FOG COMPUTING IN LOGISTICS SYSTEMS

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Abstract: *The extension of cloud computing to the edge of the network through fog computing provides efficient resource utilization and higher performance regarding the delay, bandwidth and energy consumption. Fog computing is not a substitute for cloud computing. It enables data storage and processing at the edge of the network, with the possibility of interaction with the cloud data centers. Therefore, these technologies are adequate complements. Due to numerous advantages, fog computing is a promising technology for many applications, especially latency-sensitive applications requiring real-time processing. This paper analyzes the possibility of fog computing deployment in logistics systems. The benefits of fog computing deployment in an intelligent logistics center are observed. The architecture of a fog computing model in supply chain management is also addressed.*

Keywords: *fog computing, cloud computing, end devices, logistics systems*

1. INTRODUCTION

Computing paradigms have evolved from distributed, parallel and grid to cloud computing. Cloud computing provides scalability, on-demand physical and virtual resources allocation, reduced management efforts, flexible pricing and service provisioning. Virtualization, as a key cloud computing characteristic, can be defined as a set of techniques that abstracts the details of a physical element (e.g. hardware platform, storage device, operating system, or network resources) and provides virtualized resources. Due to virtualization, cloud resources can be provided in the form of virtual machines (VM). The virtual machine is a computing environment in which an operating system can be installed and run. Software execution on VMs is separated from the underlying hardware resources. Hence, VM emulates a physical computing environment that can be easily shared, copied or moved between host servers. The migration capability followed from virtualization enables on-demand resources allocation to applications. Furthermore, virtualization introduces elasticity, load balancing and economy of scale in the cloud environment. Due to numerous advantages, cloud computing has widespread use. However, there are some limitations. The major limitation is the connectivity between cloud and end devices, especially for latency-sensitive cloud-based applications,

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according to Mouradian et al. (2018). In addition, cloud-based applications are often distributed and consist of multiple components. Sometimes, application components are provided separately over multiple clouds, by Pop et al. (2016) and Martino (2014). Thus, the latency is increased due to the overhead introduced by inter-cloud communications. In addition, data processing might be necessary at locations where a cloud provider may have no data center.

Fog computing is a computing paradigm introduced as the extension of cloud computing architecture to the edge of the network, with the aim to mitigate the above-mentioned challenges. With fog, the latency-sensitive application can be processed at the edge of the network, near end devices, while delay-tolerant and computational intensive components can be processed in the cloud. Therefore, the greatest advantage of fog computing is low latency, provided by enabling data processing at specific locations at the network edge, i.e. at fog nodes. Densely-distributed points for gathering data generated by the end devices are also provided. Furthermore, cloud computing is not viable for most of the Internet of Things (IoT) applications and fog computing can be a promising alternative. However, it should be emphasized that fog computing is beyond IoT and comprises other aspects of communication, such as content provisioning.

Fog computing is considered as a promising solution to support the tasks with bandwidth, latency and reliability constraints. There is a full potential to fulfill a wide adoption of fog computing in various applications, ranging from smart cities, transportation, surveillance, healthcare and agriculture and military to large-scale industries. In this paper, the possibilities of fog computing application in logistics systems are presented.

The paper is organized as follows. After the introductory remarks, Section 2 provides an insight into the concept of fog computing, the architecture and differences compared to cloud computing. In Section 3, the possibilities of fog computing deployment in logistics systems are observed. Some open research issues in fog computing are presented in Section 4. Concluding remarks are given in Section 5.

2. KEY CHARACTERISTICS OF FOG COMPUTING

Fog computing is introduced in order to support geographically distributed, latency sensitive and Quality of Service (QoS)-aware applications. The concept is first initiated by Cisco (2014), with the aim of extending cloud computing to the edge of a network. The term *fog* refers to as *the cloud close to the ground*, i.e. *From cOre to edGe computing*. It is a highly virtualized platform providing computing, storage, and networking services between end users and cloud data centers.

The main fog capabilities include security, cognition, agility, latency and efficiency, according to OpenFog (2017). Fog computing is characterized by low latency and location awareness, heterogeneity, end device mobility, provides wireless access, capacity for processing numerous nodes, supports geographic distribution and real-time applications, according to Mukherjee et al. (2018). Numerous geo-distributed devices, such as end user devices, routers, switches and access points, are placed at the edge of the network. Their management is performed in a distributed manner. The aim of fog computing is to avoid upload/download data to/from the core network, using the edge devices which are in proximity. Edge devices in fog computing can release some of their resources to support the demands of their neighboring devices. Only the task that is not possible to be provided by the edge device is sent to the core cloud resources for further processing.

2.1 Definitions of fog computing

There are several definitions of fog computing. According to Vaquero and Rodero-Merino (2014), fog computing represents a concept for enabling communication and cooperation between heterogeneous (wireless and potentially autonomous) ubiquitous and decentralized devices, and between devices and the network, in order to satisfy processing and storage requests, without third party's involvement. OpenFog Consortium in OpenFog (2017) defines fog computing as "a system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along the continuum from cloud to Things". According to IBM (2016), fog computing and edge computing can be considered as the same computing paradigm, that enables placing some processes and resources at the edge of the cloud, instead of establishing channels for cloud storage and utilization. In Naha et al. (2018), fog computing is defined as a distributed computing platform where virtualized and non-virtualized end or edge devices perform most of the processing. Fog computing is also associated with the cloud for non-latency-aware processing and long-term storage of useful data. This definition considers all devices with computing and storage capacity as fog devices and identifies the role of the cloud in the fog computing environment.

2.2 Architecture of fog computing

The architecture of fog computing can be presented as the hierarchical structure, according to Sarkar et al. (2018). This structure can be illustrated as shown in Figure 1.

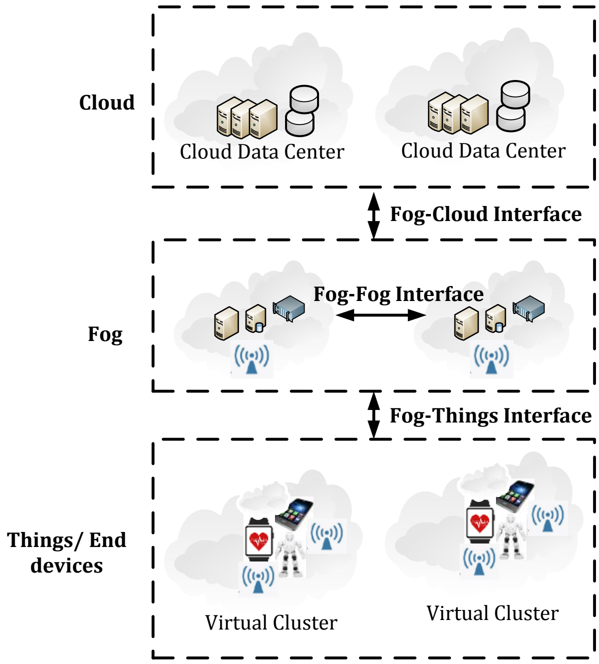

Figure 1. The three-tier fog computing architecture

The first tier comprises end devices, IoT enabled devices including sensor nodes, smart devices, etc. These end devices can also be referred to as Terminal Nodes (TN). The second tier represents the fog computing layer. The fog nodes in this layer are routers, gateways, switches, etc. These fog nodes can share storage and computing resources. The third tier is the cloud layer, and consists of cloud data centers, providing sufficient storage and computing resources.

The architecture of fog computing can also be presented as the layered structure, by Aazam and Huh (2016). The layered architecture consists of the following layers: physical and virtualization layer, monitoring layer, preprocessing layer, temporary storage layer, security layer and transport layer. Physical TNs and virtual sensor nodes are placed in the physical and virtualization layer. The energy consumption of underlying physical devices and provisioning of requested tasks is analyzed by the monitoring layer. Data filtering, data trimming and other data management related tasks are performed in the preprocessing layer. The temporary storage layer is in charge of storing the data only for a limited time. The security-related issues are managed in the security layer. Data transmission to the cloud is performed in the transport layer.

2.3 Difference between fog and cloud computing

Fog computing and cloud computing are interdependent in terms of providing storage and computational resources. However, they are different computing paradigms. The main differences are summarized in Table 1. Fog computing extends storage and computational resources, communication and networking provided by cloud computing near to end devices. Hence, fog is a promising solution for resource-constant devices. Due to high latency, real-time interactions are not possible for the cloud. In fog computing, end-to-end latency is significantly reduced. However, the reliability in service provisioning is higher in the case of cloud computing.

Table 1. Comparison of cloud computing and fog computing

Feature	Cloud computing	Fog computing
Management	Centralized	Distributed fog nodes can be controlled in both centralized and decentralized manner
Size	Very large cloud data centers	A large number of small fog nodes
Latency	High	Low
Resource optimization	Global	Local
Access	Fixed and Wireless	Mostly wireless
Mobility	Low	High
Computation capacity	Very high	Low
Scalability	Average	High
Application type	Non-latency-aware	Latency-aware
Nature of failure	Predictable	Highly-diverse
Deployment costs	High	Low

Furthermore, cloud computing aims at overall resources optimization, while fog computing includes local resources allocation and management. However, fog computing enhances overall system efficiency. The rate of failure in the fog is high, due to dominant wireless connectivity and decentralized management. It should be noted that fog cannot replace cloud computing. Both technologies contribute differently to performances improvement.

2.4 Comparison with similar paradigms and technologies

Fog computing deploys computing resources near underlying networks, located between cloud resources and edge devices, in order to provide more efficient service and application provisioning. There are several similar computing paradigms, such as Mobile Cloud Computing (MCC), Mobile-Edge Computing (MEC) and Edge Computing (EC). These technologies do not exclusively depend on cloud resources.

Remote provisioning of mobile services can be performed with the support of MCC near end devices, in accordance with Sanaei et al. (2014). MCC can overcome computational and storage limitations of resources of smart mobile devices. It is a mobile computing technology, providing unrestricted functionality, mobility and storage through heterogeneous network connectivity. It is expected that MCC will be implemented in education, urban and rural development, healthcare, applications such as augmented reality, etc. Mobile computing requires essential changes to cloud computing, including a low-latency middle tier, infrastructure optimization for mobile applications and introduction of mobile cloud services.

The co-location of computing and storage resources at the base stations of cellular networks is enabled in MEC, by Naha et al. (2018). In addition, MEC can be connected or disconnected to cloud infrastructure in a remote location. Therefore, the architecture of MEC can be two or three-tier. In such an environment, a MEC server should be deployed near base station towers, in order to provide data processing and storage at the edge of the network. The participants in this environment are the following: mobile end users, network operators, Internet infrastructure provider and application service provider. Mobile end users require service provisioning. Network operators are in charge of management and maintenance of the base station operation, mobile core network, and MEC servers. Internet infrastructure providers enable connectivity to the Internet, while application service providers host the application servers in the Content Delivery Network (CDN) or within data centers. End users' requests are being served by the closest MEC, instead of forwarding it to remote Internet services. If it is not possible to serve the request at the MEC server, remote CDN or data center will serve the given request.

Edge computing deploys edge devices or edge servers to provide computation facilities. Generally, edge computing is more focused on the IoT devices, and less on cloud-based services, by Shi et al. (2016). The aim of edge computing is to provide computation facilities at a closer location to the data sources. Edge nodes perform data storage and processing. The edge device can also to distribute requests for service provisioning and provide service on behalf of the cloud to the end users. In such a situation, edge devices need to satisfy numerous requirements, including privacy, reliability and security.

3. POSSIBILITIES OF FOG COMPUTING APPLICATION IN LOGISTICS SYSTEMS

With the advancements in the technology and the appearance of Industry 4.0, the whole logistics process, from storing to shipping products, can be performed using intelligent technologies, with no manpower needed. Advances in the Internet of Things, robots and drones also reduce the need for manpower in logistics systems. Therefore, the efficiency in logistics procedures is significantly improved. In this Section, the possibilities of fog computing application in an intelligent logistics center and supply chain management are described.

3.1 Fog computing application in an intelligent logistics center

An intelligent logistics center can be described by Lin and Yang (2018). Suppliers' trucks deliver cargos to the receiving area. Once cargos are uploaded, they are moved by mobile robots to the warehousing space through Radio Frequency Identification (RFID) door, in order to confirm the quantity of cargos from each supplier. Robots can classify cargos and shift them to a warehouse space, and concurrently update data of inventories of the space in the given system. In addition, robots can extract the required products from the warehouse space, and move them to the picking area depending on the received customer orders. The best routing path is selected by each robot. Thus, the collisions between robots are avoided. Once receiving a task of picking a product, a robot can perform the delivery of the required product to a workstation. Afterwards, the product is picked up and placed to the conveyor. Along a conveyer, the product is posted by a tag and then moved to the sorting area. Using RFID sensing doors, the amount of products is confirmed. After sorting, products are moved to the shipping area, where robots move them to the trucks which deliver products to customers.

In observed intelligent logistics center, cloud resources are located and managed in a centralized manner. If the factory area is too large, latency is significantly increased in communication between numerous IoT sensors and centralized cloud. Distributed fog computing can be a promising solution for high latency in the system with thousands of IoT devices in a centralized cloud computing system. A part of the computing tasks for operations in the logistics center can be finished using only local information from nearby fog computing resources, instead of from the centralized cloud. Thus, tasks can be finished flexibly and more efficiently. Furthermore, fog computing implementation and integration with the IoT environment can lead to reductions in power consumption for over 40%, according to Sakar and Misra (2016).

An intelligent computing system in a logistics center consists of a cloud center, gateways, fog devices, edge devices, sensing devices, automated guided vehicles (AGV), robots, machines, etc. Usually, locations of the cloud center and sensing devices are fixed. Some sensing devices are mobile, however, their movements are constrained. The deployment of gateways, fog and edge devices in the logistics center differs from other deployment applications. For example, the deployment of fog computing in vehicular networks or smart cities is of large scope and open space, while the deployment in logistics center is performed in a relatively small scope and in closed space. Compared to some production factories with the harsh environment (such as refineries and nuclear power plants), where all devices may be restricted to the harsh environment, in logistics center deployment only placements, package, and delivery of products are concerned.

The framework of a computing system that can be deployed in a logistics center is shown in Figure 2. It consists of a cloud computing center, gateways, fog devices, edge devices and sensing devices.

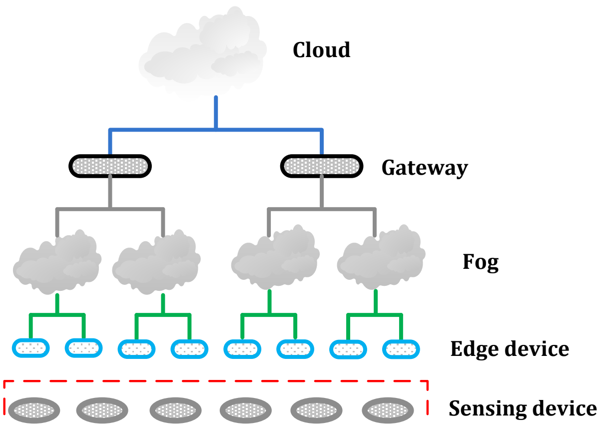

Figure 2. The architecture of fog computing in a logistics center

The cloud center provides the access to physical and virtual resources in different deployment models, such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). The gateway connects incompatible network facilities. Fog device collects data from extreme edges and transmits data to the cloud center through gateways. Edge devices are deployed close to physical machines, conveyor and warehouses in the logistics center. Thus, decisions based on local information can be determined locally, without the involvement of cloud computing. It is important to emphasize that edge computing devices are deployed on terminal facilities or sensors, while fog computing devices are deployed on the data center nodes within a certain region. Additionally, the main function of edge devices is to respond to requests of terminal facilities, while fog devices extend cloud services to network edges. Sensing devices in the logistics center aim at monitoring boy shuttles, AGVs and robots. In the computing system deployed in a logistics center, edge devices are used for data transmission to fog devices and provide AGVs real-time information about trajectories of other AGVs. Afterwards, fog devices temporarily store and process the data, send determined decision back to AGVs and forwards the data to cloud center for historical analysis and long-run storage.

3.2 Fog computing deployment in a supply chain management

Supply chain comprises the sequence of organizations involved in the different processes and activities that produce value in the form of products and services. Supply chain management consists of several phases: planning, implementing and controlling the operations of the supply chain. Global supply chain scenarios are characterized by massive amounts of data collected for processing from numerous geographically dense endpoints. Storing and analyzing data in a centralized, remote data center is not optimal due to several reasons. Foremost, the data volume generated by devices may exceed the network bandwidth. This may result in delays. Data transmission to a remote cloud data center may introduce an unacceptable delay for latency-sensitive applications, especially in situations when a real-time response is required (for instance, automatically alerting the shipping manager if the critical value of the observed parameter is exceeded). In addition, retailers in a highly competitive market need to provide their customers with the possibility to buy anywhere, receive anywhere, and return anywhere. This requires the ability, in real-time, to locate and allocate available inventory from any location, such as a store, distribution center, in transit, or on order from the manufacturer. Network and compute resources need to be configured in a more suitable architecture, where computing facilities are split between local sites (for temporary data storage and processing) and the cloud (where the data is further analyzed and stored). Therefore, fog computing is a promising computing paradigm for supporting supply chain management, according to Musa and Vidyasankar (2017).

Tracking and monitoring the environmental conditions from the field to retailer can help the producer, distribution manager and retailer to calculate the remaining shelf time and to identify potential quality issues. A fog computing framework for supply chain management comprises three layers.

Layer 0 represents data producers, including RFID embedded sensors and other sensing devices. Data generated in this stage are related to different environmental parameters measured by the sensors, temperature, humidity, internal and/or external pressure, light exposure, etc.

Layer 1 represents monitoring and control layer. Control logic is executed through analysis of the sensor readings, which comprises computing alarms and generating events, which may trigger workflows through machine-to-machine or human intervention. Fog devices include active or smart readers and trucks as a mobile fog node. These readers are installed in the field, truck, dock doors and the retail display unit. Smart readers have the ability to store and forward data at specified intervals when the network connection is poor, to support business intelligence within the reader and the ability to be configured in order to provide alerts and notifications if a device fails. All sensor readings aggregated by the fog node are filtered and stored in a temporary buffer. A smart reader can serve as a processing hub, and the first processing stage of the system is performed by this layer. Truck as a mobile fog node consists of RFID tags, smart readers, Onboard Decision Support Unit (ODSU) and Event Notification Unit (ENU). The ODSU receives filtered sensor measurements from the smart reader and matches them against the critical values of the observed parameters. When the critical values are exceeded, the ODSU triggers an alarm and corrective actions or automatic adjustments are performed. The ENU manager is triggered by the ODSU after corrective actions are being performed. The ENU unit sends alerts to the distribution/warehouse manager and the driver.

Layer 2 represents cloud data centers. The main task of this layer is to store and analyze the entire history of the supply chain operations. This layer is in charge of determining the amount of product to be delivered to downstream retail stores/distribution centers and for providing optimal routes at each level of the supply chain.

4. OPEN ISSUES IN FOG COMPUTING

Fog computing is an evolving technology with the possibility to achieve wide adoption in many applications, including logistics systems. Despite its numerous advantages, there are some open challenges.

Since the number of connected devices is excessively increased, the number of levels in the fog layer may cause latency problems. Therefore, the number of tiers in a fog computing architecture must be determined. Deployment decisions are based depending on requirements related to the amount of task provided by each tier, the total number of sensing devices, the capability of each fog node and reliability of fog devices. Application and resource allocation is also an important segment of fog computing deployment.

Due to the diversity of devices and their available resources, fog computing is characterized by the dynamic and heterogeneous environment. Resource allocation and scheduling in the fog computing is more challenging in comparison with resource allocation and scheduling in cloud computing since fog uses idle resources available on any fog device. Therefore, the improvement of available resources prediction on each fog device is another important issue to be solved.

Fog devices' failure may occur due to hardware failure, software failure, end user' activity, or due to problems with connectivity, mobility or power source. Since the management of the devices is decentralized, and devices are mostly mobile, the probability of the failure is high. In order to satisfy the requirements of time-sensitive applications, it is necessary to ensure the uninterrupted connection between devices. The connection type and protocols used by different devices need to be coordinated, which is also an important research issue. A standard form of communication protocol is necessary so that generic applications can communicate and operate with different types of fog devices.

5. CONCLUSION

Fog computing is an emerging computing paradigm that attracts a lot of research attention since it supports latency-sensitive applications with low traffic congestion, low energy consumption and minimum bandwidth. It extends the computation, communication and storage facilities from cloud data centers to the edge of the network. Additionally, fog supports virtualization and represents a complementary technology to cloud computing. In this paper, the key characteristics of fog computing are indicated. The comparison with cloud computing, as the complementary technology, is provided. In addition, some similar computing paradigms are described and the comparison with fog computing is analyzed. The paper also analyzes the possibility of fog computing deployment in logistics systems, with the special emphasize on fog computing deployment in an intelligent logistics center and a fog computing framework for the supply chain management. In logistics systems, the deployment of fog computing can improve energy efficiency, reduce latency, reduce costs and supports mobility. Furthermore, the advanced automation of the manufacturing systems is enabled. Fog computing in logistics systems also contributes to the improvement of product quality, production efficiency, condition monitoring and decision making. Although fog computing has great potential to achieve wide adoption, it is still an emerging computing paradigm. Some research challenges and open issues are presented in the paper.

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