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Review Article

Fog Computing: A Comprehensive Analysis of Simulation Tools, Applications and Research Challenges with Use Cases

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Abstract

The emerging trend of computing technologies and the Internet of Things (IoT) makes applications optimal and more responsive for real-time data processing. It generates an unprecedented and heterogeneous amount of data. To address this data explosions problem, cloud computing technologies were introduced with on-demand and highly scalable resources. However, challenges like bandwidth limitation, high response time, latency-sensitive and real-time application resource demands have still existed which are mostly solved through cloud computing. Therefore, cutting edge technologies fog, edge, mist and dew computing are developed to improve utilization of network bandwidth, latency and mobility in an efficient way. Research in fog computing is still in investigation mode, and several productive issues still need to be dig in depth based on platform, infrastructure, and applications-oriented. Among them, such key challenges are task partitioning, scheduling, and resource allocation. Aim of this presented survey is to provide comprehensive analysis and gives the inside journey and evolution of cutting-edge technologies. The survey of simulation tools is also presented which helps to understand & conclude the results with respect to several scenarios and algorithms. Furthermore, major technology areas of fog, case studies on various applications and open issues are also presented.

Keywords: Fog computing, Cloud Computing, Simulation tools, Resource allocation, Internet of Things, Distributed Computing

1. Overview

The advancement in internet technology has exceptionally relied upon three parameters: Connectivity, Network economy, and Collaborative experience to realize the importance of the internet of everything. During the late 1980s, information access has been digitized via email, search, and web browser. In the late 1990s, the second phase was the network economy, which digitalized the whole business process by introducing e-commerce and digital supply chains. It is completely reforming the way of shopping and product marketing. The third phase started in the early 2000s, which was based on social and business interaction as well as highly utilized cloud computing technology to bring-up IT industries. The current and most important phase was the Internet of Everything which connects people, process, data, and things for customer experience, innovation, employee productivity, and a tremendous amount of automation and opportunities [1]. Standardize views on current trends and technology by well-known institutes and organizations like The National Institute of Standards and Technology(NIST) and Cisco. With the rapid advancement in technology, industrialist and researchers highly focus on computation resources and sensor technologies like a wireless sensor network, IoT, high performance or distributed computing, blockchain for optimal and efficient performance. In which the term IoT, initially presented by Kevin Ashton in 1998 which has changed the future of the computing. Table 1 describes the various terminologies and definitions of IoT. The internet of things allows people and objects to be connected at any time (with any context), anywhere (with any device), and anyone else, preferably through any path/network or any form of service (business). The IoT word for Sensors, Connectivity, and Computing is demonstrated after surveying multiple views of several research firms and some industries. [2].

According to the Ericsson Mobility Report, every person in the world would be having connected by June 2018. As shown in figure 1, the number of cellular IoT connections exponentially increases with an annual growth rate of 30% hence in 2023, and the expected number will be around 3.5 billion. Apart from this, mobile phones are also the largest category of connected devices being IoT devices [5].

In this technological revolution, ubiquitous computing plays a significant role in industries and research organizations, which have been bounded with upper and lower requirements in terms of technologies that must require like cloud computing (upper bound) and Internet of Things or sensor (Lower bound).

According to figure 2, there are four layers where the cloud computing is one of the fast-growing environment, which transforms computing from a desktop to a worldwide network and fulfils users requirements for the on-demand platform like storage, networks, applications, and services as well as reduce the maintenance cost. With limited organizational effort or with the help of a professional company, this may be easily achieved and discharged.

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Table 1. Internet of Things definitions

Terminology	Definitions
Internet of Everything (IoE)[1]	• Networked Connection of 1. People ("Connecting more relevant and valuable way") 2. Process ("Delivering the right information to the right person at the right time") 3. Data ("Convert data into valuable information for decision making") 4. Things ("Physical object connected with internet for smart decision making")
Internet of Things (IoT)-NIST [2]	• Objects that communicate with the real world; • IoT nodes have processing, sensing, and networking capabilities.
Internet of Things –Cisco – [3]	• Networks of sensors attached to objects and communication devices • Analyze data and used it to initiate automated actions.
Network of Things (NoT)-NIST [4]	• Distributed Computing Model • Four key features:-Sensing, Computing, Communication, and Actuation. • Share messages about tasks between networked devices.

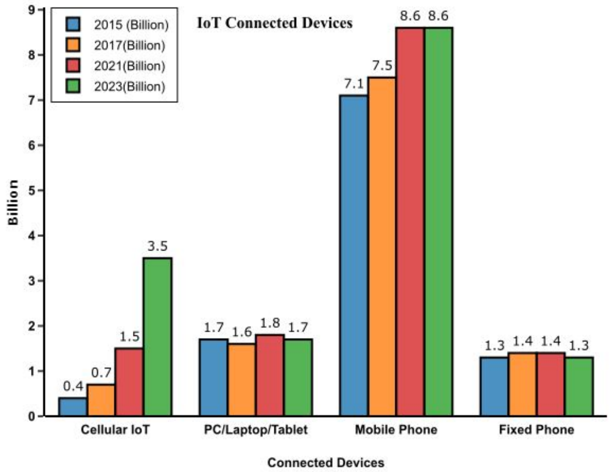

Fig. 1. Various IoT Enable Devices [5].

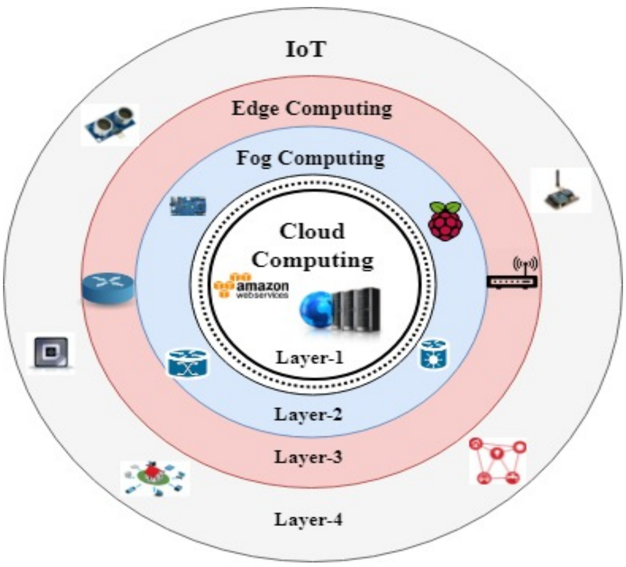

Fig. 2. Layered Architecture of Computing Paradigm.

2. Evolution and discussion of Distributed Computing

In the 1970s, the first distributed system was introduced that is a local area network in which multiple computers connected in one network for a common purpose. Distributed computing is a model of a distributed system where computation is divided into different sub-tasks that are executed on different network devices, and these network devices communicate with each other via message passing interface [6-7]. There are four significant advantages of distributed computing like 1) Varies Economical (reduce overall cost by adding more server as needed), 2) Scalability: computation node can be increased or decreased whenever required, 3) Speed (run parallel tasks to speed up execution): distribution of computational tasks over different nodes increases the execution speed. 4) Reliability: the distributed system can work smoothly even though if one node fails. On the other side, distributed computing is too much complex, less secure, and network dependent. The distributed computing model has been used by various new computation paradigms like utility, cluster, grid, and currently used in cloud & fog computing models. In this section, we cover a summary of the occurrence of various distributed computing paradigms which gradually evolved since 1960 as the utility era to 2012 as fog computing and currently mist and dew computing.

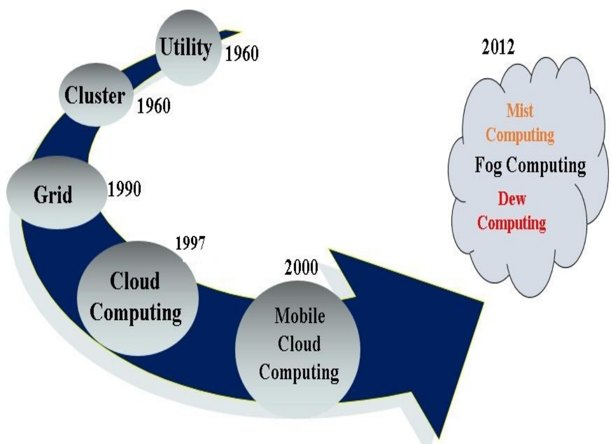

Fig. 3. Evolution of Computing Paradigms.

2.1. Utility Computing

According to figure 3, John McCarthy has firstly presented utility concepts in the 1960s. As a service, numerous computing facilities was introduced to the general public [8]. Initially, utility computing was not commonly used during this period, but this was reintroduced in the late 1990s as the provision of services and utility-based computing hardware costs. In the distributed computing edge, utility computing model played a critical role as everything was based on pay as you go model. It contains the organization and provision of a broad range of computing services, such as public utilities, telecommunications, water, gas, and electricity. Nowadays, utility computing is a core module of distributed technology that enables various cloud service providers to provide services for end-users based on a Service Level Agreement (SLA) and pay as you used.

2.2. Cluster Computing

Nearly every IT industry in the mid-19th century needed fast computing capability tools. The supercomputer was designed for the multiprocessor to meet the high computing power requirements. However, a supercomputer at an exact cost was approximately millions of dollars because of their specialized hardware and software. On the other hand, Cluster computing is cheaper and fast in computing. Cluster computing word first time introduced by IBM in 1960. Cluster word itself a group of similar things. In cluster computing, many stand-alone computers are connected via a local area network that works together for a single task and acts as a single computer. Cluster computing is designed to provide a tremendous amount of computing and storage capacity to end-user to execute processing and storage-intensive applications. Cluster architectures highly classified into two categories 1) High-Performance Computing, 2) High Availability, choice based on purpose, and type of computing applications [9]. There are various types of clusters like the High Availability cluster (HA) which is also called the failover cluster. HA aims to provide consistent services to the user at time failure leveraging redundancy of clusters. Another one is Load Balancing Cluster which manages the computational workload of multiple connected computers. Mostly cluster computing is used for scientific and engineering applications [10]. There are various categories of cluster computing, popular among the scientific community is Beowulf cluster, Message passing in computer clusters (MPICH), OpenHPC [11].

2.3. Grid Computing

In early 1990, the word "Grid Computing" (GC) was introduced and also functions as distributed computing. Grid computing overcomes the few drawbacks of cluster computing. GC connects geographically distributed, heterogeneous and loosely coupled computing resources, which are working to achieve a common goal. Simply GC makes an easy way to utilize computing power in the global network like WAN. Usually, it is designed and managed by the organization according to application-oriented. It plays a vital role in the high-performance computing era. The workflow of grid computing is like, the first user will submit computation or data-intensive task to the grid in order to boost up the execution process. Secondly, grid resource broker will collect all the information about available resources (cluster, supercomputer, or PC's) for computation globally and then it will allocate the task to globally available resources according to QoS or SLA. After successful completion of the task execution, the grid resource broker will merge all the results return the final output to the user.

The standard definition includes "*A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities*" defined by Ian Foster et al. [12]. Foster [13] also described three significant adherent characteristics for grid (1) Computing resources are not centrally managed, (2) standards are open source, and (3) Nontrivial QoS is achieved. IBM [14] stated grid computing as "*the ability, using a set of open standards and protocols, to gain access to applications and data, processing power, storage capacity, and a vast array of other computing resources over the internet. A grid is a type of parallel and distributed system that enables the sharing, selection, and aggregation of resources distributed across 'multiple' administrative domains based on their (resources) availability, capacity, performance, cost, and users' quality-of-service requirements*". Grid computing is the global initiative in which significant contributions are from the USA, Europe, and many countries from Asia-Pacific. Some of the active grid toolkit groups are like The Globus, the Global Grid Group, and two more [15-16] in which the Globus toolkit (open source software) is the main project of the Globus. The Global Grid group is managed by academics and industries like IBM, HP, and Universities(Berkeley, University of Edinburgh). Simulation tools are also available to simulate with different objectives like GridSim for job scheduling, SimGrid for single client multiserver scheduling, G3S for Grid Security services simulator – security services, OptoSim for Data Grid Simulations.

2.4. Cloud Computing

In 1997, Professor Ramnath Chellappa first time introduced "Cloud Computing" terms at INFORMS Annual Meeting [17]. The word "cloud" means the internet and "computing " means to use computer hardware and software to perform tasks like calculation or function. For instance, day to day computing task are swiping credit or debit cards, sending an email, and cell phone tasks. So in simple words cloud computing is computation on the internet instead of the local machine. Cloud computing is one of the incredible alternatives among small to medium-sized businesses and future business prototypes that only use services in terms of resources that are provided based on pay as you go and virtual mode. "Cloud computing is a new operations model that carries together a set of existing technologies like utility computing, cluster computing, grid computing, and virtualization to run business innovatively and fulfil the economic and the technological requirements of today's demand for IT industries " [18]. NIST provided a typical definition of cloud computing [19] "A model for enabling convenient, on-demand network access to a shared pool of configurable computing resources like servers, networks, storage, applications, etc., that can be rapidly provisioned and released with minimal management effort or service provider interaction." According to Wikipedia, "cloud computing is shared pools of configurable computer system resources and higher-level services that can be rapidly provisioned with minimal management effort, often over the Internet"[20]. The few keywords are common in above definitions defined by various authors which make cloud computing a unique and optimal way of computation. The keywords are on-demand self-service, broad network access, shared pool of configurable computing resources and rapid elasticity. The three most significant pillars of cloud computing are the service model, deployment model, and characteristics on which cloud computing works. Cloud offers various services that can be categories as SaaS, PaaS, and IaaS.

1. Software as a Services: SaaS is designed for end-users which provides on-demand software services like a business application or media services over the internet. Example of SaaS providers are Rackspace [21], DropBox [22],Cisco WebEx [23] and Salesforce.com [24].
2. Platform as a Services: PaaS is designed for software developers which provides various framework platforms including the operating system. Major PaaS Providers include Microsoft Windows Azure [25], Force.com [26], and Google App Engine [27].

3. Infrastructure as a Services: IaaS is designed for system administrator which provides on-demand hardware resources as VMs. IaaS providers are Google Cloud, Azure, IBM Cloud, Alibaba, AWS [28], Flexiscale [29] ,GoGrid [30] and Oracle Cloud[31].

Cloud and grid computing many times confused as its initial vision was the same like reduce cost, increase flexibility, and reliability of distributed computing but as per the current situation, it's different now. Cloud computing is emerged form and also depends on grid computing as it is mainly a pillar and support infrastructure. Grid computing focused on infrastructure level which provides compute and storage resources while cloud computing mainly focused on economic perspective by providing a more abstract level of services. Instead of creating, maintaining, and operating mainframes or grid, Cloud-based computing is a more efficient and appropriate option as per the current demands of industries. Millions of dollars being invested by known companies like Amazon, Microsoft, IBM, and Google to design the massive-scale system as a datacenter with 1,00,000+ computers.

There are a few more technical aspects where grid and cloud computing create a difference like the grid ownership can be a multiple while cloud work under single ownership. Grid computing needs to use standard and open source software or operating system, while cloud use hypervisor and on top of that multiple different operating systems can run. As well as failure management is very high on cloud computing compared to grid computing. More detail comparison is covered in Table 3. Technical evaluation of computing technologies.

2.5. Dew Computing

Dew Computing is a part of vertical extension of distributed computing cloud to dew computing.The client-server architecture in which the local computer is connected to the cloud server. In a local computer, there is a replica of a cloud server that is called dew server which provides the same functionality as an offline server(without internet). The fundamental objective is to fulfil the computing demand of IoT applications to access data and resources efficiently to improve performance and lower the cost. In [32] author was designed cloud-dew architecture which was distributed information to all end-users smart devices so that they can access data even if there is no internet connectivity. Another computing paradigms have also some issues related to network connectivity, so dew computing is the best way to solve this issue to some extent as DC can work without internet also. Y. Wang et al. [32] define "*Dew computing is an on-premises computer software-hardware organization paradigm in the cloud computing environment where the on-premises computer provides functionality that is independent of cloud services and is also collaborative with cloud services. The goal of dew computing is to fully realize the potentials of on-premises computers and cloud services*". This definition introduces two keywords (1) "independent" implies that on *premises* of a computer that provides services and functionality without cloud server connectivity and 2) "collaboration" means that automatically share program data from the internet.

PP ray et al. [33] defined dew computing as "*Dew Computing is a programming model for enabling ubiquitous, pervasive, and convenient ready-to-go, plug-in facility empowered personal network that includes Single-Super-Hybrid-Peer P2P communication link. Its main goal is to access a pool of raw data equipped with meta-data that can be rapidly created, edited, stored, and deleted with minimal internetwork management effort (i.e. offline mode).*" Proposed Definition "*Dew computing is a software model which provides quick services to users with the help of replicated functionality of cloud services as an offline mode for efficient response*." Different categories work based on dew computing principles, including Software in Dew (SiD)(Google Play), Internet in Dew (Wid), Data in Dew (Did), Storage in Dew (STiD), Database in Dew (DBiD)[32].

2.6. Mist Computing

Mist Computing is an additional layer of fog computing which is more closely to the smart end-devices. Mist computing is a lightweight fog node, named as the mist computing layer, which is an optional layer in fog computing [34]. Mist computing helps to reduce latency and processing time which is most important for real-time and latency-sensitive applications like healthcare, smart city, data analytics, and crowdsensing. Preden, J et al. [35] proposed self-aware health monitoring using mist computing track critical parameters of the human body in the sense of individual behaviour and process data using mist and fog computing paradigms. The authors Arkian et al.[36] have defined mist computing "cost-efficient resource provisioning for IoT crowdsensing applications".

2.7. Fog Computing

Fog computing idea is emerging as a distributed computing phenomenon that expands cloud computing technology to the edges of the network. "Fog Computing" term has been developed by Cisco [37] in 2012. According to the Ericsson Mobility Report (figure 1), June 2018 (Swedish multinational networking and telecommunications company), the number of IoT devices has grown significantly. It will eventually be generated via the Internet of Things. Hence the massive amount of data will be generated. However, some data are time or latency-sensitive, which require real-time processing or quick response, it is quite tricky in decentralizing computing environment, so fog computing is the efficient solution for current issues in distributed computing. Fog computing is defined by various industries and authors like IBM, Cisco, and other fog associations. Still, the first definition proposed by Bonomi et al. [38], in which they define that it requires a highly virtualized platform. Here, Table 2. summarizes various definitions of fog computing by known industries, research scholars and community.

Table 2. Fog Computing definitions

Defined by	Definition
IBM [39]	• Fog and edge use a distributed model which place resources at the edge of the network, not like a centralized cloud computing system. • Reserves some of the assets at the edge of the cloud for fast computing.
Cisco Systems [37]	• The fog expands the cloud technology so that it is closer to the IoT devices which generate and operate on the information. • Fog is flexible to deploy anywhere.

Naha, Ranesh Kumar, et al. [40]	• The majority of computing will be finished at the "virtualized and non-virtualized" end or edge nodes. • In combination with the cloud for high latency computing and durable storage.
NIST [41]	• Horizontal, tangible and digital asset paradigm. • There is also shrewd end-gadgets and conventional cloud farms or server farms. Aid latency-sensitive vertically shielded and applications.
Openfogconsortium [42]	• Horizontal system-level architecture. • Distributes computing resources and services. For example, networking, processing, control and, anywhere along the cloud-to-thing continuum.

3. Why Fog Computing?

IoT and distributed computing are making a remarkable transformation in our modern world. However, significant issues still arise, which need to be addressed by modern computing. Those issues are overcome with the help of fog computing and make it truly successful. Here, the IoT devices are integrated gradually with different computing technology such as cloud and edge computing, but there are some challenges along with advantages too. To overcome these problems, it is essential to integrate cloud, edge, and IoT with fog computing.

From the last eight years, cloud computing has been made a massive revolution in IT industries and later on edge and fog computing also contributing to various non-IT industries for automation and performance improvements. In the above figure 4, 5 and figure 6 statistics are related to the analysis of cloud fog, and edge computing models research and publications trend in highly reputed journals (ACM, IEEE, Science Direct).

In figure 4, the graph compares the last eight years of different computing articles publication trend in the ACM digital library. In which, minimum 200 and maximum around 400+ articles published on cloud computing while edge and fog computing research trend and publication gradually increased from 2014 and it is still under 50 in number. Figure 5 & 6 are comparing individuals for fog and cloud computing publication in three known digital libraries. The overall trends of fog computing research publications are gradually increased in all the three libraries and currently(2020) gained massive attention, while cloud computing publication trend slowly decreased over the years as it now started using with fog and edge computing technology. According to the above graphs and statistics, enough research work has been carried out on cloud so industries and academics are now changing their research focus and more concentrate on the lower layer of the computing paradigms.

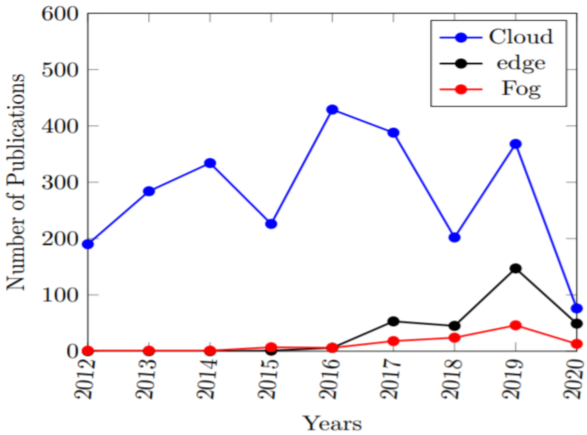

Fig. 4. Published articles with the title "Cloud Computing", "Edge Computing" and "Fog Computing" in ACM Digital library.

3.1. Cloud Computing along with IoT

Cloud Computing is known for on-demand resource provisioning to users over the internet with minimal management interaction. Since 2011, the number of internet-connected devices has rapidly increased, which is almost equal to the earth's population and still growing in the future, as referred to in figure 1. These billions of IoT devices generate massive amounts of data which are different types, nature & produced at different speeds. All of these data are not important and need to store in location. Also, this enormous amount of data must be used in the way it deserves, which follows some objectives. A large amount of data cannot be processed at the IoT device level because of the lack of resources and not because it is cheap. Therefore, the integration of cloud computing with IoT is very important and cloud computing will also fulfil the virtualization of resources and storage space requirements. It has many features such as on-demand services, a considerable amount of data storage and infinite scalability—these capabilities of cloud computing extent IoT to connect with remote cloud servers for information storage and processing.

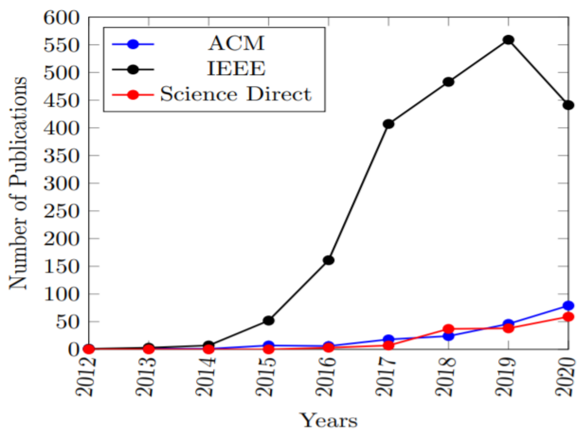

Fig. 5. Number of fog computing-related paper in three digital libraries.

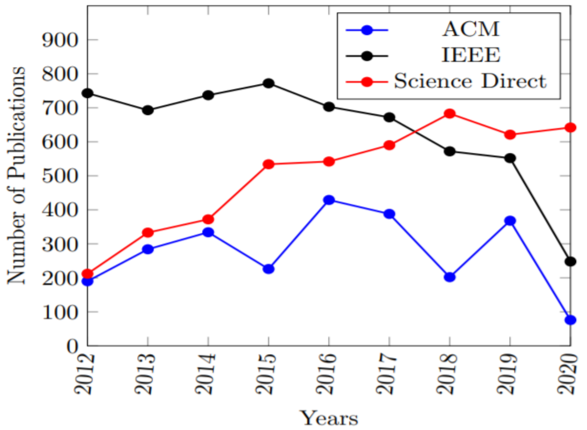

Fig. 6. Number of Cloud computing-related paper in three digital libraries.

In figure 7, there are two-layer, cloud & IoT, combinedly named as Cloud of Things (CoT). The IoT layer has sensors, which only sense and collect the data, and actuators, which take action on device/resources. The cloud layer is full of computing recourse like memory, storage, and other resources which helps to perform data processing and analytics tasks. So, whatever data has been generated by IoT devices are directly communicate to the cloud server via internet connectivity. There are some advantages as well as issues of integration.

3.1.1. Advantages of the cloud, and IoT integration [43-45]

- Communications will be fast.
- Storage data can be stored at appropriate storage technology.
- Scope of execution will increase.
- Processing capabilities- a new tier of computing becomes available.
- New abilities- Various types of application can be run with high availability, security and many more.

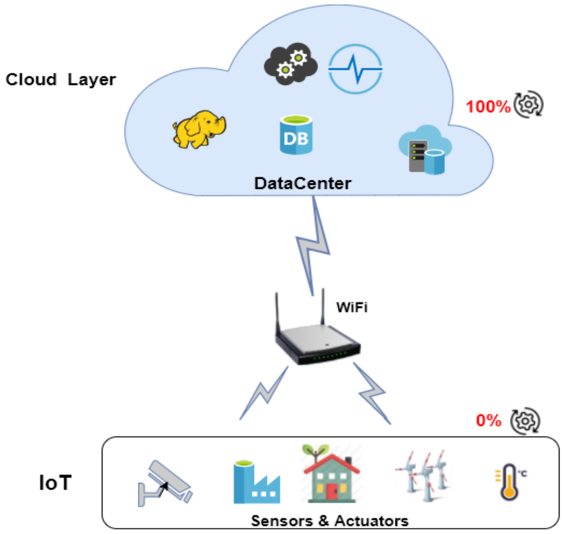

Fig. 7. Cloud Computing with IoT.

3.1.2. Issues in Cloud of Things [46-50]

- Resource allocation: - There are two methods for resource allocation in the cloud,
- static and dynamic. Dynamic resource allocation is more challenging compare to static as it has to resource allocation decision at runtime according to the current situation.
- Quality of Service provisioning and SLA enforcement:- It is essential when a vast amount of data and unpredictability increase.
- Identity management:- Uniquely identification of IoT devices is complicated in a ubiquitous network.
- Heterogeneity:- CoT is wholly designed on heterogeneous based so complexity will be increased.
- Energy efficiency:- Various devices in CoT environment consume differently amount of power.
- IPv6 deployment:- Proper adoption of network architecture is also essential.
- Security and privacy of data in the heterogeneous environment of CoT is a very crucial thing.
- Service discovery:- In CoT, the discovery of new services and checking update of status is a very challenging task.
- Location of data storage:- Where to store and compute during processing data is also essential.
- Protocol support:- Many sensors could not support some known protocols.
- Unnecessary communication of data

3.2. Cloud Computing, Edge Computing and IoT

In Cloud of Things architecture, many times data lose their value because it could not analyze quickly. In the 2000s, the term edge computing was introduced by observing this problem. Edge computing is one part of distributed computing that has data processing capacity at the boundary of the network. Still, it has limited computing capability as compared to cloud processing power or a central data warehouse. The objective of cutting-edge computing is to optimize latency and response time. Edge computing does not replace cloud computing, but its reduce processing load indirectly by downloading a few data from the cloud and work as a stand-alone device. Edge computing is devices and entities that are independent and aware of tools and resources but are not fully aware of the entire domain. As shown in figure 8, the edge layer is added between cloud and IoT devices. Edge layer has a significantly less computing capability. For instance, remote edge devices or micro data centres can collect real-time data and facilitate partial data processing (20%) at the edge layer and cloud layer will process remaining (80%) data. Surveillance cameras, smart traffic lights, motion sensors and vehicles are only the sources that generate information that can be captured and needs to be processed in real-time.

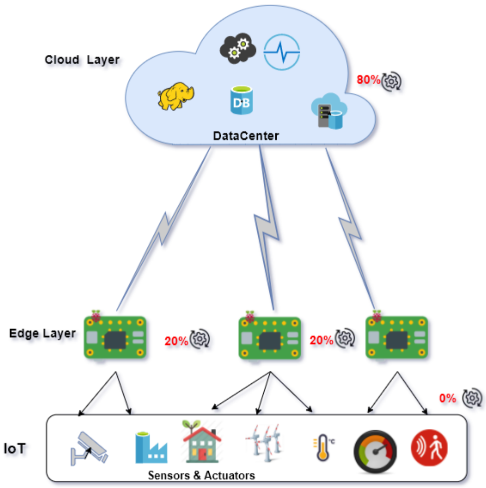

Fig. 8. Cloud Computing with Edge and IoT.

There are many situations where edge computing plays a significant role, such as (1) Retail customer behaviour analysis: - Using edge computing, a retailer can improve customer purchase experience from purchase history. Which will help marketers to connect with a potential customer with high demand products. It will also help to keep sufficient product stocks at the right place in the market. (2) Review of compliance at commercial retail locations: - When data send from cloud to IoT devices As computing resources get closer to IoT devices, compliance and security risk will be increased. As edge computing is closer to IoT devices, the edge layer can reduce the risk by filter out the data locally and only send the required data on the cloud. (3) Remote control and review of oil and gas activities.

3.2.1. Advantages of edge computing:-

- Improved redemption and accessibility for companies

- Lower latency
- Avoid the congestion of the network and data centre
- Lower cost of operation, access and storage
- Expanded interoperability

3.2.2. Issues in Edge computing:-

- Programmability [51]
- Real-time data processing
- Naming[51]
- Optimization metrics[51]
- Latency
- Bandwidth
- Energy
- The intelligent connection scheduling policy
- Services Management[51]
- Scalability
- Reliability
- Resource management
- Privacy and security:- Though security risk is always present, edge computing is of course more secure than cloud because there is less traffic on the network, so the data is less exposed. Here are some possible security attacks like Denial of Service (DoS) attacks and Eavesdropping.
- Ensuring end-users privacy
- Protecting against malicious attacks
- Creating an efficient authentication mechanism

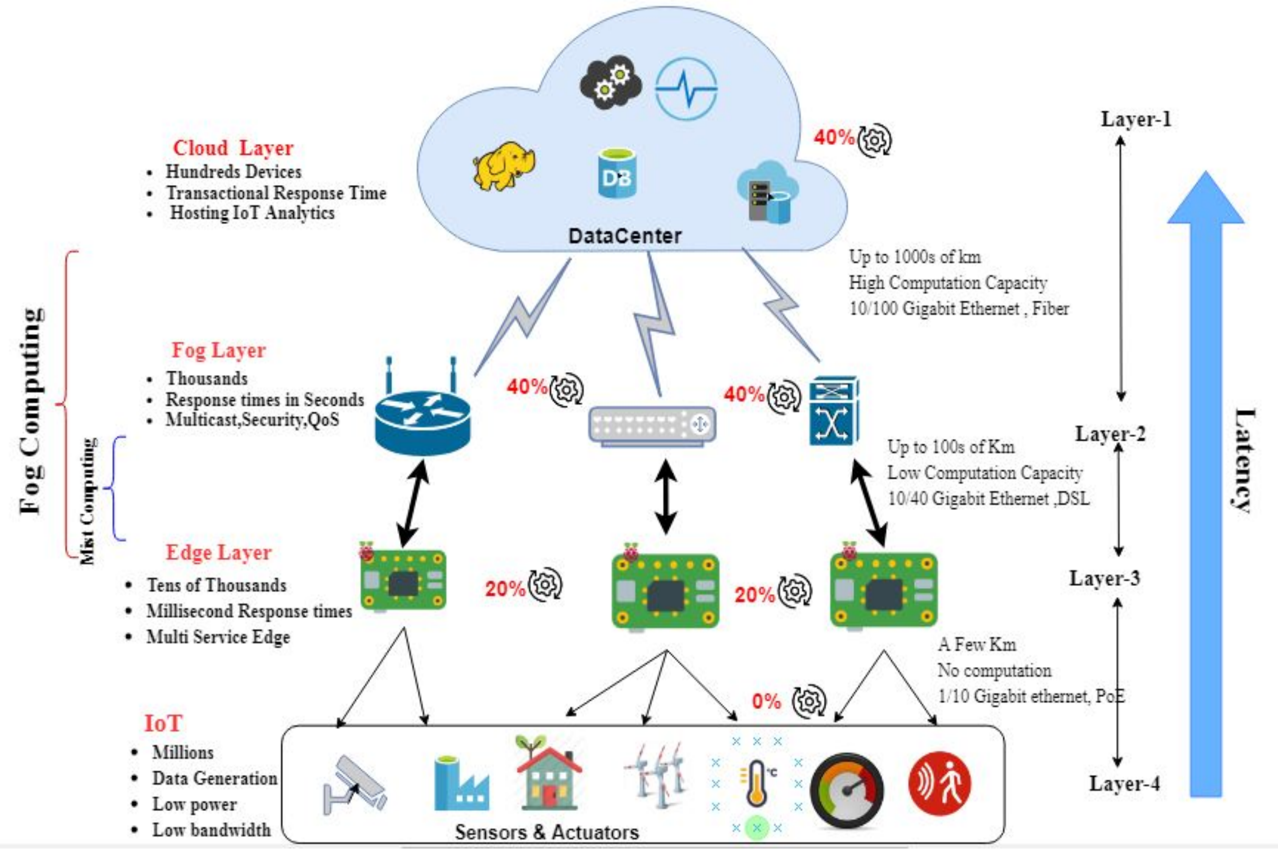

Fig. 9. Cloud, Edge, Fog and Mist Computing with IoT layer) that IoT works on three parts (1) sense (2) compute and (3) action.

3.3. Cloud Computing, Fog Computing, Edge Computing and IoT

Cloud, fog and edge computing offer storage, computation and application services to end-users but they all are loosely coupled. These three computing technologies can work independently according to application requirement but it will not replace each other like fog cannot replace edge or cloud computing altogether. Instead of that edge support fog, fog support cloud computing(superset) to improve performance and user experience.

4. Major application areas of fog computing and case studies

In the last few years, various industries and academic institutions were collaborated and make a community like OpenCORD, OpenFog Consortium, and ETSI mobile edge computing, etc. to solve the current research problems in the computing field. Members of OpenFog Consortium [164](now its reform “Industrial Internet Consortium”) are high tech industries like ARM, Dell, Cisco, Intel and academic institutions like Microsoft and Princeton University are jointly working on fog computing-related challenges. In 2018, OpenFog consortium was carried out one survey in various members’ organizations and found that the top 3 segments are gain moment to adopt fog technology. Which are smart cities, manufacturing and transportation and other sectors are gradually adopting fog computing for overall growth.

Table 6, covered nine major application sectors of fog computing along with applications and the main objective to adopt fog computing technology is to improve performance and operating cost. Manufacturing or factories, Smart city and Transportation sectors are highly adopting fog computing technology as it helps to reduce downtime by quickly identifying problems on the assembly line, also take quick action if required, reduce production cost and waste which is directly increase the revenue of the company. It also plays a vital role when real-time, latency-free action needs to be taken like a smart city and transportations applications. Based on the above survey, it is observed that fog computing is cheaper and secure than cloud computing as majorities of data are filtered and process locally and preserve the bandwidth to reduce the operating cost.

Table 7 shows that, the case studies of specific application areas and name of companies which overcome the existing problem with the help of fog computing[132], fog computing is known for cost savings and performance enhancement. Therefore most businesses in Table 7 below use fog computing to dramatically minimized costs and improve performance and total productivity.

Table 3. The technical evolution of computing technologies.

	Cluster	Grid	Cloud	Edge	Fog
RAM	Limited (GB)	Initially, it's limited (Node will be added it will increase)	High (Pool of RAM)	Very limited(MB)	Limited(GB,MB)
Number of Core available	High	High	High	Limited	High compare to Edge
Storage capacity	Cumulative of nodes	Cumulative of nodes	High (Datacenter)	Very few (MB)	Limited (GB)
Latency	Very low	High	High	Low	Low
Bandwidth Capacity	Very High	High	High	Low	Low
Jitter	Very low	Moderate	Very Low	High	Low
Network type	LAN	LAN & WAN	WAN	LAN & WAN	LAN & WAN
Power Consumption	High	High	High	Low compare to cloud	Low
Computation power available	Limited	Limited	Very High	Very Low	Low
Bandwidth availability	Very High (as it works in LAN)	Medium	High	Low	Low
Cooling/Maintenance requirement	None	None	Very High	None	Very low
Geo-distribution support	NA	Supported	Supported	-	Centralized
Security strength	High	High but doesn't reach the level of cluster	High (virtualization)	Partial Point Solution VPN(Limited)	E2E, Data Protection, Session & Hardware level
Real-Time Communication	Enabled	Enabled	Enabled	Enabled	Enabled
Mobility support	Not Supported	Limited	Limited	Supported	Supported
Communication architecture support	Private IP network	IP network	IP network	IP network	WLAN,3G,4G,5G, WiFi, ZigBee and IP networks
Scalability	No	Moderate	High	Moderate	Moderate
Major focus	Infrastructure level	Middleware	Infrastructure level	Thing level	Infrastructure Level (Specific area or level)
Architecture	Centralized	Distributed ,decentralized	Distributed ,decentralized	Decentralized, Hierarchical, Distributed,	Hierarchical, decentralized, distributed
Loose Coupling	No	Both (tight & loose)	Yes	Yes	Yes
Response time	Milliseconds to micro Second	Milliseconds to micro Second	Minutes, days, weeks (According to scenarios it will change)	Milliseconds to micro Second	Second or Minute *(According to scenarios or application, it will change)
Service providers	Beowulf cluster. Sun Microsystems Solaris Cluster	Berkeley Open Infrastructure GridLab, Globus Project.	Microsoft Azure, IBM, Google, and AWS	AWS, IBM, Azure, Google & Telecommunication firms	Intel and Cisco.

Table 4. Comparison of existing surveys of fog computing

Author	The primary focus of the survey	Characteristic	Applications	Algorithms	Architecture	Simulation Tools	Case Study	Future Research Challenges
Zhang, Peng, et al. [53]- 2018-IEEE	• Highlighting security problems and challenges • Access control problems	✓ (Cloud vs Fog)	✗	✗	✓	✗	✗	✓
Roman, et al. [56] 2018- Elsevier	• Security • A systematic study of security threats, problems, and processes inherent in all edge approaches	✓	✓	✗	✗	✗	✗	✓
Jiang, Xiaohui, et al. [57] 2018-Elsevier	• Real-time nearest neighbour (NN) request over streaming data • A Dynamic Adaptive Quantization	✗	✗	✗	✗	✗	✗	✓
Nath, Shubha Brata, et al. [58] 2018- arXiv	• The overall survey of fog computing • Evaluation of computing, architecture, platforms, and services.	✓	✓	✗	✓	✗	✗	✓
Naha, Ranesh Kumar, et al.[40] 2018- arXiv	• Resource allocation and scheduling • Fog based microservices • Fault tolerance	✓ (Cloud vs Fog)	✓	✗	✓	✓	✗	✓
Hu, Pengfei, et al.[60] 2018- Elsevier	• Key technologies for fog computing	✓ Cloud vs Fog vs Edge	✓	✗	✓	✗	✗	✗
Mahmud, Redowan et al.[62] 2018-Springer	• The effort on a transitional layer between IoT sensors and cloud datacentres	✗	✓	✗	✗	✗	✗	✓
Mouradian, Carla, et al. [54] 2017-IEEE	• Set of evaluation parameter for fog systems	✗	✓	✓	✓	✗	✗	✓
Ni, Jianbing, et al. [55] 2017-IEEE	• The essential position of fog nodes • Methods of privacy and security in fog computing	✓ (Cloud vs Fog)	✓	✗	✓	✗	✗	✓
Perera, Charith, et al.[59] ACM-2017	• Mainly focus on building sustainable smart cities	✓ (Cloud vs Fog)	✓	✗	✗	✗	✗	✓
Abouaomar, Amine et al. [61] 2017-IEEE	• Deal with the backhaul problems • Offload of the network	✗	✗	✓	✓	✗	✗	✗
Yi, Shanhe, Cheng Li, and Qun Li [63] 2015-ACM	• Issues encounter when designing and implementing fog computing systems	✗	✓	✗	✗	✗	✗	✓
Yi, Shanhe, Zhengrui Qin, and Qun Li.[64] 2015-Springer	• Security and privacy challenges	✗	✓	✗	✓	✗	✗	✗

Verma, R., & Chandra, S.[160] 2020-Springer	• Security attacks on IoT-Fog occurred between 2012- 2020	✓	✗	✗	✓	✗	✗	✗
Martinez et al. [161] 2020-IEEE Journal	• Fog resource allocation for IoT applications • Fog infrastructure designing and implementation	✓	✓	✗	✓	✓	✗	✓
Moura, J et al.[162] 2020- Elsevier	• Design resilient fog computing system for latency-sensitive applications	✓	✓	✗	✗	✗	✗	✓
This Paper	• Fog Simulation Tools, applications and Case studies	✓ Cluster vs Grid vs Cloud vs Fog vs Edge	✓	✗	✓	✓	✓	✓

Table 5. Taxonomy of existing Cloud-Fog-IoT Simulation tools

Sr. No	Tools	Type of Tool	Research base	Programming Language	For Networking	Architecture	Protocols	WSN Platform	Cost Model	Energy Model	Operating System	Type	Features	Applications
1	**Cooja**	Emulator	Yes	JAVA	Yes	IoT	RPL, LIBP	Yes	Yes	Yes	Linux, Window	Open-source	Multitasking kernel, Personal web server, Simple telnet client Internet Protocol Suite, Windowing system and GUI.	[65-66]
2	**FiT-IoT**	Testbed	Yes	Python, JSON	No	IoT+ Cloud + Fog	6LoWPAN, RPL, CoAP, MAC, MAC IEEE802.15.4e, 6TiSCH, IETF RPL	Yes	Yes	Yes	FreeRTOS, RIOT, Contiki, Linux	Open-source	Run Script, CLI tools 2.4.0	[67-70]
3.	**Cayenne**	Emulator	No	C/C++, Java, Python, Javascript	No	IoT+ Cloud + Fog	MQTT	Yes	Yes	Yes	Android, Linux, IoS	Open-source	Scheduling, Data visualization, Triggering, Custom Code	All IoT related applications[71]
4	**AWS-IoT**	Platform	Yes	C, JavaScript	No	IoT+ Cloud	MQTT, HTTP	No	Yes	No	Linux, Window	Commercial	Device Gateway, Message Broker, Authentication and Authorization, Rules Engine	[72]
5.	IoTivity	Simulator	Yes	C, C++, Java	Yes	IoT+ Cloud	Ethernet, Z-Wave, WiFi, Thread, Bluetooth low energy (IPSP)	No	No	Yes	Linux, Tizen, Android, Windows, ios	Open-source	Discovery Data Transmission, Device management, Data management	[73-74]

6.	**IoTSim**	Simulator	Yes	JAVA	Yes	IoT+ Cloud+ fog BigData	MQTT	No	Yes	Yes	Linux, Xen, Window	Open-source	IoT Big Data analysis simulation using the MapReduce framework	[75-77]
7.	**CloudSim**	Simulator	Yes	JAVA	No	IoT+ Fog+ Cloud	custom protocols (As per requirement)	Yes	Yes	Yes	Linux, Xen, Window	Open-source	Prototyping and implementation of large-scale cloud computing data centres, virtualized application hosts, software containers, energy-efficient computing resources	[78-80][150][152] [155][158]
8.	**CloudAnalyst**	Simulator	Yes	JAVA	Yes	Fog+ Cloud	custom protocols (As per requirement)	Yes	Yes	Yes	Linux, Xen, Window	Open-source	Attractive GUI Flexible to Configure Evaluating Cost & Performance	[81-82]
9.	**EdgeCloudSim**	Simulator	Yes	JAVA	Yes	IoT+ Edge+ Cloud	custom protocols (As per requirement)	Yes	No	Yes	Linux, Xen, Window	Open-source	Task execution on mobile devices, with Cellular access network 3G/ 4G/5G, Task migration among the Edge or cloud VMs, Energy consumption model for cloud VMs and edge	[83-84]
10.	**FogTorch**	Simulator	Yes	JAVA	No	IoT+ Fog+ Cloud	custom protocols (As per requirement)	Yes	Yes	Yes	Linux, Window	Open-source	QoS aware deployment of IoT applications	[85-86]
11.	**FogDirSim**	Simulator	Yes	Python	No	IoT+ Fog+ Cloud	custom protocols (As per requirement)	No	No	Yes	Linux, Window	Open-source	manage the entire life-cycle of IoT application	[87]
12.	**FogDirMime**	Simulator	Yes	Python, RESTful APIs	No	IoT+ Fog+ Cloud	Custom protocols (As per requirement)	Yes	No	Yes	Linux, Window	Open-source	Fog application management with CISCO FogDirector, performance and tuning of management	[87]
13.	FogDirector	Simulator	Yes	Python	Yes	IoT+ Fog+ Cloud	Custom protocols (As per requirement)	Yes	No	No	Ubuntu Server, Linux	Cisco Fogdirector (Commercial) Fog director (Open source)	experiment different application management policies, simulating, Decrease costs, Continuous application monitoring	[87]
14.	EmuFog	Simulator	Yes	Java	No	IoT+ Fog+ Cloud	Custom protocols (As per requirement)	Yes	Yes	No	Linux, Window	Open-source	Implementation of Fog Computing architecture and emulation of real applications and workloads	[88]

15	FogTorchPI-Cost model	Simulator	Yes	JAVA	No	IoT+ Fog+ Cloud	Custom protocols (As per requirement)	Yes	Yes	Yes	Linux, Window	Open-source	The extended version of FogTorchPi, Estimate monthly deployment cost and run multiple threads	[89-90]
16	iFogSim	Simulator	Yes	Java	No	IoT+ Fog+ Cloud	MQTT	Yes	Yes	Yes	Linux, Window	Open-source	Resource management techniques in terms of latency, network congestion, energy consumption, and cost	[91-92] [151][153] [154][156][157]
17	Cisco Packet tracer	Simulator	No	Python, JavaScript, Blocky	Yes	Cloud+ IoT	MQTT(IoT), RIP, OSPF, EIGRP, BGP	Yes	No	Yes	Windows, Linux, Mac	Open-source	Create and simulate network topologies, protocols	[93]
18	Network Simulator (NS2 & NS3)	Simulator	Yes	C++, Otcl, Python	Yes	IoT+ WSN	UDP, TCP, RTP, SRM	Yes	No	Yes	Linux	Open-source	discrete-event computer network simulators, primarily used in research	[94-95]
19	SimpleIoTSimulator	Simulator	Yes	without requiring any user programming	Yes	IoT+ Fog+ Cloud	CoAP, MQTT, BACnet, and HTTP	Yes	No	No	RedHat Enterprise Linux	Commercial	Single point Tracking of IoT devices,	[96-97]
20	NetSim	Simulator +Emulator	Yes	Java	Yes	IoT	6LoWPAN,TCP,UDP,MPLS, Wi-Max, MANET,GSM,CDMA WSN, Zigbee, Cognitive radio LTE	Yes	No	No	Windows	Open-source	network design, planning, and network R & D	[98]
21	CupCarbon	Simulator	Yes	SenScript,	No	IoT+WSN	zigbee,Lora,wifi protocol	Yes	No	Yes	Windows	Open-source	The smart city-related simulation design tool	[99-100]
22	WSNet	Simulator	Yes	Java	Yes	IoT+ Cloud	Routing Protocols	Yes	Yes	Yes	Linux	Open-source	Node simulation Environment simulation Radio medium simulation Extensibility	[101-102]

Table 6. Major application areas of fog computing

Application Area	Research Work	Services/Sub-Application	The objective of using fog
Smart Healthcare	Nandyala et al.[103]	Healthcare monitoring	Low latency, improved, scalability, reliability, flexible processing
	Gu et al.[104]	Cyber-Physical System for healthcare	Leveraging the fog computing paradigm and designed a cost-effective system.
	Cao et al.[105]	Real-time Fall detection	Quick response, high fall detection accuracy and less energy consumption
	Dubey et al.[106]	Speech Treatments of Patients	Improve their speech intelligibility and voice quality
	Loai A et al.[107]	Big Data Analysis	Fog real-time analysis of patient records
	Gia et al.[108]	ECG feature extraction	Extraction of features with P wave and T wave, heart rate
Smart City	Perera Et al.[109]	Efficient Waste Management	Reduce cost, time, and labour
	Aazam et al. [110]	Emergency Alert Service	Quickly contact to the appropriate emergency department.
	Giordano et al. [111]	Intelligent streets, noise pollution monitoring, and public drainage systems.	Bring computation as close as possible to the physical part, More adaptive and decentralized algorithms.
	Fatima et al. [112]	Smart Buildings	Effective resource distribution reduce cost and time
Smart Home	Chang et a[113]	Smart home surveillance	Increase the privacy and security of the surveillance services
	Zhang et al.[114]	Home automation	Optimize number deployment of a gateway, Improve data Privacy issues
	Nath et al.[58]	Home Temperature Management	Reduce response time, Overcome the privacy and security of personal data
Transportation	Bitam et al.[115]	Vehicle management	Reduce traffic security and offer digital services to road users
	Hou et al.[116]	Parking behaviour analysis	The pattern of parking behaviour understanding of utilizing the vehicular resources
	Salonikias et al.[117]	Intelligent transportation systems	local data storage at roadside units and low latency, less congestion at the cloud
	Markakis et al.[118]	Traffic management and surveillance	High data speed, Ultra-low Latency
	Luan et al. [119]	Inter-state bus entertainment	Fast Response, Easy to find out user access behaviour
Retail	Perera Et al.[109]	Smart Inventory	Reduce operation and management costs
	Lin et al.[120]	Smart logistics	Installation cost is minimized, increase computational efficiency, Reduce operation and management costs.
	Chang et al.[109][11]	Smart checkout	React promptly to demands from customers and Reduce operation and management costs
Energy or Smart Grid	Al Faruque et al.[121]	Energy management-as-a-Service, Home energy management, Microgrid energy management	Reduce the implementation cost, Take less time to deliver to the market, Operate on different domains, Customizable based on requirements
	S. Gao et al.[122]	Smartphone energy saving	Overcome a predefined message delay minimize the smartphone energy consumption
	Okay et al.[123] Perera Et al.[109]	Smart wind power, Smart solar power	Improve the transmission efficiency of electricity. It reduced latency and operation cost. React and restore timely after power disturbances. Fewer management costs. It increased privacy and locality for smart grids.
Agriculture	Caria et al.[124]	Smart Farming	Effectively monitor related to animal welfare Reduce the cost of operational cost.
	Libelium [125]	Monitoring greenhouse conditions	In-depth Monitoring of plant, Improve the quality of crops Help to take necessary action quickly

	Byers [126]	autonomous equipment Irrigation, crop monitoring, yield assessment, pest control,	Reduced Network Bandwidth, Geographic Locality of Control Data-Rich Mobility, Energy Efficiency
Manufacturing	Yni et al.[127] Li Liangzhi et al. [128] Aazam et al. [129]	Smart Assembly Line Efficient Manufacture Inspection System Plant automation, robotics, analytics	Minimize task delays and improve the concurrent number of tasks Improve computing efficiency and indicate the defect type and its degree Overall Equipment Effectiveness (OEE) of the equipment is significantly improved
Augmented reality	Zao et al. [130] Ha et al. [131]	computer interaction game using augmented brain Wearable cognitive assistance based on Google Glass	Processing and identification in real-time Reach a quick end-to-end latency limit provides automatic degrade services

Table7. Case study related to fog computing applications

Sr. No.	Application Area	Case Study	Company	Case study Results
1.	**HealthCare**	Medical equipment company cuts MRI service Time by 50% With a handheld analyzer "BK Medical: Distributed Systems for Medical Ultrasounds"	Keysight Technologies RTI	• Cuts MRI service time by 50% • Faster service call times resulting from the more straightforward setup • Less test equipment damage • Provide real-time response and action in a distributed system • Develop applications independently • Implement plug and play
2.	**Agriculture**	"Keysight Technologies Helps Customers Reduce Water Waste and Cost" The Impact of IoT on Smart Farming and Water Usage Efficiency Smart Agriculture project in Salerno (Italy) to monitor "baby leaves" fourth-generation vegetable production for efficient use of fertilizers and irrigation	Keysight Technologies Machfu EVJA	• Reduce water waste and cost • Resolved a design flaw causing high power consumption and excess battery drain • Smart farming and water usage efficiency 1. Reduce the cost of irrigation system installation, labour, and power • Remotely observe • Prevent plant diseases 2. Improve plant health
3.	**Transportation & Logistics**	GE Transportation: A Leader in Transforming Rail Reducing Logistics' environmental impact by "air quality monitoring in the Baltic Sea Port of Gdansk, Poland."	GE Transportation Libelium	• Increase railroad capacity • Maximizing existing railroad resources. • Movement planner system also improves railroad crew management availability. • A railroad can save up to $200 million a year in the capital. • Time savings • Increased safety of workers • Cost savings
4.	**Manufacturing**	"Keysight Technologies' Data Analytics Solution Improves Manufacturer's	Keysight Technologies	• Improves the efficiency of manufacturing operations equipment by 40% • Improve productivity & throughput by optimizing manufacturing Process

		Operational Equipment Effectiveness by 40%."		
		Global Automaker uses Remote Access Cybersecurity to Maintain safety at its Manufacturing Production Zones	Bayshore Networks	• Maintain safety at its manufacturing production zones • Zero downtime & more efficient management of outages 1. Use advanced predictive maintenance.
		Beer Distributor Improves Security, Shipping Capacity, and Service	Cisco	• Beer distributor enhances safety, shipping ability, and service • Prevent theft and better control over all entrance and restricted areas 2. Increase responsiveness to customer
		Delivering Business Value to Manufacturing	Intel	• Delivering business value to manufacturing • Save millions of dollars annually • Boost efficiency 3. Reduce downtime
5.	**Smart City**	"Smart City project in Serbia for environmental monitoring by Public Transportation."	Libelium	• Environmental parameters can be monitored • People can take advantage of buses location.
		"Urban Resilience in the Smart City: River Flood and Forest Fire Early Detection"	Libelium	• Can readily manage critical facets 4. Strive to improve resilience for neighborhoods

5. Open research challenges

5.1. Security and privacy of fog computing

In computing paradigms, fog computing is also a vulnerable layer (based on application) which deployed and managed by the different service provider. Based on their ownership and physical location, they are vulnerable to the attacks. Security in terms of fog devices and data is a more important aspect because if device control were compromised, then nobody can do anything. Due to the resource constrain in fog computing, some of the prominent attacks which can happen on fog computing are:

- Man in the middle [133]
- Authentication [134]
- Distributed Denial of Service (DDOS) [135]
- Access Control[136][138]
- Fault Tolerance [137]

On the flip side of it, data security is also significant and evolved at the fog layer. Fog nodes are usually more vulnerable, as they are closer to the attackers, and some malicious tasks may happen like data hijacking, black hat hacker, and eavesdropping [60]. There are many other ways in cloud computing to defend against security threats, but they may not use for fog computing as they operate at the edge of networks. Privacy issues arise in fog computing due to the fog nodes present in the territory of the end-clients. Fog nodes may have critical information for partial computing, so the main task is to establish confidentiality between the end device and gateway to maintain a consistent and secure IoT based fog environment.

5.2. Fog resource management

Fog is evolved as a paradigm of cloud technology. So the goal of fog computing is to utilize idle resources available on any fog devices. Fog nodes are resource-constrained such as having low memory storage CPU, workstations, network bandwidth sensors must be done in fog environment. Due to the diversity of devices and various resources in fog environment, resource allocation and scheduling is a very complex and challenging task than traditional one in cloud computing. In fog computing, efficient resources allocation is playing a significant role to perform the job quickly and cost-effectively.

5.3. Static resource allocation at fog node (Predefine)

In static resource allocation, Prior knowledge of the global status of the distributed system must be required, which does not take into account the current state or behaviour of the fog nodes while assigning resources. There are many applications in IoT and fog computing in which specific requirements and other information are known in advance, and that is fixed IoT devices & type of sensor, data type, data frequency likewise. So based on some fixed input of data in fog devices, resource allocation strategies are defined. Static resource allocation may increase the stability of fog nodes, Utilize fewer resources but it does not fault-tolerant and less reliable. Some applications that are ideally suited for static allocation of resources. Example are Health Care, Smart Water Irrigation Network, Industry (Supply Chain and Logistics, Chemical Industries), agriculture & breeding.

5.4. Dynamic resource allocation at fog node (Resource estimation)

As fog is a distributed part of computing, it requires precise estimation of resources at different fog devices, and according to requirement, appropriate resources can be provided. Programming middleware or controller mostly perform resource estimation task. Proper resource estimation improves response time and reliability, which ultimately push up fog nodes performance. It considers the current state or behaviour of a node while allocating the resources. Previously, knowledge of the global status of the distributed system is not required. It distributes client requests by the capability of all existing fog nodes. Resource estimation should be done based on relinquishing probability of service type, customer or device priority, QoS, and SLA. In the majority of cases, fog environment is dynamic like smart city, smart grid. So, the dynamic allocation of resources is needed due to the dynamic nature of the application environment.

It needs to take care of the various resources that should be allocated appropriately to different fog nodes based on prior knowledge of resource estimation. Proper and sufficient resources should be allocated, which helps to achieve end-users Quality of Services requirements. Network resource allocation is also a challenging task in the perspective of fog computing as the fog devices are heterogeneous and various distributed connectivity.

5.5. Energy Management

In fog computing, computing resources are less as compared to cloud computing, so energy consumption should be less. In some cases of fog environment, requests are redirected on a cloud that requires huge computing resources. In contrast, the majority of IoT applications require real-time services, and that needs to be executed over fog nodes only. To improve energy consumption, fog computing for real-time applications is also challenging. Resource consolidation in fog is a difficult task. However, it is a significant advantage in cloud computing to make highly energy efficient by consolidating resources. In [121], the author proposed “energy management as a service” over fog computing platforms, which provide an actual requirement for power management over fog to reduce energy waste.

5.6. Application-Oriented Issues

There are currently some critical issues related to application development, modelling, application service management, application programming platform, and application-aware resource provisioning. Application modelling and service management are a challenging task because of the heterogeneous environment of fog computing in which different nodes use their protocols and various type of services. So it is challenging to design a multidisciplinary application. K. Hong et al. [139] proposed a “high-level programming model” from a large scale to globally distributed use to improve the performance of the application. However, the research challenge is still present, how to find the better placement of request based on available resources and workloads. The authors of Aazam and Huh et al.[140] proposed a framework for resource management and estimation based on various factors like service type, price, and customer type.

5.7. Infrastructure & Platform related – issues

5.7.1. Deployment issues

Deploying and managing N-tier IoT enable applications in a fog computing environment is a challenging and problematic task due to the dynamicity and heterogeneous devices. It is very crucial to the provision of adequate support and component management to successfully deploy applications in fog computing. Stefano Forti et al. [141] proposed models, algorithms, and methodologies to support the adaptive deployment and management of fog applications. For instance, processing data of the application suggests how to identify, validate and distribute application components to the best sequence of actions. Current large scale applications are not monolithic supported [142] and because of that fog compatible applications contain a set of independently deployable services or microservices which are work together to fulfil specific requirements. Stefano Forti et al. [85,89,90,143] proposed a simple model based “QoS-aware Deployment of Fog Applications” to determine the number of available deployments.

5.7.2. Failure management

Gazis V et al. [144] proposed architecture of “Adaptive Operations Platform” to perform efficient deployment of the system, mapping failure models and carry out end-to-end control of fog infrastructure. It was also set up the prototype model for AOP for performance evaluation. There is a high probability of failure in fog computing because it is distributed [40]. So there are many possibilities of device failure like internet connectivity, hardware failure, mobility, power failure, software failure, or unusual activities from users. The majority of fog devices are connected via wireless media, and all those devices work based on battery power, so they are less reliable and maximum chances of failure.

5.7.3. Communication among different layers

In current computing architecture, a reliable and secure network connection must be required for efficient communication between various layers of computing. To perform different computational tasks at different levels, continuous interaction at the right time among devices is significant to achieve SLA. From the figure 9,Cloud-Fog-IoT architecture, if connectivity between cloud to fog layer will fail, then it might be tolerated. Still, the connectivity from IoT devices to fog must be connected all-time quick response to specific tasks and latency-sensitive applications [40].

5.7.4. Interoperability and federation of fog

Fog Computing is known for low latency but in such scenario when users request overwhelming on fog devices, then device unable to handle many applications. However, it is also not an efficient solution to send over cloud due to latency compromise issues. Hence, fog devices must be interoperable so they can communicate with heterogeneous devices at the same layers to tolerate fault up to a certain level. Cloud federation and interoperability feature help to migrate resources between different domains. There are two perspectives for interoperability [145], one from a service provider and another from a service user which helps to overcome issues like vendor lock-in. R. Mahmud et al. [146] proposed solutions of cloud –fog interoperability in IoT – enable health care which is maintained coordination of allocations and services among different devices and domains so that maximum resources could be utilized.

5.7.5. Cloud-Fog Orchestration

Cloud and fog computing are interdependent computing layers in which both use the main features of each other to resolve such limitations, such as lower processing ability. However, fog is entirely contradicted from cloud computing. On the other hand, fog is known for quick response to end-users which is not possible in some cases in cloud computing and increase the overall performance. So coordination between cloud-fog is a critical task. However, such cloud-fog orchestration rises various research challenges like [58]:

- Partitioning of functions or services
- Enforcing semantics in fog computing
- Multi-domain orchestration
- Interaction among fog devices

From the above-listed challenges, partitioning of tasks or services is a very crucial challenge in fog computing. Task partitioning and allocation are well defined in various computing scenarios apart from fog computing such as cloud computing [147], parallel computing [148], and distributed computing [149]. Partitioning task in fog computing also depends on various other parameters like the estimation of resources at fog devices, resource availability, and accepted time to complete the job, placement of subtask, evaluation of over or under-utilization of fog nodes for migration.

6. Conclusion

To recapitulate, in the last few years, fog computing has been reshaping the future landscape of significant industries like Cisco, Dell, HP, IBM, etc. which rapidly increase performance, revenues and also cut down the costs. Fog computing fully utilizes existing distributed edge devices in-network and brings many services and applications form an upper layer to the lower layer at the edge of the network, and it reduces latency, mobility, network bandwidth, the data transfer time, security, and fulfils the demand of real-time applications to a great extent. In this survey paper, we discussed an overview of IoT and existing basic computing technologies with a layered architecture. Based on the layered architecture of various computing technologies, we covered step-by-step integration of the IoT environment with cloud, fog, and edge computing along with its existing issues. We have also presented a detailed survey of the various simulations tools of edge, fog, cloud, and IoT enable applications that help to simulate various modified application scenarios to observe behaviour and feasibility of application in different environments. In addition to that, through the comparison of three computing technologies with details QoS parameters, we came to know that which simulation tool is suitable for which type of application and which are the necessary modification can be done before deploying in the real environment. Then, we covered significant application areas that are currently adopting fog computing technology in the major industries and also included case studies of various companies. Finally, a range of problems and open-ended research concerns with resource allocations, device implementations, energy usage, protection and privacy, and cloud-fog orchestration is worth further study and analysis. In a nutshell, this comprehensive survey helps you to understand and execute IoT applications on a fog computing environment, and it also helps to work on the current research directions, which are still unsolved.

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