"FOG COMPUTING"
Focusing on Users at the Edge of Internet of Things

NATRAJ A V

Computer Science & Engineering, Department of PG Studies
V T U Regional Center Mysuru
mailto:nata.natraj@gmail.com
Contact Number: +91-8722338384

Abstract: Datais now being delivered in large quantities to many more users. To optimize the concept of the cloud, organizations need a way to deliver content to end users through a more geographically distributed platform. The idea of fog computing is to distribute data, compute, storage to move it closer to the end-user to eliminate latency and numerous hops, and support mobile computing and data streaming. Already, we're seeing "everything-as-a-service" models. The user is asking for more data access from any device, any time, from anywhere. This means that the future of the cloud must support the idea of the "Internet of Things (IoT)." That's where Fog Computing comes in.

Keywords: Fog computing , Internet of things, Mobile Computing

1. INTRODUCTION

We are embracing the prevalence of ubiquitously connected smart devices, which are now becoming the main factor of computing. Along with the development of wearable computing, smart metering, smart home/city, connected vehicles, large-scale wireless sensor network, smart farming, the Internet of Things (IoT) has received attentions for years and is considered as the future of Internet. IDC (International Data Corporation) has predicted that in the year of 2016, "The IoT will continue to rapidly expand the traditional IT industry" up 14% from 2014. An estimated 50 billion "things" will be connected to the Internet by 2020. However, due to the limited computation/storage on smart devices, cloud computing is considered as a promising computing paradigm, which can provide elastic resources to applications on those devices. In spite of attempts of augmenting IoT applications with the power of cloud, there are still problems unsolved in that IoT applications usually require mobility support, geo-distribution, location-awareness and low latency.

Fog computing is proposed to enable computing directly at the edge of the network, which can deliver new applications and services especially for the future of Internet - Fog, simply because the fog is a cloud close to the ground. For example, commercial edge routers are advertising processor speed, number of cores and built-in network storage. Those routers have the potential to become new servers. In fog computing, facilities or infrastructures that can provide resources for services at the edge of the network are called fog nodes.

2. METHODOLOGY

In Fog computing, 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 things. 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**. In this framework, each smart thing is attached to one or more of Fog nodes. Fog devices could be interconnected and each of them is linked to the Cloud.

While Fog and Cloud use the same resources (networking, compute, and storage), and share many of the same mechanisms and attributes (virtualization, multi-tenancy) the extension is a non-trivial one in that there exist some fundamental differences. The Fog vision was conceived to address applications and services that do not fit well the paradigm of the Cloud. They include:

- Applications that require very low and predictable latency—the Cloud frees the user from many implementation details, including the precise knowledge of where the computation or storage takes place. This freedom from choice, welcome in many circumstances becomes a liability when latency is at premium (gaming, video conferencing).
- Geo-distributed applications (pipeline monitoring, sensor networks to monitor the environment).
- Fast mobile applications (smart connected vehicle, connected rail).
- Large-scale distributed control systems (smart grid, connected rail, smart traffic light systems).

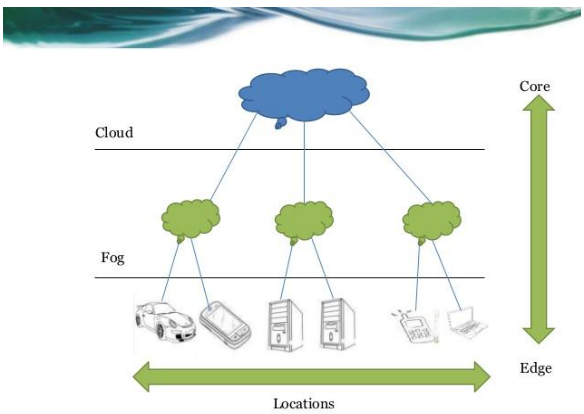

Fig1: Fog between edge and core.

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3. CHARACTERIZATION OF FOG COMPUTING

Fog Computing is a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network. **Figure 2** presents the idealized information and computing architecture supporting the future IoT applications, and illustrates the role of Fog Computing.

Compute, storage, and networking resources are the building blocks of both the Cloud and the Fog. Edge of the Network", however, implies a number of characteristics that make the Fog a non-trivial extension of the Cloud. Let us list them with pointers to motivating examples.

- Edge location, location awareness, and low latency. The origins of the Fog can be traced to early proposals to support endpoints with rich services at the edge of the network, including applications with low latency requirements (e.g. gaming, video streaming).
- Geographical distribution. In sharp contrast to the more centralized Cloud, the services and applications targeted by the Fog demand widely distributed deployments. The Fog, for instance, will play an active role in delivering high quality streaming to moving vehicles, through proxies and access points positioned along highways and tracks.
- Large-scale sensor networks to monitor the environment, and the Smart Grid are other examples of inherently distributed systems, requiring distributed computing and storage resources.
- Very large number of nodes, as a consequence of the wide geo-distribution, as evidenced in sensor networks in general, and the Smart Grid in particular.
- Support for mobility. It is essential for many Fog applications to communicate directly with mobile devices, and therefore support mobility techniques, such as the LISP protocol, that decouple host identity from location identity, and require a distributed directory system.
- Real-time interactions. Important Fog applications involve real-time interactions rather than batch processing.
- Predominance of wireless access.
- Heterogeneity. Fog nodes come in different form factors, and will be deployed in a wide variety of environments.
- Interoperability and federation. Seamless support of certain services(streaming is a good example) requires the cooperation of different providers. Hence, Fog components must be able to interoperate, and services must be federated across domains.
- Support for on-line analytic and interplay with the Cloud. The Fog is positioned to play a significant role in the ingestion and processing of the data close to the source.

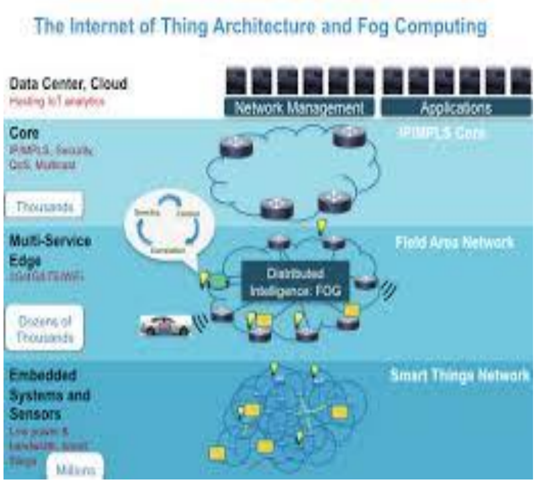

Fig2: The Internet of Things and Fog Computing.

4. APPLICATION SCENARIOS

The explosive growth of the Internet of Things (IoT) is creating millions of new endpoints including sensors, devices, IP cameras, and other connected smart devices. These devices are generating more data every day. Moving all that data to a central data center for analysis presents latency, bandwidth, security, and reliability challenges.

Fog Data Services lets you act on data at the source, the edge of the network. So your operation can use more data immediately, lessen the security risks of transmitting all of it to the cloud, and relieve the strain on your network, cloud resources and infrastructure. We elaborate applications of Fog computing in the following motivating scenarios. The advantages of Fog computing satisfy the requirements of applications in these scenarios.

4.1 ***Smart Farming or Precision Agriculture:***Despite being one of the world's oldest industries,agriculture is rapidly embracing IoT as an enabler for automation and process control. Bigger and stronger machines with GPS-based autonomous steering are replacing smaller, less efficient implements, and sophisticated precision equipment sensors relay information to help increase farms' productivity, reduce operating costs, and secure both resources and assets. Precision agriculture uses IoT applications, which help farmers to increase the quality, quantity, sustainability and cost effectiveness of agricultural production. These tools allow the farmers to know what seeds to plant, the amount of fertilizer they need to use, the better time to harvest as well as the expected crop outputs. Through the implementation of IoT, farmers can also monitor sensors that can be used to detect soil moisture, crop growth and livestock feed levels, among other key functions. The sensors can also remotely manage and control connected harvesters and irrigation equipment.Certain IoT platforms used in the agriculture industry allow farmers to manage the big amounts of data collected from sensors, cloud services such as weather or maps, connected equipment and existing systems. The platforms also leverage big data and analytics tools to provide insight and recommendations to improve the decision-making process.

4.2***Smart Grid:*** Energy load balancing applications may run on network edge devices, such as smart meters and microgrids. Based on energy demand, availability and the lowest price, these devices automatically switch to alternative energies like solar and wind. Fog collectors at the edge process the data generated by grid sensors and devices, and issue control commands to the actuators. They also filter the data to be consumed locally, and send the restto the higher tiers for visualization, real-time reports and transactional analytics. Fog supports ephemeral storage at the lowest tier to semi-permanent storage at the highest tier. Global coverage is provided by the Cloud with business intelligence analytics.

4.3*Smart Traffic Lights and Connected Vehicles:* Video camera that senses an ambulance flashing lights can automatically change street lights to open lanes for the vehicle to pass through traffic. Smart street lights interact locally with sensors and detect presence of pedestrian and bikers, and measure the distance and speed of approaching vehicles. Intelligent lighting turns on once a sensor identifies movement and switches off as traffic passes. Neighboring smart lights serving as Fog devices coordinate to create green traffic wave and send warning signals to approaching vehicles. Wireless access points like WiFi, 3G, road-side units and smart traffic lights are deployed along the roads. Vehicles-to-Vehicle, vehicle to access points, and access points to access points interactions enrich the application of this scenario.

4.4*Wireless Sensor and Actuator Networks:* Traditional wireless sensor networks fall short in applications that go beyond sensing and tracking, but require actuators to exert physical actions like opening, closing or even carrying sensors. In this scenario, actuators serving as Fog devices can control the measurement process itself, the stability and the oscillatory behaviors by creating a closed-loop system. For example, in the scenario of self-maintaining trains, sensor monitoring on a train's ball-bearing can detect heat levels, allowing applications to send an automatic alert to the train operator to stop the train at next station for emergency maintenance and avoid potential derailment. In lifesaving air vents scenario, sensors on vents monitor air conditions flowing in and out of mines and automatically change air-flow if conditions become dangerous to miners.

4.5 *Decentralized Smart Building Control:* The applications of this scenario are facilitated by wireless sensors deployed to measure temperature, humidity, or levels of various gases in the building atmosphere. In this case, information can be exchanged among all sensors in a floor, and their readings can be combined to form reliable measurements. Sensors will use distributed decision making and activation at Fog devices to react to data. The system components may then work together to lower the temperature, inject fresh air or open windows. Air conditioners can remove moisture from the air or increase the humidity. Sensors can also trace and react to movements (e.g, by turning light on or off). Fog devices could be assigned at each floor and could collaborate on higher level of actuation. With Fog computing applied in this scenario, smart buildings can maintain their fabric, external and internal environments to conserve energy, water and other resources.

4.6 *Content Delivery and Caching*: The fog server can provide dynamic customizable optimization based on client devices and local network conditions. And since fog server is in client's vicinity, it can gather client side knowledge and user experience, to optimize the rendering of web page. Similarly, caching technique can be better implemented within the fog nodes to further save the bandwidth and reduce latency for content delivery.

4.7 *Big Data Analytics:*Fog computing can provide elastic resources to large scale data process system without suffering from the drawback of cloud, high latency. In cloud computing paradigm, event or data will be transmitted to the data center inside core network and result will be sent back to end user after a series of processing. A federation of fog and cloud can handle the big data acquisition, aggregation and preprocessing, reducing the data transportation and storage, balancing computation power on data processing. For example, in a large scale environment monitoring system, local and regional data can be aggregated and mined at fog nodes providing timely feedback especially for emergency case such as toxic pollution alert. While detailed and thorough analysis as computational-intensive tasks can be scheduled in the cloud side. We believe data processing in the fog will be the key technique to tackle analytics on large scale of data generated by applications of IoT.

4.8 *IoT and Cyber-physical systems (CPSs):*
Fog computing based systems are becoming an important class of IoT and CPSs. Based on the traditional information carriers including Internet and telecommunication network, IoT is a network that can interconnect ordinary physical objects with identified addresses. CPSs feature a tight combination of the system's computational and physial elements. CPSs also coordinate the integration of computer and information centric physical and engineered systems. IoT and CPSs promise to transform our world with new relationships between computer-based control and communication systems, engineered systems and physical reality. Fog computing in this scenario is built on the concepts of embedded systems in which software programs and computers are embedded in devices for reasons other than computation alone. Examples of the devices include toys, cars, medical devices and machinery. The goal is to integrate the abstractions and precision of software and networking with the dynamics, uncertainty and noise in the physical environment. Using the emerging knowledge, principles and methods of CPSs, we will be able to develop new generations of intelligent medical devices and systems, 'smart' highways, buildings, factories, agricultural and robotic systems.

4.9 *Software Defined Networks (SDN):*Fog computing framework can be applied to implement the SDN concept for vehicular networks. SDN is an emergent computing and networking paradigm, and became one of the most popular topics in IT industry. It separates control and data communication layers. Control is done at a centralized server, and nodes follow communication path decided by the server. The centralized server may need distributed implementation. SDN concept was studied in WLAN, wireless sensor and mesh networks, but they do not involve multi-hop wireless communication, multi-hop routing. Moreover, there is no communication between peers in this scenario. SDN concept together with Fog computing will resolve the main issues in vehicular networks, intermittent connectivity, collisions and high packet loss rate, by augmenting vehicle-to- vehicle with vehicle-to-infrastructure communications and centralized control.

5. COMPARISON OF CLOUD AND FOG COMPUTING

While Fog nodes 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 analytics and Big Data. The concept of Fog computing is very much similar to cloud computing. But following few parameters shows the difference between these two close concepts. Table 1 summarizes comparison between cloud and fog computing.

Requirements	**Cloud Computing**	**Fog Computing**
Latency	High	Low
Delay Jitter	High	Very low
No. of server nodes	Few	Very large
Real Time Interactions	Supported	Supported
Support for Mobility	Limited	Supported
Location Awareness	No	Yes
Distance between Client and Server	Multiple hops	One hop
Location of Service	Within the Internet	At the edge of the local network
Security	Undefined	Can be defined
Ge0-distribution	Centralized	Distributed

Table1: Comparison of Cloud computing and Fog Computing

6. AN EXAMPLE OF FOG NODE

Cisco IOx- Cisco Iox platform is an architecture that brings together Cisco IOS, the industry-leading networking operating system, and Linux, the leading open source platform. Because Linux-based applications can run on Cisco devices in the Cisco Iox framework, businesses can bring their own applications and interfaces to the network. Cisco Iox offers developers a way to create IoT applications such as data aggregation, control systems, and access control and have them run on edge network devices. Businesses in manufacturing, transportation, energy, and beyond can now harness the value in the Internet of Things.

Iox architecture is shown in Figure 3. Iox works by hosting applications in a Guest Operating System (GOS) running in a hypervisor directly on the Connected Grid Router (CGR). On IoX platform, developers can run python scripts (supports many programming languages), compile their own code, and even replace the operation system with their own.

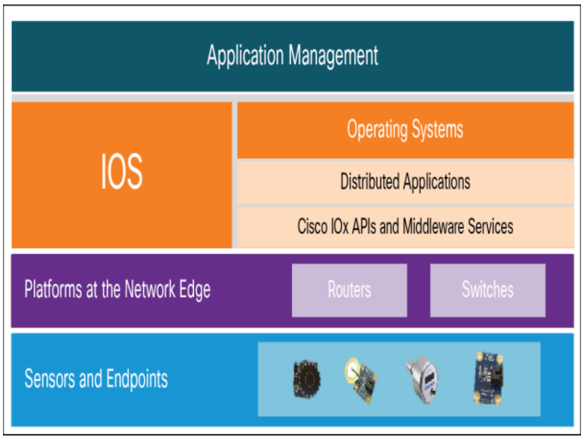

Fig 3: Cisco IOx Architecture

CONCLUSIONS

Fog Computing complements the Cloud Computing, does not substitute it.Fog computing gives the cloud a companion to handle the tremendous amount of data generated daily from the Internet of Things. Processing data closer to where it is produced and needed solves the challenges of exploding data volume, variety, and velocity.

Fog computing accelerates awareness and response to events by eliminating a round trip to the cloud for analysis. It avoids the need for costly bandwidth additions by offloading gigabytes of network traffic from the core network. It also protects sensitive IoT data by analyzing it inside company walls. Ultimately, organizations that adopt fog computing gain deeper and faster insights, leading to increased business agility, higher service levels, and improved safety.

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