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Scheduling in Fog Computing: A Survey

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Abstract: *Fog computing provides computation, storage and network services for smart manufacturing. However, in a smart factory, the task requests, terminal devices and fog nodes have very strong heterogeneity, such as the different task characteristics of terminal equipment: fault detection tasks have high real-time demands; production scheduling tasks require a large amount of calculation; inventory management tasks require a vast amount of storage space, and so on. In addition, the fog nodes have different processing abilities, such that strong fog nodes with considerable computing resources can help terminal equipment to complete the complex task processing, such as manufacturing inspection, fault detection, state analysis of devices, and so on. Fog computing provides a distributed infrastructure at the edges of the network, resulting in low-latency access and faster response to application requests. With this new level of computing capacity, new forms of resource allocation and management can be developed to take advantage of the Fog infrastructure.*

Keywords: Fog Computing, Distributed Infrastructure, Network, Applications, Computing Capacity.

I. Introduction

In computing, scheduling refers to the process of allocating computing resources to an application and mapping constituent components of that application onto those resources, in order to meet certain Quality of Service (QoS) and resource conservation goals. The application itself may be represented or concrete form using different programming primitives such as processes, threads, tasks, jobs, workflows, petri nets, and so on. Similarly, the computing resource may be diverse, ranging from local cores and processors on a host, to distributed resource like nodes in a cluster, virtual machines (VM) in a cloud, edge or mobile devices in an Internet of Things (IoT) deployment, or desktops in a volunteer computing network. QoS for the application, such as their latency, and conservation goals, such as minimizing the quanta of resource or their energy footprint, can likewise be used to determine the schedule. Consequently, examining application scheduling requires us to understand the behavior of the computing resources, application models, and QoS goals in an integrated manner.

With the rapid development of emerging technologies such as the Internet of Things (IoT), big data and cloud computing , the industrial revolution has entered the so-called stage 4.0, and manufacturing modes have also entered the intelligent category. Emerging technologies are widely used in the intelligent plant; in particular, a large amount of IoT equipment is deployed in the intelligent plant, analyzing and processing enormous amounts of data that introduce challenges to cloud computing. Considering the disadvantages of cloud computing, fog computing is used to solve the processing of real-time tasks in the Industrial IoT. The main difference between fog computing and cloud computing is that fog computing can provide low latency computing services for terminal devices, which is decided by the fog nodes deployed at the location. Fog nodes are usually deployed around the terminal devices, and often through one jump, they can complete data forwarding, greatly reducing the data transmission delay; however, this advantage cannot be achieved with cloud computing.

II.. Fog Computing Overview

Definition

There are a few terms similar to fog computing, such as mobile cloud computing, mobile edge computing, etc. Below we explain each of them.

A) Local Cloud: Local cloud is a cloud built in a local network. It consists of cloud-enabling software running on local servers and mostly supports interplay with remote cloud.
Local cloud is complementary to remote cloud by running dedicated services locally to enhance the control of data privacy.

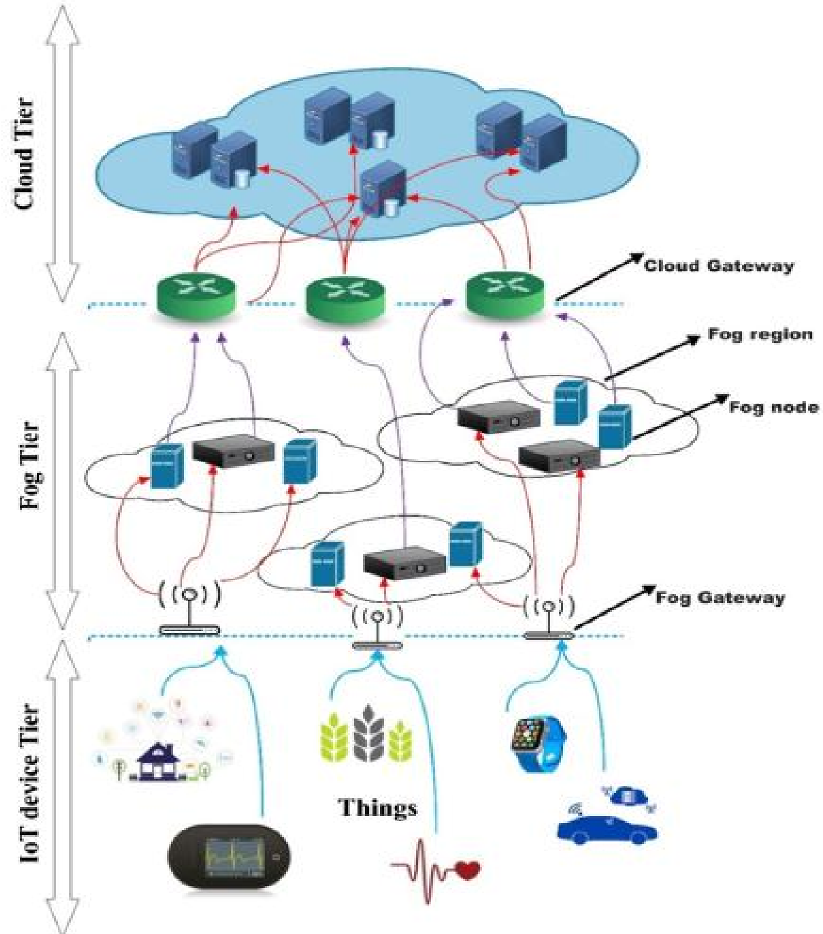

Figure 1: Three layer architecture: end user/fog/cloud

B) Cloudlet: Cloudlet is "a data center in a box", which follows cloud computing paradigm in a more concentrated manner and relies on high-volume servers . Cloudlet focuses more on providing services to delay-sensitive, bandwidth limited applications in vicinity.

C) Mobile Edge Computing: Mobile edge computing is very similar to Cloudlet except that it is primarily located in mobile base stations.

D4) Mobile Cloud Computing: Mobile cloud computing (MCC) is an infrastructure where both data storage and data processing happen outside of mobile devices, by outsourcing computations and data storage from mobile phones to cloud. With the trend of pushing cloud to the edge, MCC starts to evolve to mobile edge computing.

E) Fog Computing: Fog computing is generally considered as a non-trivial extension of cloud computing from the core network to the edge network . offers a comprehensive definition of fog computing, which arise from challenges and technologies that will shape the fog, with emphasis on some prominent properties, such as predominance of wireless access, heterogeneity and geographical distribution, sand-boxed environment and flexible interoperability, and large scale of nodes. However, current definitions are all developed from different perspectives and thus not general.

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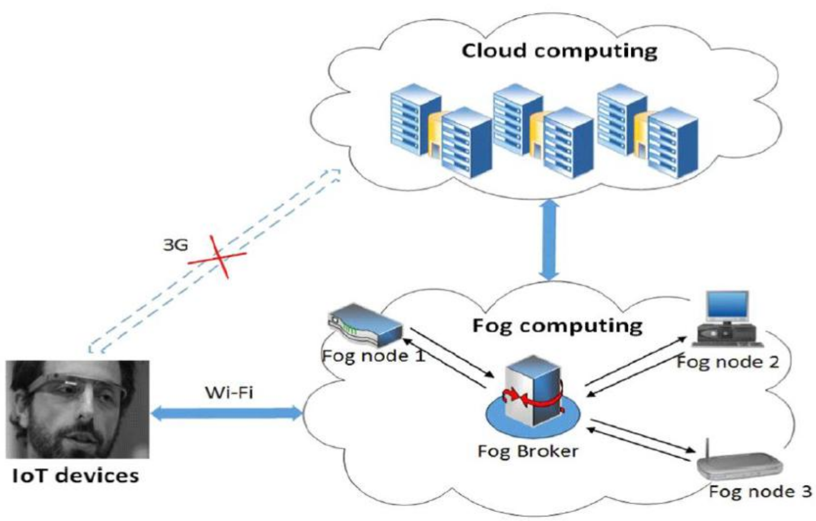
For example, though mobility comes first in edge computing, we do not necessarily narrow it down to mobile edge computing. Fog computing should be defined for a broader range of ubiquitous connected devices. The definition from gives integrative view of fog computing but fails to point out the unique connection to the cloud. We need a more general definition that can abstract all those similar concepts.

Fog computing is a geographically distributed computing architecture with a resource pool consists of one or more ubiquitously connected heterogeneous devices (including edge devices) at the edge of network and not exclusively seamlessly backed by cloud services, to collaboratively provide elastic computation, storage and communication (and many other new services and tasks) in isolated environments to a large scale of clients in proximity.

III. A Literature Survey

Scheduling is the optimal use of CPU time and proper allocation of resources to programs. The main task of the scheduler is to decide which process to run in the next step by having a set of applicable processes. The scheduling objectives include cost, make span, workload maximization, VM utilization, energy, consumption, reliability, awareness and security, awareness. Fog computing includes accessible IoT application components running in the cloud data center that is, in switches, routers, proxy servers, set-top boxes, smart gateways, base stations or other fog devices. It allows location-awareness, mobility support, context awareness, distributed data analytics, real-time interactions, interface heterogeneity, scalability and interoperability to address requirements of latency-sensitive applications. On the other hand, due to the variety of resource heterogeneity and dynamic negotiations, highly variable, and unpredictable of fog network, it needs the resource management as one of the challenging issues to be addressed to increase the fog computing efficiency. For the rest of this section, we first expose brief overview three-tier architecture of fog landscape, and we then describe some related review and survey studies in the resource management issues on the fog and edge computing. the Internet of Things (IoT) is one of the real transformations in data and correspondence innovation. The IoT and its related innovations, for example, machine-to-machine (M2M) innovation, expand the Internet network past customary brilliant gadgets like cell phones, tablets to an assorted scope of gadgets, and regular things (for example objects, machines, vehicles, structures) to play out an assortment of administrations and applications (for example social insurance, prescription treatment, traffic control, vitality the board, vehicular systems administration). These associated gadgets are creating an exceptional measure of information, which should be put away, prepared, and broke down for determining profitable bits of knowledge just as legitimately gotten to by end clients or potentially customer applications. Together with it, the amount and the size of administrations and applications are expanding quickly, which may require handling abilities past what could be offered by the most dominant shrewd gadget.



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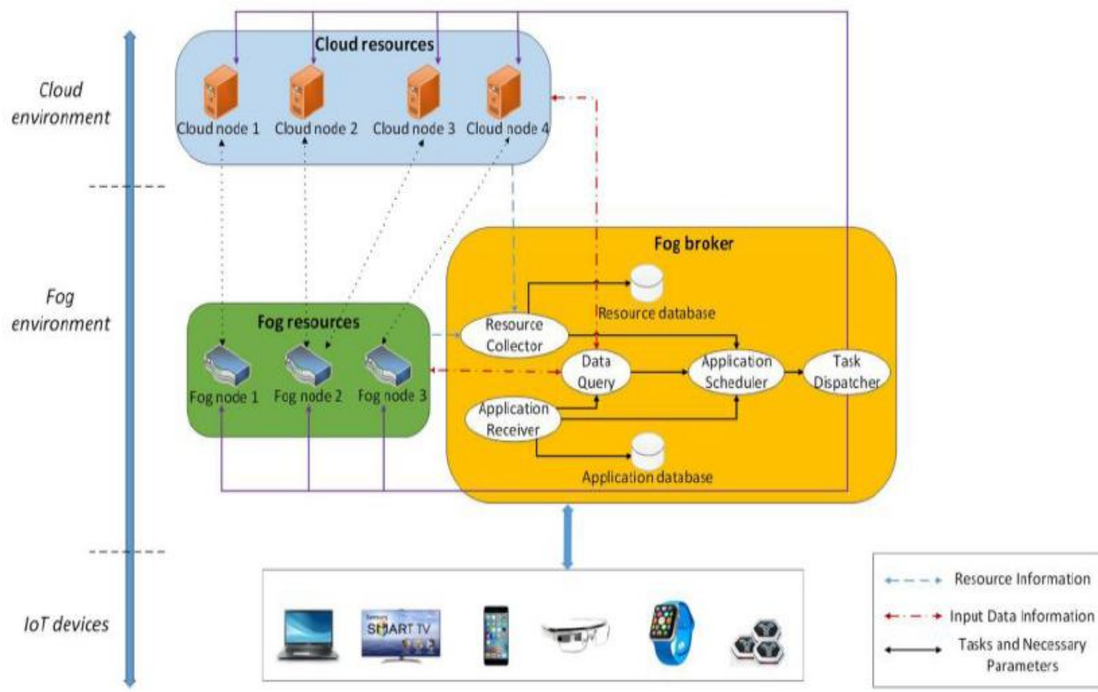
Then, distributed computing, in which progressively versatile and frequently virtualized assets are given as an administration over the Internet, may offer a huge supplement to IoT. The inherent confinements of lightweight shrewd gadgets (for example battery life, preparing power, stockpiling limit, arrange assets) can be eased by offloading process serious, asset devouring undertakings up to an incredible figuring stage in the cloud, leaving just basic employments to the limit constrained savvy gadgets. Be that as it may, when IoT meets cloud, numerous difficulties emerge. As per Information Handling Services (IHS) Markit organization, the IoT market will develop from an introduced base of 15.4 billion gadgets in 2015 to 30.7 billion gadgets in 2020 and 75.4 billion in 2025.1 With the anticipated blast in the quantity of associated gadgets, conventional unified cloud-based designs, in which processing and capacity assets are gathered in a couple of huge server farms, won't almost certainly handle the IoT's information and correspondence needs any longer.



IV. Related Work

In recent years, many scholars worldwide have conducted research on fog computing, and the main research directions are focused on the definition, architecture, application ,computing offloading and task scheduling. Based on the terminal equipment and its requirement of real-time performance and energy consumption, the task scheduling of the fog computing model is a necessary research hotspot. The task scheduling research on fog computing is still at the preliminary stage. Yin et al. introduced fog computing in the intelligent manufacturing environment in which the container virtual technology was adopted, and through the task scheduling and resource allocation to ensure the real-time task performance, the reallocation mechanism to further reduce the computing delay of the task was accomplished. Yang et al. studied the task scheduling in a homogeneous fog network; they put forward a novel delay–energy balance task scheduling algorithm, and reduced the average service time delay and delay jitter of minimizing the overall energy consumption at the same time. Pham et al. formulated the task scheduling problems in a cloud-fog environment, and proposed a heuristic-based algorithm. Chekired et al. designed a multilayer fog computing architecture, in which they calculated the priority of IoT data and task requests; then, according to the priority conduct rank, high priority tasks that required fast deployment were accommodated by using two priority queuing models to complete industrial network scheduling and analysis of the data. Liu et al. investigated a joint optimization algorithm of scheduling multiple jobs and a light path provisioning for minimizing the average completion time in a fog computing micro datacenter network. Bettencourt et al. studied mobility-aware application scheduling in fog computing. Zeng et al. designed an efficient task scheduling and resource management strategy with a minimized task completion time for promoting the user experience. Deng et al. studied workload scheduling towards worst-case delay and optimal utility for a single-hop Fog-IoT architecture. A workload dynamic scheduling algorithm is proposed, which can maximize the average throughput utility while guaranteeing the worst-case delay of task processing. Chen et al. applied fog computing technologies for enhancing the vehicular network, and two dynamic scheduling algorithms are proposed based on the fog computing scheme for the data scheduling in vehicular networks, in which these algorithms can dynamically adapt to a changeable network environment and achieve a benefit in efficiency. Zhao et al. proposed a fog-enabled multitier network architecture which can model a typical content delivery wireless network. A new fog enabled multitier operations scheduling approach based on Lyapunov optimization techniques is developed to decompose the original complicated problem into two operations across different tiers. Extensive simulation results show the algorithm is fair and efficient. Wang et al. designed a fog computing-assisted smart manufacturing system, and a Software-Defined IoT system architecture based on fog computing was set up in a smart factory. An adaptive computing mode selection method is proposed, and simulator results show that this method can achieve real-time performance and high reliability in IoT. Ni et al. proposed a resource allocation strategy for fog computing based on priced timed Petri nets (PTPN). The strategy comprehensively considers the price cost and time cost to complete a task, and constructs the PTPN models of tasks in fog computing in accordance with the features of fog resources.

V. Challenges In Fog Computing

Fog computing is considered as the promising extension of Cloud computing paradigm to handle IoT related issues at the edge of network. However, in Fog computing, computational nodes are heterogeneous and distributed. Besides, Fog based services have to deal with different aspects of constrained environment. Assurance of security is also predominant in Fog computing. Analyzing the features of Fog computing from structural, service oriented and security perspectives, the challenges in this field can be listed as follows:

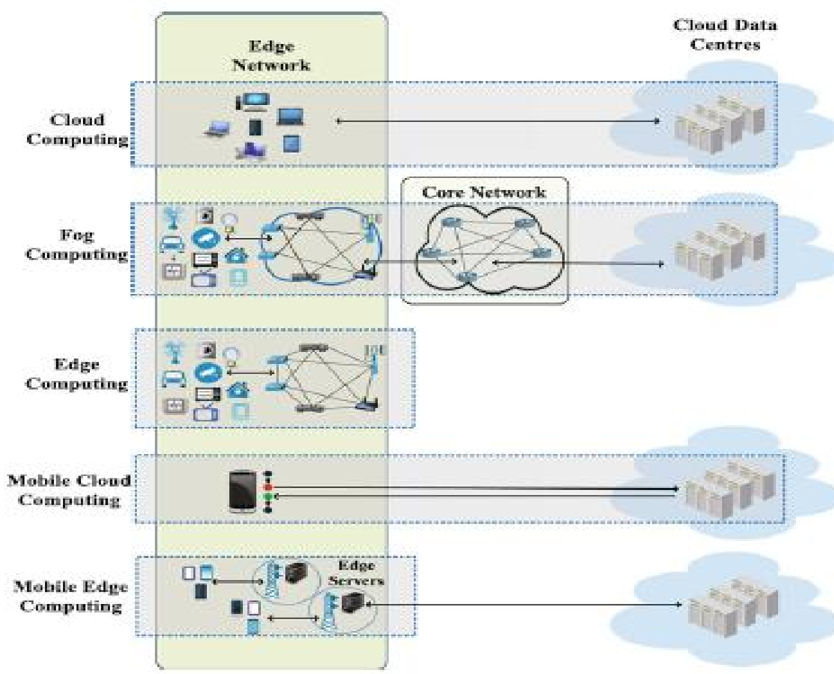


Figure: Computation domain of Cloud, Fog, Edge, Mobile Cloud and Mobile Edge computing

Structural Issues

- Different components from both edge and core network can be used as potential Fog computing infrastructure. Typically these components are equipped with various kinds of processors but are not employed for general purpose computing. Provisioning the components with general purpose computation besides their traditional activities will be very challenging.
- Based on operational requirements and execution environment, the selection of suitable nodes, corresponding resource configuration and places of deployment are vital in Fog.

Service oriented

- Not all Fog nodes are resource enriched. Therefore, large scale applications development in resource constrained nodes are not quite easy compared to conventional Data centers. In this case, potential programming platform for distributed applications development in Fog are required to be introduced.
- Policies to distribute computational tasks and services among IoT devices/sensors, Fog and Cloud infrastructures are required to be specified. Data visualization through web-interfaces are also difficult to design in Fog computing.

Security aspects

- Since Fog computing is designed upon traditional networking components, it is highly vulnerable to security attacks.
- Authenticated access to services and maintenance of privacy in a largely distributed paradigm like Fog computing are hard to ensure.
- Implementation of security mechanisms for data-centric integrity can affect the QoS of Fog computing to a great extent.

VI. Fog Nodes Configuration

A) Servers

The Fog servers are geo-distributed and are deployed at very common places for example; bus terminals, shopping centers, roads, parks, etc. Like light-weight Cloud servers, these Fog servers are virtualized and equipped with storage, compute and networking facilities. There are many works that have considered Fog servers as main functional component of Fog computing.

B) Networking Devices

Devices like gateway routers, switches, set-top boxes, etc. besides their traditional networking activities (routing, packet forwarding, analog to digital signal conversions, etc.) can act as potential infrastructure for Fog computing. In some existing works, the networking devices are designed with certain system resources including data processors, extensible primary and secondary memory, programming platforms, etc.

C) Cloudlets

Cloudlets are considered as micro-cloud and located at the middle layer of end device, cloudlet, and Cloud hierarchy. Basically cloudlets have been designed for extending Cloud based services towards mobile device users and can complement MCC.

D) Base Stations

Base stations are very important components in mobile and wireless networks for seamless communication and data signal processing. In recent works, traditional base stations equipped with certain storing and computing capabilities are considered suitable for Fog computing.

E) Vehicles

Moving or parked vehicles at the edge of network with computation facilities can serve as Fog nodes . Vehicles as Fog nodes can form a distributed and highly scalable Fog environment. However, the assurance of privacy and fault tolerance along with desired QoS maintenance will be very challenging in such environment.

VII. Service Level Objectives

In existing literature, several unique Fog node architecture, application programming platform, mathematical model and optimization technique have been proposed to attain certain SLOs. Most of the attained SLOs are management oriented and cover latency, power, cost, resource, data, application, etc. related issues.

A) Latency Management

Latency management in Fog computing basically resists the ultimate service delivery time from surpassing an accepted threshold. This threshold can be the maximum tolerable latency of a service request or applications QoS requirement. To ensure proper latency management, in some works efficient initiation of nodal collaboration has been emphasized so that the computation tasks through the collaborated nodes can be executed within the imposed latency constraints.

B) Cost Management

Cost management in Fog computing can be discussed in terms of Capital Expenses (CAPEX) and Operating Expenses (OPEX). The main contributor of CAPEX in Fog computing is the deployment of cost of distributed Fog nodes and their associated networks. In this case, suitable placement and optimized number of Fog nodes play a significant role in minimizing the CAPEX in Fog computing. Investigating this issue, a Fog computing network architecture has been proposed in that minimizes the total CAPEX in fog computing by optimizing the places and numbers of Fog node deployment.

C) Network Management

Network management in Fog computing includes core-network congestion control, support for Software Define Network (SDN)/ Network Function Virtualization (NFV), assurance of seamless connectivity, etc.

- **Network congestion** mainly occurs due to increasing overhead on the network. As in IoT, end devices/sensors are highly distributed across the edge, simultaneous interactions of end components with Cloud data centers can increase the overhead on the core network to a great extent. In such case network congestion will occur and degrade the performance of the system. Taking cognizance of this fact, in a layered architecture of Fog node has been proposed that provides local processing of the service requests. As a consequence, despite of receiving bulk service requests, Clouds get consisted version of the requests which contribute less to the network congestion.
- **Virtualization** of conventional networking system has already drawn significant research attention. SDN is considered as one of the key enablers of virtualized network. SDN is a networking technique that decouples the control plane from networking equipment and implements in software on separate servers. One of the important aspects of SDN is to provide support for NFV. Basically, NFV is an architectural concept that virtualizes traditional networking functions (network address translation (NAT), firewalling, intrusion detection, domain name service (DNS), caching, etc.) so that they can be executed through software. In Cloud based environment SDN and NFV is quite influencing due to their wide range of services. Being motivated by this, in several research works new network structures of Fog computing have been proposed to enable SDN and NFV.
- **Connectivity** ensures seamless communication of end devices with other entities like Cloud, Fog, Desktop computers, Mobile devices, end devices, etc. despite of their physical diversity. As a consequence, resource discovery, maintenance of communication and computation capacity become easier within the network.

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Several works in Fog computing have already targeted this issue and proposed new architecture of Fog nodes e.g. IoT Hub and Fog networking e.g. Vehicular Fog Computing for connectivity management and resource discovery. Besides, for secured connectivity among the devices a policy driven framework has also been developed for Fog computing .

D) Computation Management

Among the attained SLOs, assurance of proper computational resource management in Fog computing is very influential. Fog computing resource management includes resource estimation, workload allocation, resource coordination, etc.

- **Resource estimation** in Fog computing helps to allocate computational resources according to some policies so that appropriate resources for further computation can be allocated, desired QoS can be achieved and accurate service price can be imposed. In existing literature, resource estimation policies are developed in terms of user characteristics , experienced QoE, features of service accessing devices, etc.
- **Workload allocation** in Fog computing should be done in such a way so that utilization rate of resources become maximized and longer computational idle period get minimized. More precisely, balanced load on different components is ensured. In a Fog based research work , scheduling based workload allocation policy has been introduced to balance computation load on Fog nodes and client devices. As a consequence overhead on both parts become affordable and enhance QoE. In another work a workload allocation framework has been proposed that balances delay and power consumption in Fog-Cloud interaction.
- **Coordination** among different Fog resources is very essential as they are heterogeneous and resource constrained. Due to decentralized nature of Fog computing, in most cases large scale applications are distributive deployed in different Fog nodes. In such scenarios without proper co-ordination of Fog resources, attainment of desired performance will not be very easy. Considering this fact, in a directed graph based resource co-ordination model has been proposed for Fog resource management.

E) Application Management

In order to ensure proper application management in Fog computing, efficient programming platforms are very essential. Besides the scalability and computation offloading facilities also contribute significantly in application management.

- **Programming platform** provides necessary components such as interfaces, libraries, run-time environment, etc. to develop, compile and execute applications. Due to dynamic nature of Fog computing, assurance of proper programming support for large-scale applications is very challenging. In order to overcome this issue, a new programming platform named Mobile Fog has been introduced. Mobile Fog offers simplified abstraction of programming models for developing large-scale application over heterogeneous-distributed devices. In another paper , besides coordinating resources during applications execution, a programming platform based on distributed data flow approach has also been designed for application development in Fog computing.
- **Scaling** points to the adaptation capability of applications in retaining their service quality even after proliferation of application users and unpredictable events. Scaling techniques can also be applied in application scheduling and users service access. To support scalable scheduling of data stream applications, architecture of a QoS aware self adaptive scheduler has been recently proposed in Fog computing.
- **Offloading** techniques facilitate resource constrained end devices in sending their computational tasks to some resource-enriched devices for execution. Computational offloading is very common in mobile cloud environment. However, recently, as a part of compatibility enhancement of Fog computing for other networking systems, computation offloading support for mobile applications in Fog computing have been emphasized in several papers.

F) Data Management

Data management is another important SLO that is highly required to be achieved for efficient performance of Fog computing. In different research works data management in Fog computing has been discussed from different perspectives. In initiation of proper data analytic services and resource allocation for data pre-processing have been focused for data management policy in Fog computing. Besides, low latency aggregation of data coming from distributed end devices/sensors can also be considered for efficient data management . Moreover, the storage capability of end devices/sensors are not so reach. In this case, storage augmentation in Fog computing for preserving data of end entities can be very influential. Therefore, in besides application management, storage expansion in Fog computing for mobile devices have also been discussed as integral part of data management.

G) Power Management

Fog computing can be used as an effective platform for providing power management as a service for different networking systems. In , a service platform for Fog computing has been proposed that can enable power management in home based IoT network with customized consumer control. Additionally, Fog computing can manage power usage of centralized Cloud data centers in certain scenarios. Power consumed by Cloud data centers largely depends on type of running applications. In this case, Fog computing can complement Cloud data centers by providing infrastructure for hosting several energy-hungry applications.

VIII. Applicable Network System

Fog computing plays a significant role in IoT. However, in recent research works the applicability of Fog computing in other networking systems (mobile network, content distribution network , radio access network, vehicular network, etc.) have also been highlighted.

A) Internet of Things

In IoT, every devices are interconnected and able to exchange data among themselves. IoT environment can be described from different perspectives. Besides specifying IoT as a network for device to device interaction , in several Fog based research works this interaction have been classified under industry and home based execution environment. Moreover, Wireless Sensors and Actuators Network , Cyber-Physical Systems , Embedded system network , etc. have also been considered as different forms of IoT while designing system and service models for Fog computing.

B) Mobile Network/Radio Access Network

Mobile network is another networking system where applicability of Fog computing has been explored through several research works. Basically, in these works much emphasize has been given on investigating the compatibility of Fog computing in 5G mobile networking.

C) Long-Reach Passive Optical Network/Power Line Communication

Long-Reach Passive Optical Network (LRPON) has been introduced for supporting latency-sensitive and bandwidth-intensive home, industry, and wireless oriented backhaul services. Besides, covering a large area, LRPONs simplify network consolidation process. In , Fog computing has been integrated with LRPONs for optimized network design.

D) Content Distribution Network

Content Distribution Network (CDN) is composed of distributed proxy servers that provide content to end-users ensuring high performance and availability. In several Fog based research works , Fog nodes are considered as content servers to support content distribution through Fog computing.

E) Vehicular Network

Vehicular network enables autonomous creation of a wireless communication among vehicles for data exchange and resource augmentation. In this networking system vehicles are provided with computational and networking facilities.

In several research works vehicles residing at the edge network are considered as Fog nodes to promote Fog computing based vehicular network.

IX. Security Concern

Security vulnerability of Fog computing is very high as it resides at the underlying network between end device/sensors and Cloud data centers. However, in existing literature, security concerns in Fog computing has been discussed in terms of users authentication, privacy, secured data exchange, DoS attack, etc.

A) Authentication

Users authentication in Fog based services play an important role in resisting intrusion. Since Fog services are used in "pay as you go" basis, unwanted access to the services are not tolerable in any sense. Besides user authentication, in device authentication, data migration authentication and instance authentication has also been observed for secured Fog computing environment.

B) Privacy

Fog computing processes data coming from end device/sensors. In some cases, these data are found very closely associated with users situation and interest. Therefore, proper privacy assurance is considered as one of the important security concerns in Fog computing. In the challenges regarding privacy in Fog based vehicular computing have been pointed for further investigation.

C) Encryption

Basically, Fog computing complements Cloud computing. Data that has been processed in Fog computing, in some cases has to be forwarded towards Cloud. As these data often contains sensitive information, it is highly required to encrypt them in Fog nodes. Taking this fact into account, in a data encryption layer has been included in the proposed Fog node architecture.

D) DoS Attack

Since, Fog nodes are resource constraint, it is very difficult for them to handle large number of concurrent requests. In this case, performance of Fog computing can be degraded to a great extent. To create such severe service disruptions in Fog computing, Denial-of-Service (DoS) attacks can play vital roles. By making a lot of irrelevant service requests simultaneously, Fog nodes can be made busy for a longer period of time. As a result, resources for hosting useful services become unavailable.

X. Gap Analysis And Future Directions

Fog computing resides at closer proximity of the end users and extends Cloud based facilities. In serving largely distributed end devices/sensors, Fog computing plays very crucial roles. Therefore, in recent years Fog computing has become one of the major fields of research from both academia and business perspectives. In Table 1, a brief summary of some reviewed papers from existing literature of Fog computing has been highlighted. Although many important aspects of Fog computing have been identified in the existing literature, there exist some other issues that are required to be addressed for further improvement of this field. In this section, the gaps from existing literatures along with several future research directions have been discussed.

A) Context-Aware Resource/Service Provisioning

Context-awareness can lead to efficient resource and service provisioning in Fog computing. Contextual information in Fog computing can be received in different forms, for example;

- Environmental context : Location, Time (Peak, Off-peak), etc.
- Application context : Latency sensitivity, Application architecture, etc.

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- User context: Mobility, Social interactions, Activity, etc.
- Device context: Available resources, Remaining battery life time, etc.
- Network context: Bandwidth, Network traffic, etc.

B) Sustainable and Reliable Fog Computing

Sustainability in Fog computing optimizes its economic and environmental influence to a great extent. However, the overall sustainable architecture of Fog computing is subject to many issues like assurance of QoS, service reusability, energy-efficient resource management etc. On the other hand, reliability in Fog computing can be discussed in terms of consistency of Fog nods, availability of high performance services, secured interactions, fault tolerance etc. In the existing literature a very narrow discussion towards sustainable and reliable Fog computing has been provided. Further research in this area is highly recommended for the desired performance of Fog computing.

Table 1 Review of state-of-art in Fog Computing

Work	Fog nodes	Nodal collaboration	Provisioning metrics	SLOs	Applicable network	Security concerns
Lee et al. [16]	Servers	Master-Slave	Data (flow)	Network management	IoT	–
Aazam et al. [17]	Servers	–	Context (user)	Resource management	IoT	–
Jalali et al. [18]	Servers	Peer to Peer	Time (computing)	Power management	CDN	–
Zhu et al. [19]	Servers	–	Context (user)	Application management	CDN	–
Zeng et al. [20]	Servers	Peer to Peer	Time (communication, computation)	Resource management	IoT	–
Hong et al. [21]	Network devices	Peer to Peer	Data (size)	Application management	IoT	–
Nazmudeen et al. [22]	Network devices	Master-Slave	Data (size)	Data management	PLC	–
Aazam et al. [23]	Network devices	–	Data (size)	Network management	IoT	Data encryption
Cirani et al. [24]	Network devices	–	Context (application)	Network management	IoT	DoS attack
Dsouza et al. [25]	Cloudlets	Peer to Peer	Context (application)	Network management	IoT	Authentication
Cardellini et al. [26]	Cloudlets	Cluster	Context (application)	Application management	IoT	–
Yan et al. [27]	Base stations	Cluster	Context (user)	Application management	RAN	–
Gu et al. [28]	Base stations	Peer to Peer	Cost (deployment, communication)	Resource management	IoT	–

Truong et al. [29]	Base stations	Master-Slave	Context (application)	Network management	Vehicular network	–
Oueis et al. [30]	Base stations	Cluster	Time (deadline)	Latency management	Mobile network	–
Hou et al. [31]	Vehicles	Cluster	Context (user)	Resource management	Vehicular	Privacy
Ye et al. [32]	Vehicles	–	Time (deadline)	Application management	Vehicular	–
Oueis et al. [33]	Base stations	Cluster	Data (flow)	Resource management	Mobile network	–
Faruque et al. [34]	Network devices	Cluster	Energy consumption	Power management	IoT	–

Work	Fog nodes	Nodal collaboration	Provisioning metrics	SLOs	Applicable network	Security concerns
Shi et al. [35]	Network devices	Peer to Peer	Context (application)	Application management	Mobile network	–
Giang et al. [36]	Network devices	Peer to Peer	Data (flow)	Application management	IoT	–
Intharawijitr et al. [37]	Servers	–	Time (communication, computation)	Latency management	Mobile network	–
Peng et al. [38]	Base stations	Peer to Peer	Data (size)	Network management	RAN	–
Hassan et al. [39]	Network devices	Cluster	Cost (execution, communication)	Application management	Mobile network	Privacy
Zhang et al. [40]	Cloudlets	Peer to Peer	Cost (deployment)	Cost management	LRPON	–
Deng et al. [41]	Network devices	Peer to Peer	Data (Size)	Application management	Mobile network	–
Do et al. [42]	Network devices	–	Energy consumption	CO_2 management	CDN	–
Aazam et al. [43]	Servers	–	Context (user)	Resource management	IoT	–
Datta et al. [44]	Network devices	Peer to Peer	Context (user)	Data management	Vehicular network	–
Aazam et al. [45]	Servers	–	Context (user)	Resource management	IoT	–
Gazis et al. [46]	Network devices	–	Context (application)	Resource management	IoT	–

C) Interoperable Architecture of Fog Nodes

Generally, Fog nodes are specialized networking components with computational facilities. More precisely, besides performing traditional networking activities like packet forwarding, routing, switching, etc., Fog nodes perform computational tasks. In some scenarios where real time interactions are associated, Fog nodes have to perform more as a computational component rather than a networking component. In other cases, networking capabilities of Fog nodes become prominent over computational capabilities. Therefore, an interoperable architecture of Fog nodes that can be self customized according to the requirements is very necessary. In existing literature although many unique Fog nodes architecture have been proposed, the real interoperable architecture of Fog nodes are still required to be investigated.

D) Distributed Application Deployment

Fog nodes are distributed across the edge and not all of them are highly resource occupied. In this case, large scale application deployment on single Fog node is not often feasible. Modular development of large scale applications and their distributed deployment over resource constrained Fog nodes can be an effective solution. In existing literature of Fog computing several programming platforms for distributed application development and deployment have been proposed. However, the issues regarding distribute application deployment such as latency management, dataflow management, QoS assurance, edge-centric affinity of real-time applications etc. have not been properly addressed.

E) Power Management Within Fog

Fog nodes have to deal with huge number of service requests coming from end devices/sensors simultaneously. One of the trivial solutions is to deploy Fog nodes in the environment according to the demand. However, this approach will increase the number of computationally active Fog nodes to a great extent, that eventually affects total power consumption of the system. Therefore, while responding large number service requests, proper power management within Fog network is very necessary. However in existing literature, Fog computing have been considered for minimizing power consumption in Cloud data centers. Optimization of energy usage within the Fog network are yet to be investigated. Moreover, in order to manage power in Fog environment, consolidation of Fog nodes by migrating tasks from one node to another node can be effective in some scenarios. Investigation towards the solutions of optimal task migration can also be a potential field of Fog based research.

F) Multi-tenant Support in Fog Resources

Available resources of Fog nodes can be virtualized and allocated to multiple users. In the existing literature, multi-tenant support in Fog resources and scheduling the computation tasks according to their QoS requirements have not been investigated in detail. Future researches can be conducted targeting this limitation of existing literature.

G) Pricing, Billing in Fog Computing

Fog computing can provide utility services like Cloud computing. In Cloud computing typically users are charged according to the horizontal scale of usage. Unlike Cloud computing, in Fog vertical arrangement of resources contributes to the expenses of both users and providers to a great extent. Therefore, the pricing and billing policies in Fog generally differ significantly from the Cloud oriented policies. Besides, due to lack of proper pricing and billing policies of Fog based services, most often users face difficulty in identifying suitable providers for conducting SLA. In such circumstance, a proper pricing and billing policy of Fog based services will surely be considered as potential contribution in field of Fog computing.

H) Tools for Fog Simulation

Real-world test bed for evaluating performance of Fog based policies is often very expensive to develop and not scalable in many cases. Therefore, for preliminary evaluation of proposed Fog computing environments many researchers look for efficient toolkit for Fog simulation. However, till now very less number of Fog simulator are available (e.g. *iFogSim).*Development of new efficient simulator for Fog computing can be taken into account as future research.

I) Programming Languages and Standards for Fog

Basically Fog computing has been designed for extending Cloud based services such as IaaS, PaaS, SaaS, etc. to the proximity of IoT devices/sensors. As the structure of Fog differs from Cloud, modification or improvement of existing standards and associate programming languages to enable Cloud-based services in Fog are highly required. Moreover, for seamless and flexible management of large number connections in Fog, development of efficient networking protocols and user interfaces are also necessary.

XI. Conclusion

In this paper, we surveyed recent developments, scheduling in Fog computing. Challenges in Fog computing is discussed here in terms of structural, service and security related issues. Based on the identified key challenges and properties, a scheduling of Fog computing has also been presented. Our scheduling classifies and analyses the existing works based on their approaches towards addressing the challenges. Moreover, based on the analysis, we proposed some promising research directions that can be pursued in the future.

Future Scope

Scheduling issues are significant for the effectiveness of the framework. Our scheduling classifies and analyses the existing works based on their approaches towards addressing the challenges. Moreover, based on the analysis, we proposed some promising research directions that can be pursued in the future.

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