challenges lies in the mobility of end node since metrics such as bandwidth, storage, computation and latency will be changed dynamically. For example, in a connected vehicle scenario, we can track an in-duty ambulance and tune smart traffic light to ensure green traffic wave and give warning to all the nearby vehicles to clear the road. In order to meet the QoS requirement such as delay, we need to do provisioning in order to prepare resources to provide service mobility. MigCEP is a placement and migration method for both fog and cloud resources. By planning operator migration ahead, it ensures end-to-end latency restrictions and reduces network utilization.

7.1 Resource discovery and sharing

Resource discovery and sharing are critical for application performance in fog. N. Takayuki et al. propose a framework for heterogeneous resource sharing in fog computing by mapping heterogeneous resources such as CPUs, communication bandwidth, and storage all to "time" resources. The resource sharing optimization problems can be formulated for maximizing the sum or product of service-oriented utility functions. However, the utility function is only about service latency which can be further expanded to include metrics such as service availability, energy consumption or even revenue.

8. COMPARISON OF FOG COMPUTING AND CLOUD COMPUTING

Cloud Computing, is defined as a group of computers and servers connected together over the Internet to form a network. Today, as many enterprises and large organizations are beginning to adopt the Internet of Things, the need for large amounts of data to be accessed more quickly, and locally, is ever-growing. This is where the concept of "Fog Computing" comes to play.

Fog computing, or "fogging", is a distributed [11] infrastructure in which certain application processes or services are managed at the edge of the network by a smart device, but others are still managed in the cloud. It is, essentially, a middle layer between the cloud and the hardware to enable more efficient data processing, analysis and storage, which is achieved by reducing the amount of data which needs to be transported to the cloud.

The major difference between cloud computing and Fog computing is on the support of location awareness. The cloud computing locates in a centralized place and serves as a centralized global portal of information; cloud computing is often lack of location awareness. The Fog computing extends cloud to reside at user's premises and dedicates on localized service applications. Table 1 summarizes the differences between Fog computing and Cloud computing.

	Fog Computing	**Cloud Computing**
Target User	Mobile Users	General Internet Users
Service Type	Limited Local Information Services Related Specific development Locations	Global Information Collecting From World Wide
Hardware	Limited Storage Compute Power & Wireless Interface	Ample and Scalable Storage Space and Compute Power
Distance to Users	In the Physical Proximity and communicate through single-hop wireless connection.	Faraway from users and communicate through ip network
Working Environment	Outdoor (Streets, parklands etc) or Indoor (restaurant, shopping malls etc.)	Warehouse- size building with air-conditioning systems
Deployment	Centralized or distributed in regional areas by local business (telecommunications vendor, shopping malls retailer etc.)	Centralized and maintained by Amazon and Google etc

Table.1 Difference between Fog Computing and Cloud Computing

9. CHALLENGES OF FOG COMPUTING DEPLOYMENT

Fog computing puts additional computing and storage resources at the edge, with the purpose to fast process the localized service requests using local resources and connections. At different locations deployed, the Fog server, however, needs to adapt its services, which poses extra management and maintenance cost. In addition, the network operator of a Fog computing system needs to address the following issues challenges: [13]

9.1 Application:

At a specific location, the network operator needs to customize the applications embedded in each of the Fog servers based on the local demand.

9.2 Scaling:

The network operator needs to anticipate the demand of each of the Fog servers and deploy adequate fog resources so as to sufficiently provision.

9.3 Placement:

A group of Fog servers can collaboratively provide service applications to mobile users nearby. For example, multiple Fog servers can be deployed inside a shopping center to provide seamless fog applications. As such, with different user demands at different locations, how to optimally place Fog servers is challenging.

10. USE OF FOG COMPUTING IN EMERGING TECHNOLOGIES

10.1 5G Technologies:

Fog computing focuses on serving customized location-based applications to mobile users. The Fog layers can be adapted by using the existing accessing networks, e.g., WiFi, or emerging 5G wireless technologies with a virtualized architecture.

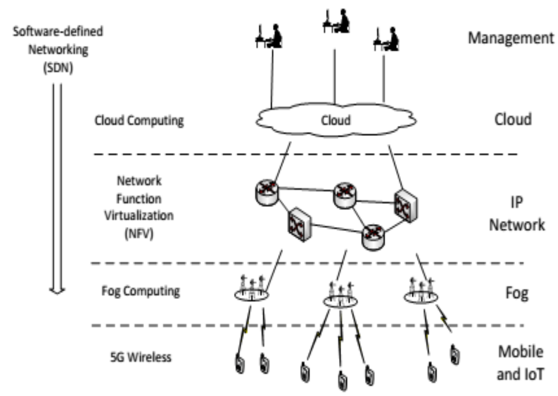

Fig. 3 Fog Computing in Emerging Technology

10.2 Network Function Virtualization (NFV):

In contrast NFV which targets to enabled virtualized network functions inside network nodes, *e.g.*, switches and routers, Fog computing aims at enabling virtualized location-based applications at the edge device and providing desirable services to localized mobile users.

10.3 Software-defined Networking (SDN):

The Fog computing, as the local surrogate of cloud, needs to synchronize frequently with cloud for data update and support. With a global network view, the cloud can manage the entire network using a SDN approach.

11. CONCLUSION

Fog computing as a new paradigm or as made-up marketing hype, you'll probably encounter the term over the next few years as the IoT gains traction. Fog computing takes some of the heavy lifting off regular cloud services by utilizing local resources for quicker and smoother processes, and whatever you want to call it, you can expect it to increase in importance as more objects become smart and connected. Fog computing will evolve with the rapid development in underlying IoT, edge devices, radio access techniques, SDN, NFV, VM and Mobile cloud. We think fog computing is promising but currently need joint efforts from underlying techniques to converged at "fog computing".

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