Moving from Cloud to Fog: Implications and Challenges

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ABSTRACT

With the rapid growth of internet of things (IoT) applications, the traditional centralized cloud computing is encountering severe challenges, such as high latency, low spectral efficiency (SE), and non-adaptive machine type of communication. Motivated to solve these challenges, fog computing is driving a trend which shifts the function of centralized cloud computing to the edge devices of the network. Fog computing extends the Cloud platform model by providing computing resources on the edges of a network. Fog computing (a term created by Cisco Systems Inc.) can enhance and complement cloud and is capable of processing large amounts of data locally and can be installed on heterogeneous hardware. In this article, we will discuss fog computing, its advantages, and its current applications. We will also present existing literature on fog computing applications to identify challenges and potential research directions aimed at using fog computing to extend cloud capabilities.

Keywords

Internet of Things, Security and Privacy, Fog Computing, Cloud Computing, Edge Computing

1. INTRODUCTION

Big data is not going anywhere soon. In the next few years, businesses, large or small, will be using some form of data analytics to make business decisions. Moreover, as the IoT becomes more widespread, high-speed data processing, analytics and reduced response times are becoming more critical than ever. To meet these requirements through the current centralized, cloud-based model is very challenging. 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 [4]. 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 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 the end users, the dense geographical distribution and its support for mobility [5].

It is estimated that the amount of data analyzed on devices that are physically close to the IoTs is approaching 40%, which will introduce challenges in making sure that the quality of the service is not degraded. With the use of a fog layer, as a decentralized architecture between the cloud and the data, many of the challenges can be alleviated by extending the functions of the Cloud computing closer to the IoT devices and only pushing relevant data to the cloud. Fog computing, also known as edge computing, is an intermediate layer that extends Cloud layer. Simply put, fog is a cloud close to the ground. Fog architecture moves part of the computing to the edges, away from the centralized data centers and cloud solutions. 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 [1]. Therefore, data can be processed locally in smart devices rather than being sent to the cloud for processing.

Cisco provides the example of a jet engine which can create ten terabytes (TB) of data about its performance and condition in 30 minutes [2]. Transmitting all that data to the cloud and transmitting response data back requires high bandwidth and a great amount of time and can increase latency. In a fog computing environment, much of the processing would take place in a router, rather than having to be transmitted. Hence, fogging focuses on lifting part of the workload off the regular cloud services by using localized resources to provide a quicker, smoother, and more streamlined experience

for end-users. Fog computing analyzes the most time-sensitive data at the network edge, close to where it is generated instead of sending vast amounts of data to the cloud. Also, in addition to acting on data in milliseconds, based on policy, it sends selected data to the cloud for historical analysis and longer-term storage.

2. FOG COMPUTING CHARACTERISTICS

Fog computing leverages cloud and edge resources along with its own infrastructure, as Figure 1 shows. In essence, the technology deals with IoT data locally by utilizing clients or edge devices near users to carry out a substantial amount of storage, communication, control, configuration, and management. The approach benefits from edge devices' close proximity to sensors, while leveraging the on-demand scalability of cloud resources. Fog computing involves the components of data-processing or analytics applications running in distributed cloud and edge devices. It also facilitates the management and programming of computing, networking, and storage services between datacenters and end devices. In addition, it supports user mobility, resource and interface heterogeneity, and distributed data analytics to address the requirements of widely distributed applications that need low latency.

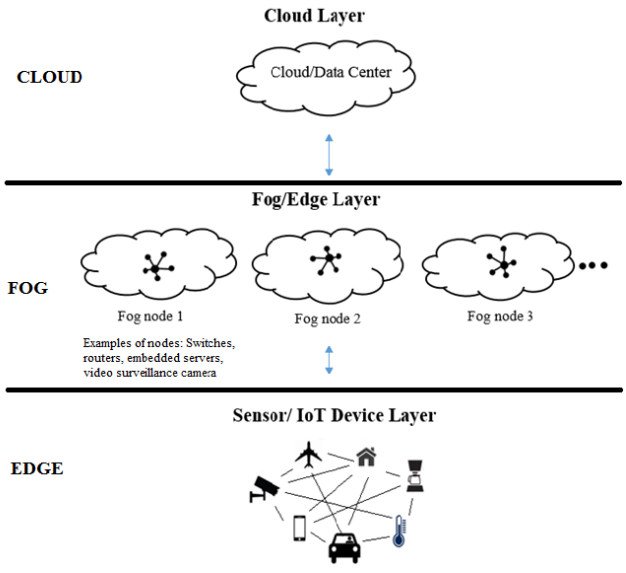


Figure 1. A typical architecture of fog computing

3. FOG vs. CLOUD COMPUTING

Both cloud and fog provide data, computation, storage and application services to end-users, however, the idea of fog computing is to place transactions and resources at the edge of the cloud, rather than to establish channels for cloud storage and utilization. This will reduce bandwidth by not sending every bit of information over cloud channels, and instead aggregating it at a certain access point. It will also eliminate latency and numerous hops, lower the costs, improve efficiency and support mobile computing and data streaming.

In many cases, fog and cloud can complement each other. A good example is a smart lighting system which operates based on movement. When motion is detected, data needs to be processed to affect the outcome that the lights are turned on. When no motion is detected for a period of time, a decision needs to be made that the lights should now be turned off. This data and resulting decisions are best processed at the fog or edge. On the other hand, the company running the smart lighting system may also want to monitor energy efficiency and the duration of time the lights were on. The data which provides this "bigger picture" of how the smart lighting is being used would require data to be assembled and processed by a reporting system run in the cloud. As another good use case, consider an example of smart vehicles where cars could collect information about road conditions. These smart vehicles can send the collected information to alert the other drivers on the same road, but also to a central cloud server when connected to the WAN to warn other drivers on other roads/highways and recommend to others to avoid that route. A great example of this is Waze, a wildly utilized crowdsourced driving application that people use for real-time traffic information, warnings about hidden police, and information about how to get around congestion. Drivers provide their location information (on their mobile device) in exchange for information that will enhance their own experiences. So each mobile device sends real time information to the main information hub, which processes all of the data and then sends personalized messages back to every device that is connected.

4. ADVANTAGES OF FOG COMPUTING

Fog layer is a computing layer closer to the sensor layer, where the sensors and actuators reside and provide computing, networking, and storage services. Fog nodes can be deployed anywhere with a network connection close to the smart device where actual data generation or end outcome takes place; i.e., in a vehicle. To accommodate the services, and address the requirements of IoT systems, the fog layer offers

several advantages. One of the immediate benefits of fog over the cloud is its proximity to the sensor layer. Another advantage is the location-awareness which is due to the large-scale geographical distribution of the devices that make up the fog layer. This will, in turn, offer communication latency. The combined benefits of location-awareness and large-scale geographic distribution support the mobility requirements of devices or "things" at the sensor layer. Also, the close proximity of the fog layer to the nodes provides real-time interaction with the sensors and actuators in the sensor layer. Fog offers additional security to endure safe and trusted transitions, provides affordable scaling under a shared infrastructure, offers real-time processing and cyber-physical system control, and increasing efficiency by pooling of unused local resources from participating end-user devices.

5. FOG COMPUTING SERVICES

Fog computing can provide computing, networking, and storage services to IoT. Consider a system which performs data processing to learn a certain pattern. In this case, the workload can be distributed in such a way that localized patterns can be identified in the fog layer while the generalized patterns are only available in the Cloud. This load sharing with increase the computing power of data. The proximity of the fog makes it an ideal way to handle events to react in real-time and enhance the reliability of the system.

Fog and cloud computing complement each other and have opened a huge door to new forms of communications, applications and human experiences. For example, there is a new trend of research on Mist computing and Fluid computing. Mist computing is closer to the ground than fog, which in turn is closer to the ground than the cloud. Simply put, Mist computing is about bringing compute, storage, and communication directly onto the things which means cloud infrastructure is high in the data center, fog infrastructure is between the devices and the cloud, and Mist infrastructure is simply the things/devices. As an emerging network architecture, fluid computing combines cloud, fog, and mist computing into a single abstraction. In other words, all three computing can be considered as an application of fluid computing in a specific, bounded context. The fluid architecture eliminates the technological separation created by cloud, fog and mist technologies. Interestingly enough, there is a fifth computing model, Blockchain computing. This model is primarily used in the financial industry and for Bitcoins. It operates like a broadcast-based cache coherent network, not relevant to the majority of cloud/fog/mist/fluid computing applications. There are no centralized data centers in a Blockchain network. Any message from one computer is sent to all the computers in the network (i.e., broadcast). How this model works is very interesting but it is beyond the scope of this article.

6. FOG COMPUTING APPLICATIONS

Various applications could benefit from fog computing. Healthcare and activity tracking fog computing could be useful in healthcare, in which real-time processing and event response are critical. One proposed system utilizes fog computing to detect, predict, and prevent falls by stroke patients [6]. Another proposed fog computing–based smart-healthcare system enables low latency, mobility support, and location and privacy awareness [7]. Smart utility services fog computing can be used with smart utility services [8] whose focus is improving energy generation, delivery, and billing. In such environments, edge devices can report more fine-grained energy-consumption details (for example, hourly and daily, rather than monthly, readings) to users' mobile devices than traditional smart utility services. These edge devices can also calculate the cost of power consumption throughout the day and suggest which energy source is most economical at any given time or when home appliances should be turned on to minimize utility use. Augmented reality, cognitive systems, and gaming fog computing plays a major role in augmented-reality applications, which are latency sensitive. For example, the EEG Tractor Beam augmented multiplayer, online brain–computer interaction game performs continuous real-time brain-state classification on fog devices and then tunes classification models on cloud servers, based on electroencephalogram readings that sensors collect [9]. A wearable cognitive-assistance system that uses Google Glass devices helps people with reduced mental acuity perform various tasks, including telling them the names of people they meet but don't remember [10]. In this application, devices communicate with the cloud for delay-tolerant jobs such as error reporting and logging. For time-sensitive tasks, the system streams video from the Glass camera to the fog devices for processing. The system demonstrates how using nearby fog devices greatly decreases end-to-end latency.

7. CHALLENGES

Realizing fog computing's full potential presents several challenges including balancing load distribution between edge and cloud resources, API and service management and sharing, and SDN communications. Enabling real-time analytics in fog environments, resource management systems should be able to dynamically determine which analytics tasks are being pushed to which cloud or edge-based resource to minimize latency and maximize throughput. These systems also must consider other criteria such as various countries' data privacy laws involving, for example, medical and financial information. In addition, most data-processing frameworks, including Apache Storm, don't provide enough scalability and flexibility for fog and IoT environments because their architecture is based on static configurations. Fog environments require the ability to add and remove resources dynamically because processing nodes are generally mobile devices that frequently join and leave networks.

Fog computing also introduces challenges in research [12]. Fog is a novel computing paradigm, which demands a new programming model. Therefore, researchers need to design intuitive and effective tools and frameworks to help developers arrange dynamic, hierarchical and heterogeneous resources to build compatible applications on diverse platforms. For instance, fog computing introduces a variety of new and interesting scheduling challenges. Since tasks can now be moved between different physical devices scheduling is much more complex. Some of the research questions are listed as follows.

Data management for fog computing applications also introduces new challenges. Ways to implement large storage systems is still an open question. Furthermore, energy consumption and network usage must be conserved on mobile devices, as they typically have energy limits enforced by limited battery technology and data limits enforced by mobile carriers. An attractive aspect of cloud computing is the automatic discovery of services. As fog nodes differ from location to location, users can arrive at a new location and take advantage of the various services provided by the fog nodes in that particular location. Given that this feature relies on the prudent deployment accomplished by service developers, implementing service discovery protocols in fog computing can be quite challenging [12].

Most importantly, fog computing introduces new challenges in security, reliability, and fault tolerance. Enforcing security in fog environments, which have multiple service providers and users, as well as distributed resources, is a key challenge. Designing and implementing authentication and authorization techniques that can work with multiple fog nodes that have different computing capacities is difficult. Public-key infrastructures and trusted execution environments are potential solutions [11]. Users of fog deployments also must plan for the failure of individual sensors, networks, service platforms, and applications. To help with these, they could apply standards, such as the Stream Control Transmission Protocol, that deal with packet and event reliability in wireless sensor networks [11].

It will be important in the future to make fog computing applications preserve user privacy, provide rigorous security guarantees, and address the needs of all the parties involved. Exploring solutions to the aforementioned problems is critical in realizing the many benefits promised by fog computing. It is our goal in the future to expose these design choices, so that developers can more easily figure them out in their implementations. We believe that this is a first step towards identifying reasonable solutions to these problems.

8. IMPLICATIONS FOR INDUSTRY

Cloud has paved the way for the rapid growth of the IoT, but with such growth, businesses need faster and more efficient solutions than ever since information that is even one day old can become invaluable. Recently, companies are turning to fog computing for higher efficiency, faster decision-making processes and lowered operating costs. A great example is in airline industry which has been cited in various articles. When a plane lands, data from its engines must be downloaded and analyzed. If any anomalies are discovered that could indicate trouble with the engine or any potential causes of failure, a new part must be procured and installed. It's a process that typically takes several hours. With fog computing, you could have the capability to do all the analytics in-flight, on the plane, and transmit any anomalies. Then when the plane lands, the part can be waiting, and your downtime is 15 to 30 minutes rather than hours. Practitioners argue that if you take an example like this and look at transportation and manufacturing industry, with their need for preventive maintenance, you can see how making this technology pervasive enhances efficiency and safety.

There are few reasons why companies are turning to fog computing. One reason is that it can help

increase data flow and efficiency by speeding up the processing of data at individual nodes, reducing the need for constant management at the cloud layer. By managing data at the node and only retaining important information, data storage and analysis no longer flood central servers. This solution has added cost benefits to businesses.

Another reason is that with the emergence of IoT applications, a real-time response can be "a matter of life or death" as explained by some practitioners [3]. For example, reliable real-time data processing is crucial for medical wearables which monitor patient conditions. Fog computing is especially feasible for applications that require a response time of less than a second [4]. Also, companies are turning to fog computing is security concerns. According to Rasmussen [3], "fog systems are designed from the ground up to protect the security of information exchange between IoT devices and the cloud, providing security suitable for real-time applications." fog systems can also be used to keep device data securely in-house and away from vulnerable public networks.

For many companies, relying on nodes on decentralized systems is a concern. For example, a major disaster could wipe out all those individual processors in a city, resulting in catastrophic data losses. By storing data in the cloud, businesses will be able to recover from disruptions much more quickly and efficiently. With fog computing, local and remotely hosted data backups remain critical, as well as making sure the businesses can access stored data in the event of an emergency. To remedy this issue, in fog computing, data backups can be safely stored allowing companies to schedule automated backups protected by military-grade encryption.

9. CONCLUSION

Fog computing is considered a novel technique that powers up the implementation of cloud computing in industry. Currently, industries such as healthcare, manufacturing, transportation systems, oil and gas production, and utilities are turning to fog computing. But more and more businesses that deal with a significant amount of data are learning about the potential of using fog computing with the understanding that it cannot entirely replace cloud computing since cloud is still preferred for high-end batch processing jobs that are very common in the business world. Hence, we can conclude that fog computing and cloud computing will complement each other with their advantages and disadvantages. Fog computing helps cloud handle the significant amount of data generated daily from the IoT. However, even though fog computing has a great potential to accelerate the next generation of the networking implementations, security and privacy concerns still are restricting its applications. The threats exist at different layers due to more parties are involved in the service processes. Both detecting threats and finding solutions are significant. Building up an intelligent security mechanism in fog computing is an urgent mission in an advanced network setting. We recommend that individual businesses adopt a hybrid model, a combination of cloud, fog, and on-site backup systems to maintain efficiency while mitigating security risks.

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