PERFORMANCE MODELING AND SUITABILITY ASSESSMENT OF DATA CENTER BASED ON FOG COMPUTING IN SMART SYSTEMS

Seminar Report

Submitted in partial fulfillment of the requirements for the award of degree of

BACHELOR OF TECHNOLOGY

In

COMPUTER SCIENCE AND ENGINEERING

of

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

Submitted By

INDHU PREETHA

Department of Computer Science & Engineering
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CERTIFICATE

This is to certify that the report entitled **Performance Modeling And Suitability Assessment Of Data Center Based On Fog Computing In Smart Systems** *submitted by* Ms.**INDHU PREETHA**, Reg. No. **MAC15CS030** *towards partial fulfillment of the requirement for the award of Degree of Bachelor of Technology in Computer science and Engineering from APJ Abdul Kalam Technological University for December 2018 is a bonafide record of the seminar carried out by her under our supervision and guidance.*

....	....	....
Prof. Joby George	**Prof. Neethu Subash**	**Dr. Surekha Mariam Varghese**
Faculty Guide	***Faculty Guide***	***Head of the Department***

Date: Dept. Seal

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ABSTRACT

Fog computing, also known as fogging, is an architecture that uses devices to carry out a substantial amount of computation, storage, communication locally and routed over the internet backbone. Initially cloud computing played a vital role in processing data and its storage. The huge data flow of IoT devices paved the way to Fog computing. It offers location-aware, latency-sensitive monitoring and intelligent control for IoT applications in the smart systems like smart home or smart grid. It extends the existing cloud computing system. A network model is proposed to show the better change in data storage and analysis of new proposed computing. The application of fog computing in smart patient monitoring and connected vehicles. It is verified that new architecture has a great improvement in terms of service latency, real time performance and bandwidth consumption in smart systems.

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LIST OF ABBREVIATION

FC	Fibre Channel
ISCSI	Internet Small Computer System Interface
NAS	Network Attached System
QOE	Quality Of Experience
QOS	Quality Of Service
UEM	User Expectation Metrics
VM	Virtual Machine
VMM	Virtual Machine Monitor

Introduction

In human-centered smart systems, traditional cloud computing has been well adopted for several years for supporting IoT applications of smart systems, however, the requirements of the IoT applications vary due to different tasks in the smart systems. In order to offer location-aware, latency-sensitive monitoring, and intelligent control for IoT applications in the smart systems like smart home or smart grid, we introduce fog computing and discuss the combination of fog computing and data center hoping to improve the quality of experience of users in human-centered smart systems. In this paper, we propose a three-layer architecture of the data center by introducing the fog computing layer between the traditional centralized data center and terminal nodes. Performance related service latency of different cloud services is modeled and evaluated based on it. It is verified that the new architecture has a great improvement in terms of service latency and network load by simulation experiments.

Internet of Things (IoT) applications have been deployed in human-centered smart system to enable efficient perception and monitoring of the smart systems like smart home or smart grid.The IoT applications in the smart systems could be used for many aspects of smart systems like monitoring the human health,smoke and fire, baby web cam of smart home,or monitoring the power transmission line, the substation, managing electric vehicle charging/discharging, user information collection in smart grid. Due to the increasing number of IoT nodes in the smart systems, e.g, smoke detector, heart pressure monitor, smart meters, phasor measurement units, etc, The traditional cloud data center computing paradigm is not able to meet the requirements of IoT applications in the smart systems.The smart systems require the IoT applications to have high bandwidth, low latency and location-awareness, especially for data center. Three-layer architecture of the data center by introducing the fog computing layer between the traditional centralized data center and terminal nodes. Fog computing was proposed by Cisco to extend the cloud computing paradigm to run distributed applications. As part of cloud computing, fog computing not only deals with latency-sensitive applications at the edge of a network, but also deals with latency-tolerant tasks with more power computing nodes in the middle of a network of smart grid.In the upper layer of a fog, cloud computing supported by powerful data centers can be applied for further processing.Centralized data center can improve the utilization rate of IT software and hardware resources, reduce the overall construction, operation and maintenance costs, and meet the needs of continuous and rapid adjustment to improve controllable capacity

In recent years, with the increase of the amount and type terminal, the cloud - terminal double centralized data center architecture is facing the following problem:

1. Latency of some real time applications cannot be guaranteed
2. The increase of traffic in the data center leads to the saturation of the core network bandwidth capacity
3. After centralized deployment of data center, server capacity of some data center is idle.

In human-centered smart systems, traditional cloud computing has been well adopted for several years for supporting IoT applications of smart systems, however, the requirements of the IoT applications vary due to different tasks in the smart systems. In order to offer location-aware, latency-sensitive monitoring, and intelligent control for IoT applications in the smart systems like smart home or smart grid, we introduce fog computing and discuss the combination of fog computing and data center hoping to improve the quality of experience of users in human-centered smart systems. In this paper, we propose a three-layer architecture of the data center by introducing the fog computing layer between the traditional centralized data center and terminal nodes. Performance related service latency of different cloud services is modeled and evaluated based on it. It is verified that the new architecture has a great improvement in terms of service latency and network load by simulation experiments.

The goal of fogging is to improve efficiency and reduce the amount of data transported to the cloud for processing, analysis and storage. This is often done to improve efficiency, though it may also be used for security and compliance reasons.

Contributions:The integration of fog computing with the IoT creates a new opportunity for services, which is called fog as a service (FaaS), where a service provider builds an array of fog nodes across its geographic footprint and acts as a landlord to many tenants from many vertical markets. Each fog node hosts local computation, networking and storage capabilities.FaaS will enable new business models to deliver services to customers. Unlike clouds, which are mostly operated by large companies who can afford to build and operate huge data centers, FaaS will enable big and small companies to deploy and operate private or public computing, storage and control services at different scales to meet the needs of a wide variety of customers.The purpose of fog computing in the IoT is to improve efficiency, performance and reduce the amount of data transferred to the cloud for processing, analysis and storage. Therefore, the data collected by sensors will be sent to network edge devices for processing and temporary storage, instead of sending them into the cloud, thus reducing network traffic and latency.The contribution of this work as follows.

- Discussing recent articles which investigate the integration of fog computing with different IoT applications.Three-layer architecture of the data center by introducing the fog computing layer between the traditional centralized data center and terminal nodes is introduced.

- IoT challenges and how they will be resolved by integrating the IoT with fog computing.Performance of different cloud services is modeled and evaluated based on it.Providing various IoT applications that benefit from the integration of the fog with the IoT.

- Discussing future research directions regarding fog computing and the IoT.It is verified that the new architecture has a great improvement in terms of service latency and network load in simulation experiments.

Proposed system

The hierarchical architecture is different to the two-tier architecture of the centralized data center. The fog based data center adds a fog computing layer between the terminal access layer and the cloud data center layer to form a bottom-up three-tier architecture.Overview of the proposed architecture is shown in Fig.2.1 depicts the Bottom-up three-tier architecture.

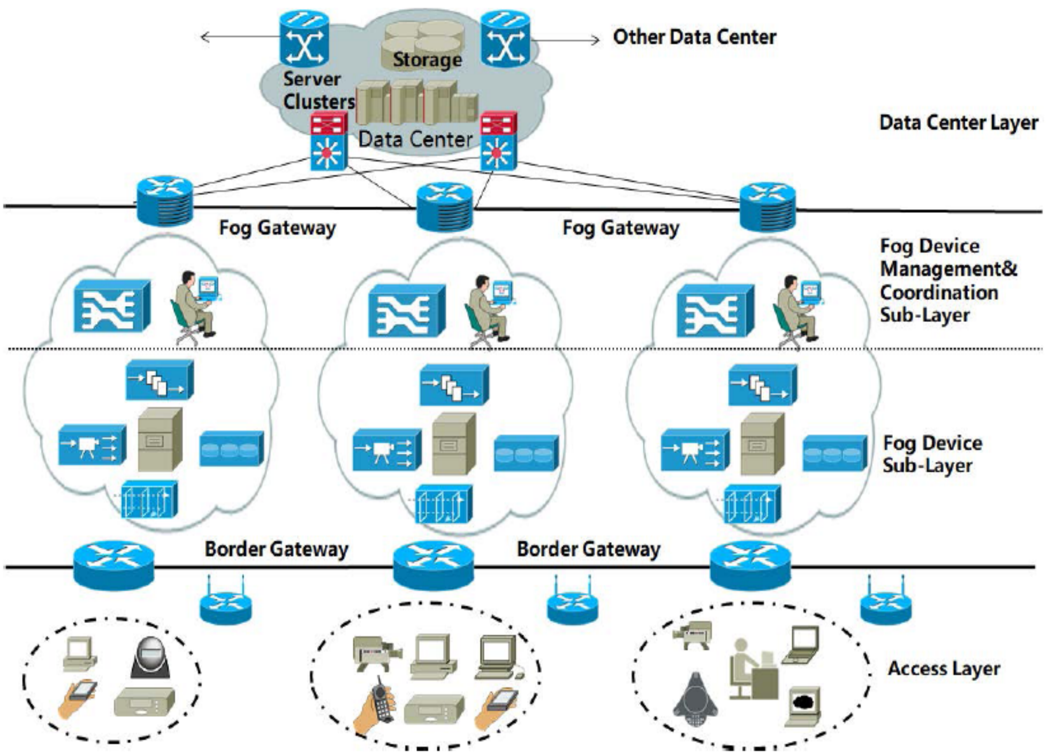


Fig. 2.1: Hierarchical architecture of data center based on fog computing.

2.1 Terminal access layer

Terminal access layer includes the service terminals, the multi-source heterogeneous access of the of terminals. The service requests from the terminals are sent to the new fog computing layer through the edge gateway.Compared to peer-to-peer (P2P) networks in the mid2000s, Fog is not just about content sharing (or data plane as a whole), but also network measurement, network management, service enablement, and real-time control of cyber-physical systems.

2.2 Cloud data center layer

Cloud data center layer is composed of high-performance server clusters and storage equipments. For those serivce requests that require storage and complicated computation of historical data, the data center servers will use cloud computing mode to store and analyze data. As shown in Figure 2.2, fog computing acts as an intermediary between the cloud and end devices which brings processing, storage and networking services closer to the end devices.

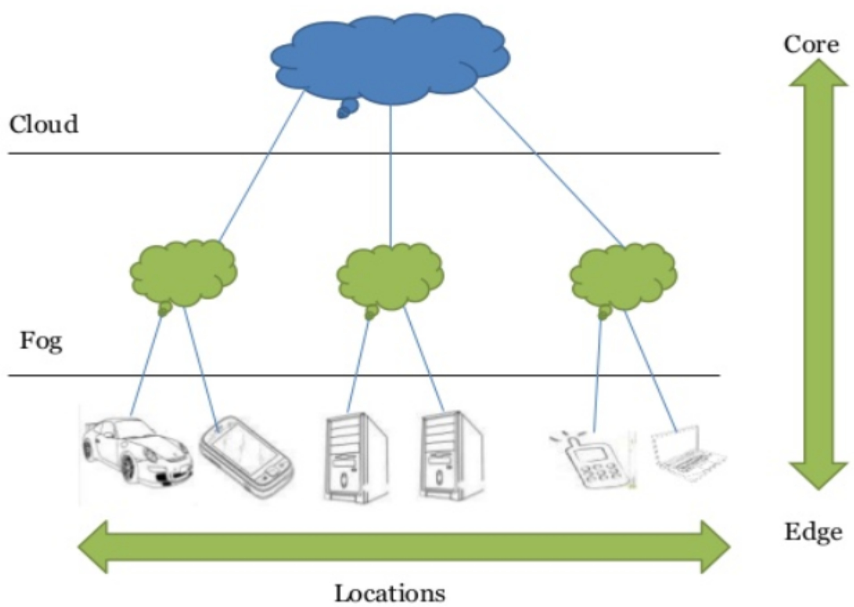


Fig. 2.2: Fog computing is an extension of the cloud but closer to end devices.

2.3 Fog computing layer

Fog computing layer comprises of fog computing devices with network processing and storage capacity, which can timely respond to the service requests from users with strict latency requirements. In addition, the fog computing equipment also serves as terminal data compression, redundancy, desensitization and other operations to improve the transmission efciency of backbone communication links and ensure the privacy of users data. Fog computing layer can be further subdivided into the fog device sub-layer and the fog device management and coordination sub-layer according to its function [1].

- Fog device sub-layer: includes fog computing devices with the capability of network, calculation and storage, which can calculate, store and process the requests of latency sensitive services from the terminals and then return the processing results in time. At the same time, some computationally intensive requests or service data requiring semi-permanent or permanent storage can be compressed, redundancy-eliminated and desensitized under the control of the fog device management and coordination sub-layer. Thereafter, all the data processing results will be sent to data center for further storage and processing.
- Fog device management and coordination sub-layer: mainly monitors the ability of fog equipment, the usage of resources and the state information in real time so as to improve the extensibility and fault tolerance of the smart system. When complicated service processing requires to be carried out between multiple fog computing devices of this layer and data centers, service routing will be worked out according to the information obtained previously to meet the requirements of service processing logic and QoS etc. The fog equipment management and coordination sub-layer includes a device management server, an application image management server and a complicated services orchestration server etc.

The Network equipment of fog computing layer is divided into border gateway devices and fog gateway devices according to its service entity. The border gateway devices are used to transmit data between the terminals and fog layer devices, while the fog gateway devices serve as the data transmission between fog computing layer and data center layer.

Fog architecture will allow the same application to run anywhere, reducing the need for specialized applications dedicated just for the Cloud, just for the endpoints, or just for the edge devices. It will enable applications from different suppliers to run on the same physical platform without mutual interference. It will provide a common lifecycle management framework for all applications, offering capabilities for composing, configuring, dispatching, activating and deactivating, adding and removing, and updating applications. It will further provide a secure execution environment for Fog services and applications. Fog will with integrate with Cloud to enable seamless end-to-end services.

It describes an emerging era of technology world from traditional cloud computing towards nearly deployed fog computing. It is also visualized that which type of interface is also included in diferent type of era (e.g., fog to cloud, fog to fog, and fog to IoT).Architectural development of computing with a resource pool where one or more ubiquitous and decentralized nodes are enabled for potentially cooperating and communicating with each other or in group transmission exclusively at the extreme edge level, rather than backed by cloud processing.

Fog computing (FC) is an emerging distributed computing platform aimed at bringing computation close to its data sources, which can reduce the latency and cost of delivering data to a remote cloud. This feature and related advantages are desirable for many Internet-of-Things applications, especially latency sensitive and mission intensive services. With comparisons to other computing technologies, the definition and architecture of FC are presented in this paper. The framework of resource allocation for latency reduction combined with reliability, fault tolerance, privacy, and underlying optimization problems are also discussed. We then investigate an application scenario and conduct resource optimization by formulating the optimization problem and solving it via a genetic algorithm. The resulting analysis generates some important insights on the scalability of the systems.Fog computing extends computing to the edge of a network, which has a perfect match to IoT applications. However, existing schemes can hardly satisfy the distributed coordination within fog computing nodes in the smart grid. In the proposed model, we introduce a new distributed fog computing coordinator, which periodically gathers information of fog computing nodes.

Related works

The amount of computation should be moved to centralized data centers in the architecture of new data center based on fog. In addition, some service data that require long-term storage should also be stored in centralized data centers for medium and long-term trend analysis. At the same time, using some obsolete server equipments to build a fog computing layer will serve the users of smart home or smart grid etc. Some of the service requests from user terminals will be quickly responded to the fog computing equipment and thereby improve Quality of Experience (QoE) and efficiency of the backbone communication links to further support more terminal access.

3.1 Key technologies of architecture implementation

From the point of the technical implementation, due to the differences in capability, resources and hardware of fog computing equipments, it is necessary to provide the parameters to be managed and operated to the upper application program in the way of API interface, which can hide the heterogeneity of the underlying devices and improve the reusability of the program. The function of multiple application servers can be implemented on a single fog computing device by virtualization technology. The main current virtualization technologies include virtual machine technology like hypervisor, and container technology like Docker,which consider various factors such as application performance, security isolation, etc. It is suggested that the deployment and migration of application service should be based on container technology on the fog computing equipment with limited resources, while the application should be deployed in the form of virtual machine on the high-performance servers in the data center. Adopting anycast strategy that takes into consideration multiple factors (such as green energy, physical distance) can autonomously select application servers to meet the services capabilities, performance requirements, and other constraints.

In fig 3.1, the complex service orchestration server supporting any broadcast service is integrated with the upper layer of SDN control device so that the cloud and fog computing resources can be integrated to provide end-to-end service routing for users[2].

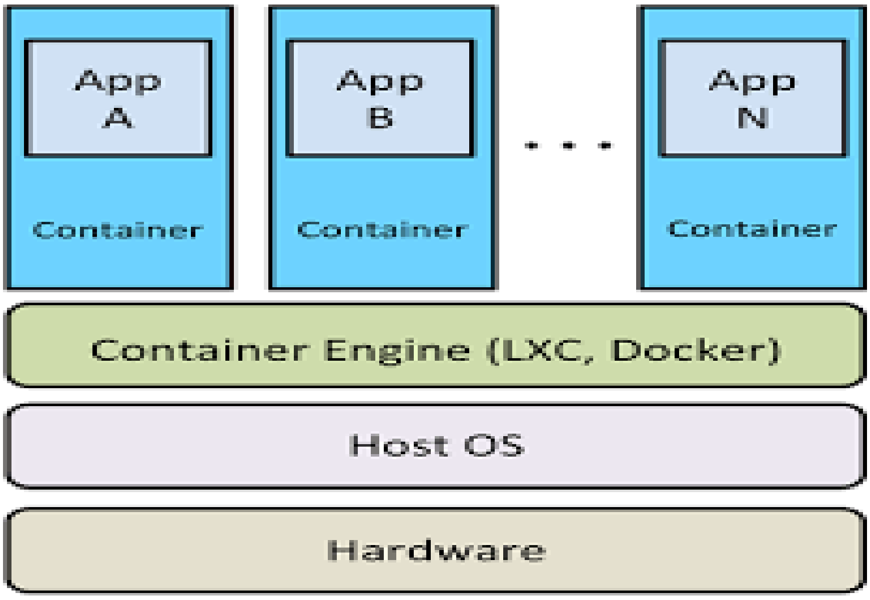


Fig. 3.1: Virtualisation in fog architecture

1. Hypervisor(Virtual Machine Monitor): It is a computer software generates and runs the virtual machine

2. Docker: It Deploys the applications inside application containers and run multiple process like Virtual machine

3.1.1 Network modelling

In network model, V is the set of network nodes and E is the set of links which connect the edge nodes from different layer.The terminal nodes could be divided into several terminal groups associated with the fog to which it is connected.

The new data center network model based on fog computing is shown in Fig 3.2,We describe it with the set G, that is G=V, E There are three types of nodes in the new data center network model,where VC, VF , VT corresponds to data center node ci of data center layer, fog computing node fi of fog computing layer and terminal node ti of terminal access layer respectively.

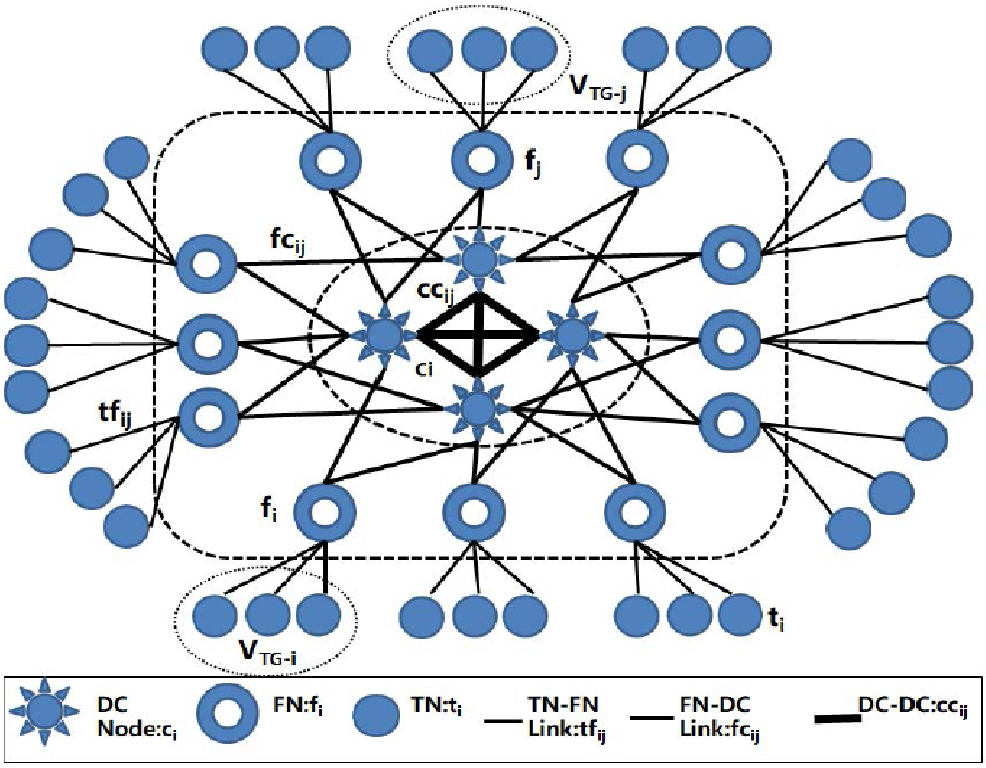
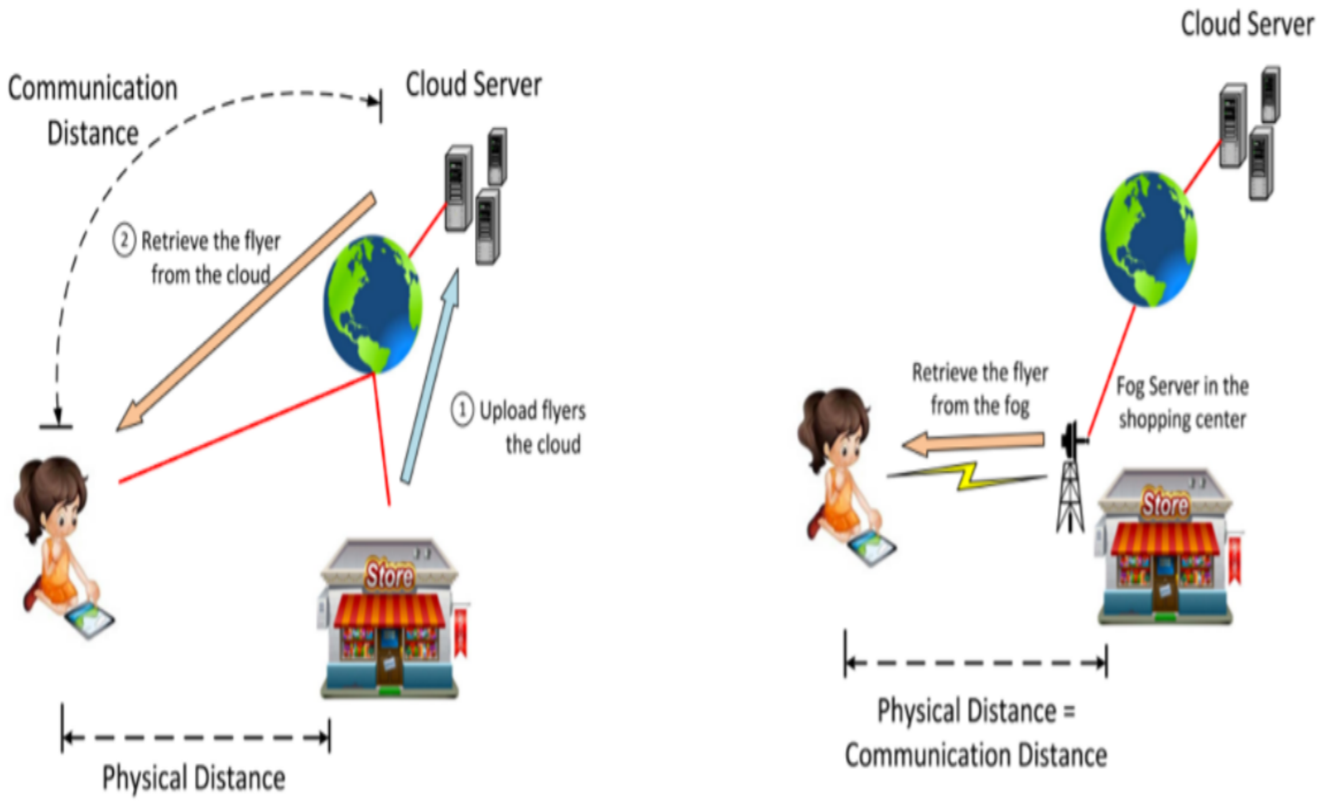


Fig. 3.2: Network modeling

According to general topology of the smart systems, the connection between nodes is not a fully connected or partially connected structure, but follows a bottom-up tree structure.For example, the service terminal ti is connected to the fog computing node fj via a single link tfij, and then connected to two remote data centers through two links that are mutually backed up. Data centers are connected directly through optical transmission networks. Considering the actual network situation and following modeling requirements, we assume that the link bandwidth of tfij and fcij is limited, while the bandwidth of ccij is not limited.

Fog computing was proposed by Cisco to extend the cloud computing paradigm to run distributed applications[3]. In fig3.3, as part of cloud computing, fog computing not only deals with latency-sensitive applications at the edge of a network, but also deals with latency-tolerant tasks with more power computing nodes in the middle of a network. In the upper layer of a fog, cloud computing supported by powerful data centers can be applied for further processing. As the representative of SS service, the field control applications carry on some processing and judgment based on the data uploaded into the database by the sensors. When the predefined threshold is exceeded, the control command is sent to the field equipment. Therefore, such applications require service latencies as small as possible.



(a) Retrieving the flyer from the cloud (b) Retrieving the flyer from the fog

Fig. 3.3: Performance modeling of fog nodes

Network load:Data compression in fog involves encoding information using fewer bits than the original representation. It implements lossless compression in which it reduces bits by identifying and eliminating statistical redundancy.

3.1.2 Characteristics 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 located at the edge of network.

IoT nodes are closer to the action, but for the moment, they do not have the computing and storage resources to perform analytics and machine learning tasks. Cloud servers,on the other hand, have the horsepower, but are too far away to process data and respond in time.

Geographical distribution: In contrast to the centralized cloud, the services and applications provided by the fog are distributed and can be deployed anywhere.

Location awareness and low latency: Fog computing supports location awareness in which fog nodes can be deployed in different locations. In addition, as the fog is closer to end devices, it provides lower latency when processing the data of end devices.

Scalability: There are large-scale sensor networks which monitor the surrounding environment. The fog provides distributed computing and storage resources which can work with such large-scale end devices.

Support for mobility: One of the important aspects of fog applications is the ability to connect directly to mobile devices and therefore enable mobility methods, such as locator ID separation protocol (LISP) which needs a distributed directory system.

Real-time interactions: Fog computing applications provide real-time interactions between fog nodes rather than the batch processing employed in the cloud. Heterogeneity in fog nodes or end devices are designed by different manufacturers and thus come in different forms and need to be deployed according to their platforms. The fog has the ability to work on different platforms.

Interoperability: Fog components can interoperate and work with different domains and across different service providers.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.

Efficiency: Pooling of local resources. There are typically hundreds of gigabytes sitting idle on tablets, laptops and set-top boxes in a household every evening, or across a table in a conference room, or among the passengers of a public transit system. Similarly, idle processing power, sensing ability and wireless connectivity within the edge may be pooled within a Fog network.

Agility: Rapid innovation and affordable scaling. It is usually much faster and cheaper to experiment with client and edge devices. Rather than waiting for vendors of large boxes inside the network to adopt an innovation, in the Fog world a small team may take advantages of smart phone Application programming interface and Software developer's kit, proliferation of mobile apps, and offer a networking service through its own API

Virtualisation: Software Defined Network separates the network

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.

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.

Support for on-line analytics and interplay with the cloud: The fog is placed between the cloud and end devices to play an important role in the absorption and processing of the data close to end devices.

3.1.3 Benefits of fog computing

Fog computing expands the cloud computing model to the edge of the network. Although the fog and the cloud use similar resources (networking, computing and storage) and share many of the same mechanisms and attributes (virtualization, multi-tenancy), fog computing brings many benefits for IOT devices.These benefits can be summarized as follows:

Greater business agility: With the use of the right tools, fog computing applications can be quickly developed and deployed. In addition, these applications can program the machine to work according to the customer needs,Low latencyin which the fog has the ability to support real-time services (e.g. gaming, video streaming).Geographical and large-scale distribution of fog computing can provide distributed computing and storage resources to large and widely distributed applications. Lower operating expense: Saving network bandwidth by processing selected data locally instead of sending them to the cloud for analysis.Flexibility and heterogeneity in computing allows the collaboration of different physical environments and infrastructures among multiple services.Scalability is the closeness of fog computing to end devices enables scaling the number of connected devices and services.

Fog networking consists of a control plane and a data plane. For example, on the data plane, fog computing enables computing services to reside at the edge of the network as opposed to servers in a data-center. Fog nodes provide localization, therefore enabling low latency and context awareness, but the Cloud provides global centralization[4]. 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.

3.2 Layered architecture of fog computing

Fog computing is an approach that takes some of a data centres operations to the edge of the network. The fog provides limited computing, storing and networking services in a distributed manner between end devices and the classic cloud computing data centres.

In fig3.4, the primary objective of fog computing is to provide low and predictable latency for time sensitive IoT applications

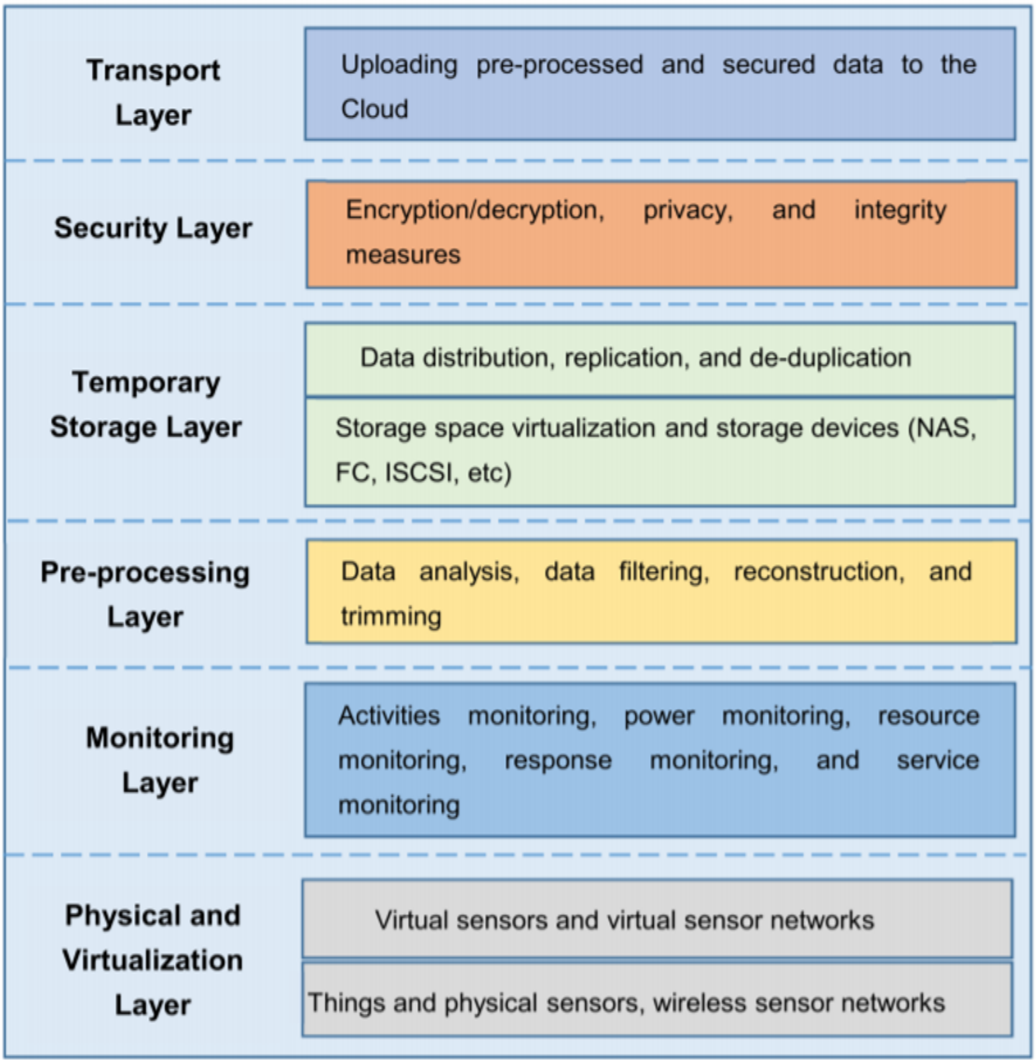


Fig. 3.4: Layered architecture of fog computing

The physical and virtualization layer involves different types of nodes such as physical nodes, virtual nodes and virtual sensor networks. These nodes are managed and maintained according to their types and service demands. Different types of sensors are distributed geographically to sense the surroundings and send the collected data to upper layers via gateways for further processing and filtering. While at the monitoring layer, resource utilization, the availability of sensors and fog nodes and network elements are monitored. All tasks performed by nodes are monitored in this layer, monitoring which node is performing what task, at what time and what will be required from it next. The performance and status of all applications and services deployed on the infrastructure are monitored. In addition, the energy consumption of fog nodes is monitored; since fog computing uses many devices with different levels of power consumption, energy management measures can be both timely and effective. The pre-processing layer performs data management tasks. Collected data are analyzed and data filtering and trimming are carried out in this layer to extract meaningful information. The pre-processed data are then stored temporarily in the temporary storage layer. When the data are transmitted to the cloud, they no longer need to be stored locally and may be removed from the temporary storage media. In the security layer, the encryption/decryption of data comes into play. In addition, integrity measures may be applied to the data to protect them from tampering. Finally, in the transport layer, the pre-processed data are uploaded to the cloud to allow the cloud to extract and create more useful services. For efficient power utilization, only a portion of collected data is uploaded to the cloud. In other words, the gateway device connecting the IoT to the cloud processes the data before sending them to the cloud. This type of gateway is called a smart gateway. Data collected from sensor networks and IoT devices are transferred through smart gateways to the cloud. The data received by the cloud is then stored and used to create services for users. Based on the limited resources of the fog, a communication protocol for fog computing needs to be efficient, lightweight and customizable. Therefore, choosing the communication protocol depends on the application scenario of the fog.

3.3 Fog computing with Internet of Things

The current centralized cloud computing architecture is facing severe challenges for IoT applications. For instance, it cannot support IoT time-sensitive applications such as video streaming, gaming and augmented reality. In addition, it lacks location awareness as it is a centralized model.Fog computing acts as a bridge between IoT devices and large-scale cloud computing and storage services. According to Cisco,fog computing is a part of the cloud computing paradigm that takes the cloud closer to the edge of the network. It provides a highly virtualized model of computation, storage and networking resources between end devices and classical cloud servers Fog computing is able to address these challenges.

Fog applications are as diverse as the Internet of Things itself. What they have in common is monitoring or analyzing real-time data from network-connected things and then initiating an action. The action can involve machine-to-machine communications or human-machine interaction. Examples include locking a door, changing equipment settings, applying the brakes on a train, zooming a video camera, opening a valve in response to a pressure reading, creating a bar chart, or sending an alert to a technician to make a preventive repair.

Efficiency: To increase the efficiency of IoT applications, most of the data generated by these IoT objects or devices must be processed and analyzed in real-time. Fog computing will bring cloud networking, computing and storage capabilities down to the edge of the network, which will address the real-time issue of IoT devices and provide secure and efficient IoT applications. Fog computing provides different services and applications with widely distributed deployments. The fog has the ability to provide efficient real-time communication between different IoT applications, such as connected vehicles, through the proxy and access points positioned according to long highways and tracks. Fog computing is considered to be the best choice for applications with low latency requirements such as video streaming, gaming, augmented reality, etc.

IoT requests in the local fog rather than involving the cloud. In the proposed reference architecture, central fog services are placed in a software-defined resource management layer .This provides a cloud-based middleware which prevents fog colonies from acting in an autonomous way. Instead, fog cells are analysed, orchestrated and monitored by the cloud-based middleware. Furthermore, F. Bonomi et al. investigated the integration of the IoT with fog computing by examining key aspects of fog computing and how the fog complements and extends cloud computing. In addition, they proposed an hierarchically-distributed architecture for the fog. To test the characteristics of their architecture, they provided use cases for a smart traffic light system and wind farm.

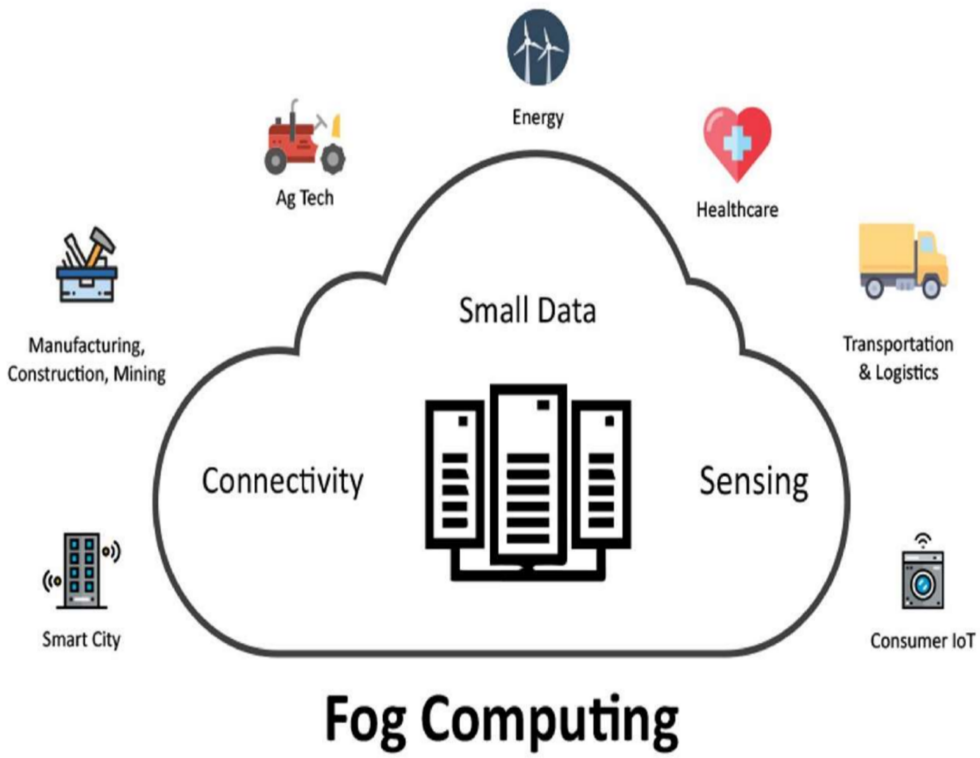


Fig. 3.5: Fog with Internet of Things

The integration of fog computing with the IoT will bring many benefits to various IoT applications. The fog supports real-time interactions between IoT devices to reduce latency, especially for time-sensitive IoT applications. In addition, one of the important features of fog computing is the ability to support large-scale sensor networks, which is a big problem with the ever-growing number of IoT devices, which will soon be counted in billions. Fog computing can provide many benefits to various IoT applications, as shown in Figure 3.5

Internet of Things (IoT) technology provides a competent and structured approach to handle service deliverance aspects of healthcare in terms of mobile health and remote patient monitoring. IoT generates an unprecedented amount of data that can be processed using cloud computing. But for realtime remote health monitoring applications, the delay caused by transferring data to the cloud and back to the application is unacceptable. Relative to this context, we proposed the remote patient health monitoring in smart homes by using the concept of fog computing at the smart gateway. The proposed model uses advanced techniques and services such as embedded data mining, distributed storage, and notification services at the edge of the network. Event triggering based data transmission methodology is adopted to process the patients real-time data at Fog Layer.

The fog extends the cloud to be closer to the things that produce and act on IoT data. These devices, called fog nodes, can be deployed anywhere with a network connection: on a factory floor, on top of a power pole, alongside a railway track, in a vehicle, or on an oil rig. Any device with computing, storage, and network connectivity can be a fog node. Examples include industrial controllers, switches, routers, embedded servers, and video surveillance cameras. IDC estimates that the amount of data analyzed on devices that are physically close to the Internet of Things is approaching 40 percent.There is good reason: analyzing IoT data close to where it is collected minimizes latency. It offloads gigabytes of network traffic from the core network, and it keeps sensitive data inside the network. Analyzing IoT data close to where it is collected minimizes latency. It offloads gigabytes of network traffic from the core network. And it keeps sensitive data inside the network.

A delay minimizing policy for fog nodes to minimize service delay for the IoT nodes. The proposed policy employs fog-to-fog communication to reduce service delay by sharing the load. For computation offloading, the policy considers not only queue lengths but also different request types that have a variety of processing times. The authors also developed an analytical model to evaluate the service delay in IoTfogcloud scenarios in detail and performed extensive simulation studies to support the model and the proposed policies. They evaluated the performance of their proposed platform using two use cases; one related to the reduction of received data and one dealing with filtering the data traffic according to sources.

3.4 System implementation

According to the typical network topology of smart systems, an experimental network is established as follows: three provider edge (PE) router nodes compose the core layer of the network in a fully connected manner. We devided the whole coverage area of smart systems into five regions. Two PE router nodes are deployed in each region in a convergence layer, which are responsible for the aggregation of user terminal data to the data center.

In fig3.6, Each PE router is connected to two core layer.

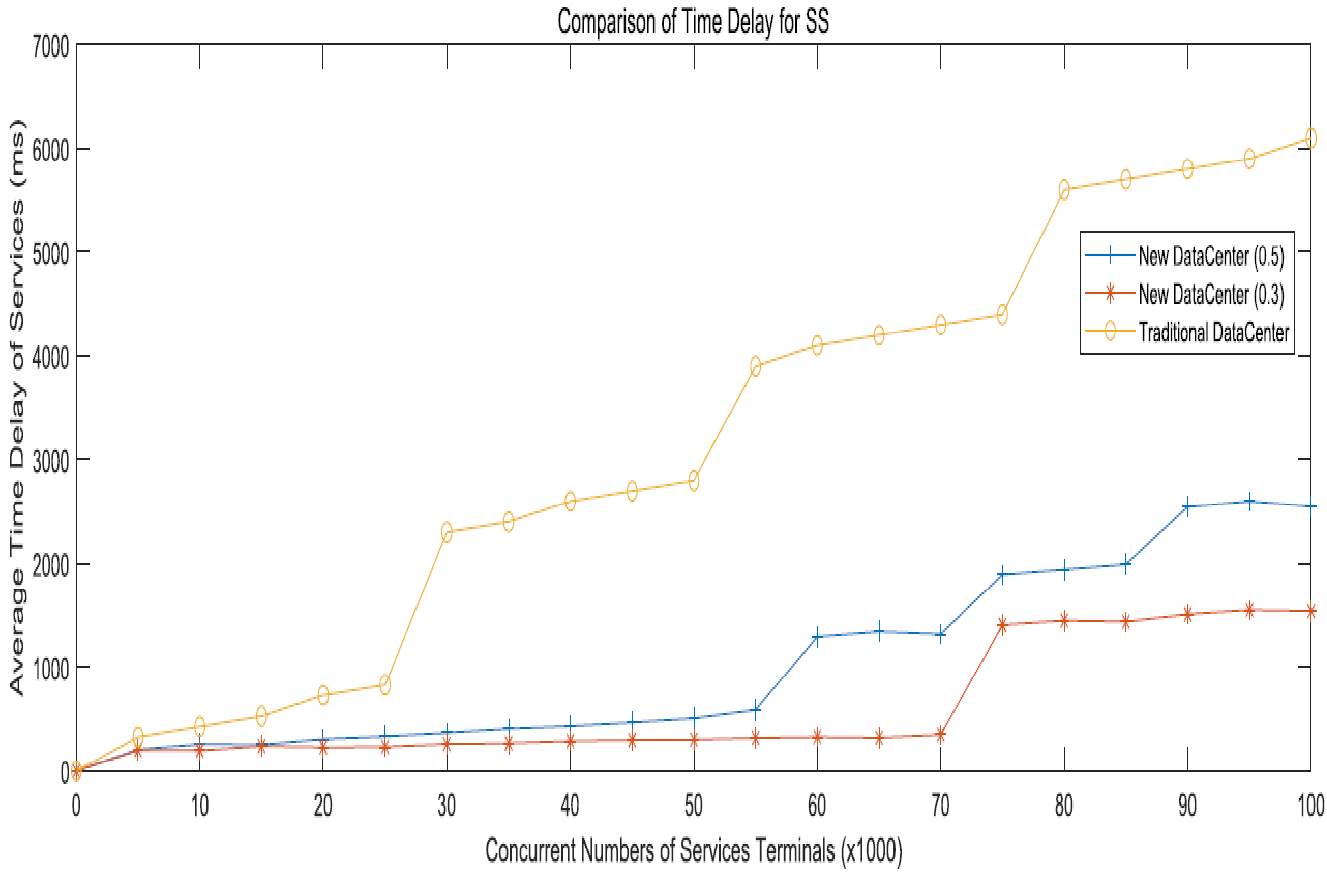


Fig. 3.6: Service latency and network load in Storage Devices

The overall network load comparison between the two data centers. Since more processing is carried out on the fog computing layer at the edge of the network, we can see that the overall network load is significantly improved. This improvement is further enhanced with the reduction of the compression coefficient.

Each PE router is connected to two core layer PE router nodes in an independent and bidirectional manner. Each region respectively deploys two PE router nodes to connect to two aggregation nodes in the region. The data center and user access terminals access the PE routers of the local area through the CE node to form the access layer. In order to ensure the reliability of connection, the data center generally adopts double CE connection. We use OMNeTCC as the simulation tool. Experimental network parameters are set as follows: the link bandwidth between all other network nodes is 1000Mbps except that the bandwidth on the CE node connected by the user terminals is 100Mbps.

On the other hand, the existence of multiple writers motivates the need for moderation of state updates.
STS and SS are the latency sensitive services, shows the comparison of service latency of STS in two data center network architectures, and the comparison of service latency of SS in two data center network architectures. In the simulation environment, the concurrency ratio is 0.1 and the fog computing server supports 100 concurrency users. The data center server supports the concurrency of 1000 users. The bandwidth requirements of each user in the two services are 1.5Kbps and 4Mbps, respectively. As we can see from the figures, compared with the traditional data center, the latency of the new data center with fog computing equipment has been significantly improved with the reduction of the compression coefficient.

We introduce fog computing and discuss the combination of fog computing and data center hoping to improve the quality of experience of users in human-centered smart systems.

The IoT has attracted the attention of both academia and commercial organizations. It is becoming an integral part of our lives. It has the ability to connect almost everything to everything else in our environment. IoT devices are dynamic in nature and have limited storage and processing capabilities. However, the traditional centralized cloud has many issues, such as high latency and network failure.With Fog services we are able to enhance the cloud experience by isolating users data that need to live on the edge. The main aim of the fog computing is to place the data close to the end user.

To overcome smart devices and Clouds limitations the new paradigm, known as Fog computing, has appeared, where an additional layer processes the data and sends the results to the Cloud. Despite numerous benefits Fog computing brings into IoT-based environments, the privacy and security issues remain the main challenge for its implementation. The reasons for integrating the IoT-based healthcare system and Fog computing, benefits and challenges.

3.5 Challenges and limitations

Although the fog computing paradigm offers many benefits for different IoT applications, it faces many challenges that stand in the way of its successful deployment. These challenges include scalability, complexity, dynamicity, heterogeneity, latency and security, as shown in Figure 3.7

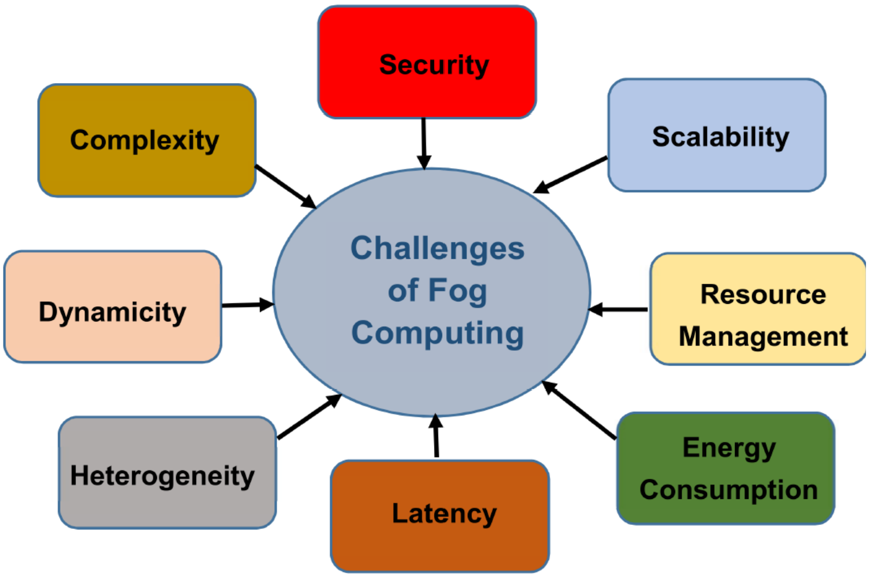


Fig. 3.7: Challenges of fog computing

- **Scalability:** The number of IoT devices is in the order of billions, which generates a huge amount of data and requires a huge amount of resources such as processing power and storage. Therefore, fog servers should be able to support all these devices with adequate resources. The real challenge will be the capability to respond to the rapid growth of IoT devices and applications.

- **Complexity:** There are many IoT devices and sensors designed by different manufacturers, choosing the optimal components is becoming very complicated, especially with different software and hardware configurations and personal requirements. In addition, in some cases, applications with high-security requirements require specific hardware and protocols to function, which increases the difficulty of the operation

- **Latency:** One of the main reasons to replace the cloud with fog computing is providing low latency, especially for time-sensitive applications. However, there are many factors presenting a high latency of application or service performance on fog computing platforms. The fog with high latency will lead to user dissatisfaction

- **Security:** Although fog nodes will need to be protected by using the same policy, controls and procedures and use the same physical security and cyber security solutions, the fog environment itself is vulnerable and less secure than cloud computing. Existing security and privacy measurements of cloud computing cannot be directly applied to the fog due to its mobility, heterogeneity and large-scale geo-distribution. Many research studies focus on cryptography and authentication to improve network security to protect against cyber-attacks in fog computing.

- **Resource management:** Fog end devices are often network devices equipped with additional storage and computing power. However, it is difficult for such devices to match the resource capacity of traditional servers, let alone the cloud. Therefore, sensible management of fog resources is required for efficient operation of the fog computing environment.

- **Energy Consumption:** The fog environment involves a large number of fog end devices; the computation is distributed and can be less energy-efficient than the centralized cloud model of computation. Therefore, reducing energy consumed in fog computing is an important challenge that needs to be addressed.

- **Dynamicity:** One of the important features of IoT devices is the ability to evolve and dynamically change their workflow composition. This challenge will alter the internal properties and performance of IoT devices. In addition, handheld devices suffer from software and hardware aging, which will result in changing workflow behaviour and device properties.

- **Heterogeneity:** There are many IoT devices and sensors which are designed by different manufacturers. These devices have various capabilities in communication radios, sensors, computing powers, storage, etc. The management and coordination of networks such heterogeneous IoT devices and the selection of the appropriate resources will become a big challenge

3.5.1 Open issues of fog

It is obvious that fog computing is a new technology that needs more research to address all the challenges previously mentioned. This section provides an overview of open issues and future research directions related to fog computing and its integration with the IoT [6].

- **Communications between the Fog and the Cloud**: Fog computing is an extension of the cloud, which is a central controller of fog servers that are deployed at different locations. The cloud manages the applications and contents of the entire system. In a fog, only selective localized applications are provisioned and synchronized with the cloud[2]. With the dual functions of the cloud, the data delivery and update from the cloud to fog faces problems related to communications sessions created during the processing of fog nodes. Selecting the appropriate communication between the fog and cloud that ensures high performance and low latency of fog nodes is a key challenge.
- **Communications between Fog servers**: Each fog server manages a pool of resources at different locations. Communication and collaboration between fog servers are necessary to maintain service provision and content delivery between them. If the communication efficiency is increased, the performance of the entire system will be improved. The data transmission between fog servers faces many challenges that need to be addressed. For instance, there is a need for service policies where fog servers are deployed at different locations with different entities to enable them to adapt to different policies defined by owners. In addition, the data transmission between fog servers needs to consider connection features. In other words, fog servers need to be able to connect to each other using either wired or wireless connection over the Internet.

- **Fog computing deployment**: Fog computing places additional computing and storage resources at the edge of the system to process local service requests quickly using local resources. As fog servers are deployed at different locations, they need to adapt their services regarding management and maintenance costs. In addition, the network operator of a fog computing system needs to address the requirements of each IoT application and fog server collaboration.

3.6 Future directions and applications

There are many significant areas where fog computing can play a vital role in different IoT applications. This section provides an overview of various IoT applications that can benefit from fog computing.

- **Connected Car**: According to Cisco, autonomous vehicles is a new trend for cars. There are many beneficial features, which depend on the fog and Internet connectivity, that can be added to cars such as automatic steering and hands-free operation or self-parking features which mean that there is no need for a person behind the wheel to park the vehicle. In the next few years, it is expected that all new cars will have the ability to communicate with nearby cars and the Internet. Fog computing will be the most efficient solution for all Internet-connected vehicles, since it provides a high level of real-time interaction. In addition, it will allow cars, access points and traffic lights to interact with each other to deliver a good service to users.

- **Smart Traffic Lights**: Fog computing allows traffic signals to open roads depending on sensing flashing lights. It senses the presence of pedestrians and cyclists and measures the distance and speed of the nearby vehicles. Sensor lighting turns on when it identifies movements and vice-versa. Smart traffic lights may be considered to be fog nodes which are synchronized with each other to send warning messages to nearby vehicles. The interactions of the fog between the vehicle and access points are improved withWiFi, 3G, smart traffic lights and roadside units.

- **Smart Home**: The IoT has many sensors and devices connected in the home. However, these devices come from different vendors and have different platforms, making it difficult to get them to work together. In addition, some tasks need a large amount of computation and storage. Fog computing solves many of these issues. It integrates all different platforms and empowers smart home applications with flexible resources. Fog computing has many benefits for home security applications. It provides a unified interface to integrate all different independent devices. In addition, it provides elastic resources to enable storage, real-time processing and low-latency

- **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.

- **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.

- **Wireless Sensor and Actuator Networks:** They were designed to extend battery life by operating at predominantly low power .Actuators 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 them entail less bandwidth, less energy, very low processing power, operating as a sink in a unidirectional fashion.

Conclusion

Fog computing technology discuss the combination of fog computing and data center hoping to improve the quality of experience of users in human-centered smart systems. In addition, we propose a three-layer architecture of the data center by introducing the fog computing layer between the traditional centralized data center and terminal nodes. Performance related service latency of different cloud services is modeled and evaluated based on it. It is veried that the new architecture has a great improvement in terms of service latency and network load by simulation experiments. In future work, we will focus on power consumption related performance of new data center in smart systems.

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