A Critical Review on the role of Fog Computing and Edge Computing in Internet of Things (IoT)

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Abstract- Fog and edge computing are two of the most popular technologies that represent work in the succeeding domain areas: networking, privacy, security, and cloud computing in a comprehensive manner in the field of IoT. It is a growing and very important computing paradigm as compared to cloud computing where many services are available like computation, data storage, calculation, interpretation of data and networking offered which are implemented with the help of fog and edge layer at edge networks in multi-level, distributed manner and possibly in a support context. These cloud elements/roles are placed at network edges physically as well as virtualized manner at edge devices, feeling the "computing everywhere" concept. This study uses the most recent approach, which extends cloud computing to network edges and provides the technology and architectural era of both fog and edge computing platforms. In this paper, different computing paradigms have been discussed from architectural and technological points of view which are as follows fog, edge computing mobile edge, and cloud. To grasp the working of fog and edge computing comprehensive survey of mentioned domain areas has been discussed and surveyed from a technological and architectural point of view. In this paper, current architectures are referencing and describing core areas of fog and edge computing in a comprehensive manner. Architectures are presented on the following areas of IoT i.e., networking, security, software, security and applications are evaluated based on the proposed model.

Keywords: Internet of Things, Smart Cities, Fog Computing, Edge Computing, Cloud Computing.

1 Introduction

Cloud computing and fog computing play interactively in which end users come close to the network edge because fog computing is an extension of cloud computing. In this research paper, many issues have been discussed which has a great impact on fog and edge computing like connectivity issue Security and privacy networking latency geographical distribution support, and quality of service. Fog computing is a popular model which extended to network edges and leads to the extension of the cloud. Edge and fog both service and address the following domain areas application service [1] data storage and retention many computing services facilities and network security and infrastructure.

Both terms fog and edge computing work alternatively in the industry domain and educational sectors. In this research paper, it explains both technologies which work on following the network communication improvement and minimizing the network latency application communication issues on a multitier level in the distributed environment but the distinguishing factor between these technologies is in which manner the data is handled computed and processed. In other words, the main distinguishing factor between fog computing and cloud computing is that fog works in a distributed style, and cloud work in a centralized manner. Further data handling storage interpretation processing works under fog architecture in distributed style. In the paradigm, the cloud works at the backend while fog and edge work at the front ends [2]. In edge, computing the sensors actuators [3] work at the network edge and the main function is to push data toward locally installed storage infrastructures, the basic source of data comes from these end devices. After this, the data has been transferred to fog which also processes stored data at its level before sending it to the cloud. Edge computing does not offer such kind of facility to offer services like fog and cloud which serve the following services which are as follows infrastructure as a service software as a service platform as a service hosting web database and much more. Fog computing support works like a cloud. Precisely the edge computing [3] main function is on the network edge level but the transmission infrastructure will be extended to fog computing see figure 1.

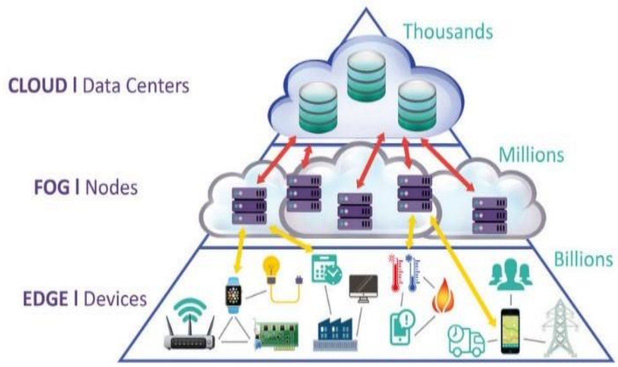

Fig.1 Different Models of Cloud [1]

Cloud computing takes part important role to provide computing facilities, which are independent of location and are in a distributed manner like cloud data centers which are much more distant locations from the end user's vicinity. However, with the speedy adoption of cloud platforms virtualization and many more services available but due to limitations of location independence network latency, many new dimensions are involved to adapt the various computing paradigms introduce to address these issues. So multi-tier cloud computing has been extended to mobile edge computing, edge computing that is important fog are necessary trends that evolved to give minimize the network latency, resource management, monitoring and overcome software and application requirements. With the evidence of IoT, smart applications require speedy response time from network and software end high-level data processing. Multi-level and intense data processing requires high computing resources and high bandwidth with low latency.

Fog computing represents a paradigm concept in which the edge of the network following domains has been addressed like network services storage facility computation capabilities and monitoring which are earlier provided in a cloud environment over the internet [1]. Further, in fog computing like a cloud, it is possible to manage the following domains like networking data storage facilities programming of networks and applications, management of computing facilities, and data management [2]. It facilitates a ubiquitous and distributed environment in which all components communicate and cooperates to perform data storage and resources management and processing tasks, which are performed without coordination of, centralized cloud-level applications. Due to distributed nature of fog computing organized computing model is utilized in IoT applications and data management [3]. From a practical viewpoint, fog computing implementation requires attention in many aspects such are network security and privacy application and system design software implementation.

Comparing the existing research papers in IoT cloud edge and fog computing and differentiating between previous papers. The concept of cloud, fog, edge, and mobile-edge computing are discussed and found similarities as well as diffusions at the end of this section, a comparative comparison of these technologies has been explained which target the importance and role of fog and edge computing. In addition, possible challenges are discussed. IoT possible technology architectural concepts including networking, software, and application introduced. In evaluation, based on proposed architectures complete model was established which gives guidance towards further research in this domain.

2 Comparing the Existing Surveys

Many extensive surveys have been performed and have already been published for research community reference in the general field [4]. In a short lot of surveys, papers have been published that address various aspects of IoT, Fog, and Edge computing models.
In research, the paper on fog computing surveys the Architecture and key technologies discussed [5], the author presented fog and edge computing general architecture but, in this paper, he did not address the previous architectures in IoT applications. A comparison of cloud, edge, and fog computing is presented in the context of six key technology areas are discussed namely which include naming conventions, privacy concerns for security data storage communication channels, and computing are explored. In the research paper [6], the author works on the thirteen key areas of IoT applications and works on seven use cases that are useful for fog and edge computing. Seventeen architectural prerequisites like multi-layer programming ability, multi-layer tenancy, storage data mobility, and geographical distribution in the context of use cases utilized in fog computing and edge computing have been discussed. In fog and edge, computing taxonomy has been explained [7].
The author concisely reviewed issues involving fog computing and show the computation off-loading model in his existing work comparative review. The work in [8] author details an exploratory survey targeting edge computing and fog computing use cases and application scenarios but did not address the application deployment in distributed environment or scenario in fog computing at network edges to support end-users' support. In [8] other architectural aspects are overlooked while only application architecture is discussed. In [9] completely works on architectural aspects but only targets the application domain area. In the application area, the author did not define specific functions of the system as compared with different levels of their internal communication and coordination. In anticipation of fog computing deployment at a large scale, the only emphasis on the system-level architectural aspects is covered while other areas are not covered by the author. From the architectural point of view security aspects of computing resources monitoring and management, and software aspects are discussed but from a security point of view, the author did not address the authorization and authentication mechanism of security levels between modules. In [10] author publishes the recent survey in his paper and shed the light on fog computing edge computing in a formidable manner as well as covering competitive computing paradigms. Based on the objective and subjective matter, he categorizes his current research.
The following domain objective point of view is discussed in a research paper. Twelve areas make the foundation of the advent of fog computing such as availability/reliability, management, programmability, large scalability, heterogeneity cost energy QoS security mobility bandwidth. With the proposed seventeen points a taxonomy has been elaborated which represents the subject's point of view. The author informally discusses a few key areas of resource management and system and explicitly do not address architectural aspects.

3 Taxonomy for Fog/Edge Computing Research

In recent years, a lot of researchers devoted their work to many aspects, and possible scenarios of different computing paradigms like cloud, mobile-edge, edge, and fog. In the area of fog and edge, computing many development efforts has been performed due to the diverse and vast nature of research in these eras. A classification framework provides the challenges, shapes, and different trends to shape the future direction of research and implementation. In [1], issues problems and issues of fog and edge computing are classified into 7 main areas domains: security and privacy in IoT monitoring challenge offloading upload of data retention intense computation multi-tier programming models different levels of interfaces quality of service and networking.
To plan and implement a taxonomy of the role of fog and edge computing research, Buyya et al. [7], presented 6 areas of relevant technology which are as follows fog node design, security and privacy concerns networking infrastructure management of computing resources, service/resource provisioning in real-time interaction at network edges, nodal collaboration. From the technology point of view, the author address above mentioned issues and did not explain the architectural aspects of the networking domain and especially the quality of service. Mouradian et al. [8] subdivided the challenges of fog and edge computing

and current research into main two categories: algorithms working and architecture implementation. The author mentioned algorithms, as well as technologies that follow the provided architectural directions, provide an elaborative explanation in the context of running processes module tasks architectural aspects implementation. On the other hand, on the architectural side, the author focused on the diversity of publications in this era, and considering the previous classifications on fog computing by focusing on applications scenarios, new taxonomy was proposed which is presented in figure 2. Working three top-level research aspects are considered which are technologies, algorithms, and architectural design. A high level of system architectural dimensions has identified the main core functional parts and system organization. Technologies and algorithms are the architectural dimensions, which provide the implementation, tasks, and underlying processes in terms of system design.

Each of the three aspects mentioned earlier has been applied in many subject areas, which are subdivided into six categories: security and privacy, computing resource management, networking, application, software, and computing paradigm. Therefore, previous classifications encompass a matrix of research areas in fog, and edge computing is defined. The taxonomy provides a comprehensive framework in which all previous research classification has been mapped.

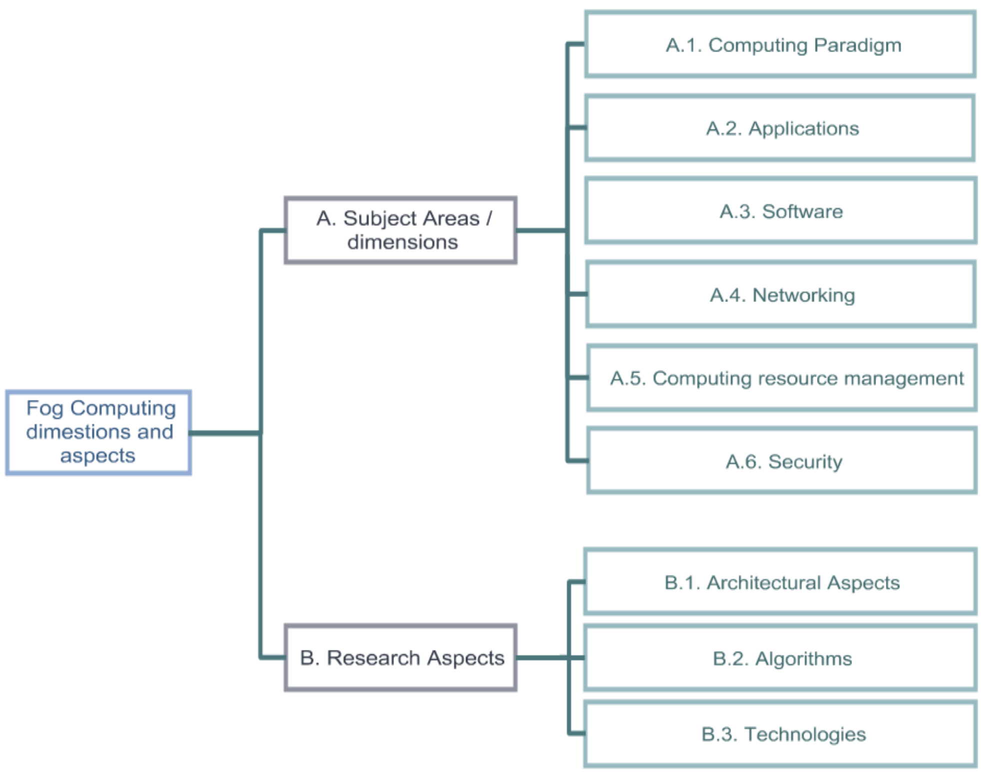

Fig.2 Taxonomy of Fog and Edge Computing [10]

4 Multitier Computing Models

Cloud Edge and Mobile are three technologies specifically associated with fog computing, but there are Clear variations mentioned in this article to describe the Fog application.

4.1 Cloud-Based Computing

The control and delivery over the network of on-demand services have emerged as a convincing model for cloud computing [11]. Cloud computing's rapid growth is rapidly transforming the Information technology environment and utility computing finally transforms into fact [12]. This model is providing services to substantially minimize the overhead of their provisioning strategy. It also helps them to scale up their demand-based resources. In addition, cloud computing provides secure services through virtualized computing, storage, and network technologies generated by next-generation data centers. In addition, users can access services and cloud data from anywhere and at any time.

In cloud computing, users are given services for use by cloud suppliers (for example Google) for payment to acquire platforms, infrastructure, and apps from a common pool of resources. In general, big data centers with adequate computing capacity have been developed by public cloud providers to serve several active users. In addition, users can practice services on-demand and efficiently. Cloud computing offers many services shown in Figure 3. Consequently, demands for run time or latency-sensitive computing services often experience significant oval delays, network traffic, and deterioration of service quality. Figure 3 illustrates some cloud computing problems briefly [12].

Various models of the concept for multitier cloud computing are to provide memory and computation with a succession of data centers of growing scale to minimize network delay and spread computing load over geographically distributed cloud resources [13].

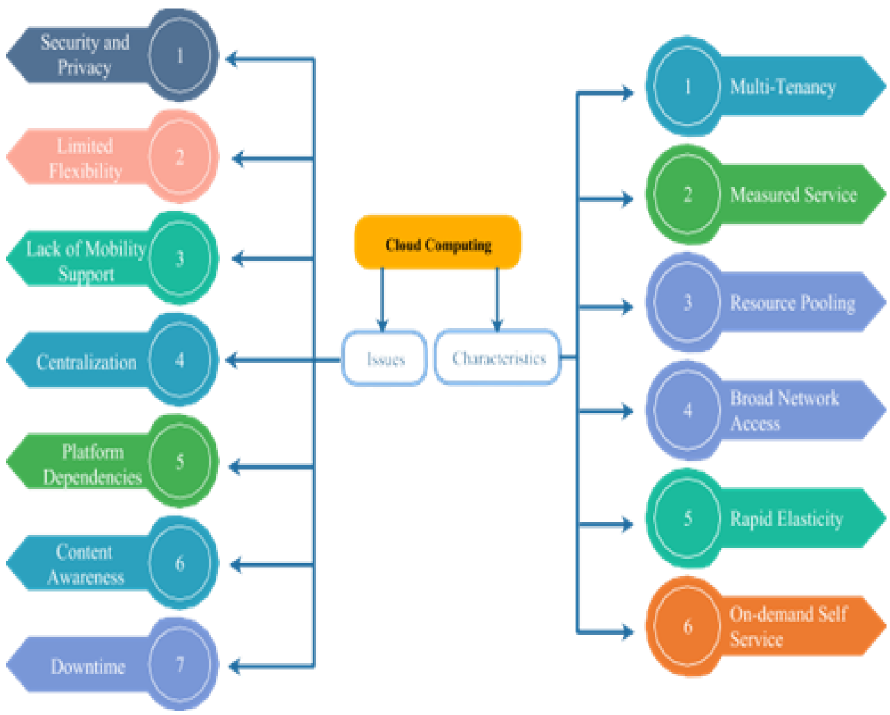

Fig.3 Cloud Computing Issues and Characteristics

4.2 Mobile Cloud Computing (MCC)

As an effective tool for learning, entertainment, social networking, video and audio messaging, and reading the news, mobile devices are used. However, smartphone users are not able to obtain the same level of service compared to desktop users because of the resource limitations of mobile devices. To address the limited resource issue of mobile devices using the cloud, mobile cloud computing (MCC) has been implemented. MCC is defined by the MCC platform as follows:' MCC applies to an architecture where both data processing takes place at its simplest outside the mobile devices. Apps move processing power and data storage away from mobile phones and into the cloud, introducing not only smartphone users but a much wider range of mobile subscribers to apps and mobile computing.

In other aspects, MCC is characterized as a hybrid of cloud computing and mobile apps where all computational systems are processed in the cloud [6]. With the support of base centers, or access points mobile devices connect with the cloud. Mobile system operators make sure in a good position to provide useful services such as mobile healthcare, mobile learning, mobile gaming, and mobile governance [14]. MCC key benefits and some associated threats are classified. One of the basic issues, mainly due to the massive increase in today's network traffic loads, is long WAN latencies. Among other problems facing MCC are bandwidth restrictions in wireless communication networks is mission-critical applications. On the security side knowledge of the location and activities of the user by the service provider may cause problems with privacy. In general, cloud computing security problems, such as data outsourcing and data outflow issues, still happen.

4.3 Edge Computing

Network engineers and Scholars have developed groundbreaking solutions such as cyber searching [15], cloud resources, and technological out loading to address the limitations of cloud computing and MCC. These techniques are suggested to unload components of the computation in the vicinity of the consumer from the cloud to a surrogate computer. Typically referred to as edge computing, these technologies take benefit of position knowledge [16]. Increasing the efficiency of applications and minimizing congestion problems that cannot be achieved with a modern network Structure in figure 4 [17]. ETSI has described MEC as "a model allowing cloud computing platforms to serve context-aware applications within the radio access network nearby mobile subscribers. The MEC platform makes it possible to host computing and utilities at the edge of the network, which decreases subscribers' overall latency and bandwidth consumption [18]. Network operators may allow third parties to manage the radio network edge, which facilitates are implementation of new software and edge networks to phone users. MEC offers a rich number of features that allow new technologies to be provided by service providers. MEC gives a wealth of features that allow new technologies to be provided by service providers example, the work provides a solution where the application developers are provided with RAN information, for example, network load. This network data is used to provide mobile subscribers with context-aware services, thus enhancing customer loyalty and improving the quality of experience (QoE).

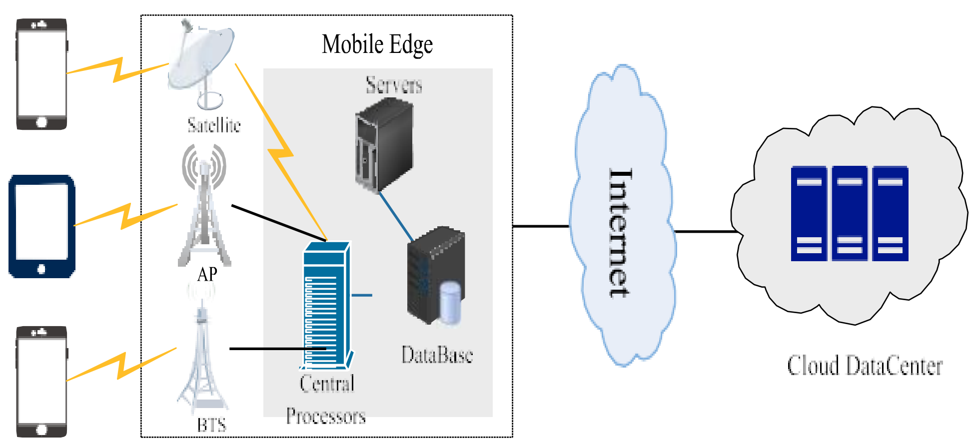

Fig.4 MCC/MEC Computing Architecture [17]

4.4 Fog Computing

Fog computing is a computing model that accumulates memory and computing resources utilizing near current-user edge devices that are used to perform the tasks of configuration, measurement, processing, control, and management. Since its creation, this one has been approached from different viewpoints by researchers. There may not be a consensus on its meaning and description as a result. Fog computing is considered by some to be the same as the expansion of edge computing [17] on another side, it is the expansion of cloud computing [13]. However, a common assumption of the following fog computing properties:

It is dependent on the situation in which a large number of diverse, pervasive, and distributed devices operate networks or applications collaboratively. Word Fog is not limited to a single field of technology which encourages the heterogeneity of devices and interfaces. It generally consists of a serverless platform that supports basic functions of the network and new application services that generally run in heterogeneous distributed locations. Fog ropes feature such as location awareness, connectivity, and managed mobility [3].

Fog nodes form the physical structure that delivers facilities at the edge and throughout the network with resources. These systems are divided into two separate classes [19]. Cloudlet is a secure server or group of computers rich in resources that are finely connected to the Internet and have access to mobile devices for use. In other words, the data center on the edge of the Internet is a mobility-enhanced and small-scale cloud data center. It supports low latency. IOx is a new Cisco fog platform that operates on the Connected Grid Router. Cisco's elementary priorities helped overcome the IoT "data tsunami" and "data severity" issues [13]. IOx is a recognition of fog in the network on an industrial scale. By spreading processing load over entire networking components, doing so eliminates a significant volume of traffic load on the cloud centers.

Paradigm/ Criteria	Cloud Computing	Mobile Cloud Computing	Edge Computing	Fog Computing
Latency	High	High	Low	Low
Delayed-Jitter	High	High	Low	Very Low
Location Awareness	No	Yes	Yes	Yes
Support for Mobility	Limited	Supported	Supported	Supported
Geo-Distribution	Centralized	Centralized	Distributed	Distributed
Real-Time Interaction	Limited	Limited	Supported	Supported
Location of Service	Within the Internet	Within the Internet	At Edge	At Edge
Distance	Multiple Hope	Multiple Hope	Mostly one Hop	Mostly one Hop
Storage Capacity	High	High	Few	Few
Storing Data	Permanent	Permanent	Transient	Transient
Coverage	Global	Global	Local	Very Local
Response Time	Seconds	Seconds	Milliseconds	Milliseconds

Fig.5 Comparison of Computing Paradigms

5 Evaluation Base Metrics and Challenges in Computing Models

Outdated cloud-based systems are challenged by IoT on the scenario of applications in IoT devices, their fragmentation, and the inactivity seen in the cloud. Using a distributed and decentralized computing model, Fog computing distributed systems, organization, and data processing through the network. It facilitates the reduction of network traffic, making it an acceptable application for IoT tasks [9]. Fog computing can be used synonymously with edge computing in certain situations [8].

5.1 Network Latency

The execution of network edge fog computing allows data to be processed close to end devices, rapid data processing and reducing the delay [2]. Lesser fog delay offers better support for time-sensitive applications that are responsible for real-time analysis of raw data obtained from sensors, sending control commands to sensors and actuators, and eventually delivering central cloud overview reports for data visualization purposes. A time-sensitive application requiring actual analytics is cloud robotics. The motion control of a robot relies on information that is obtained by sensors.

5.2 Location Awareness

Although fog nodes are physically dispersed and are near to the points, particularly it can accurately estimate the physical position of the objects. This helps fog nodes to monitor objects based on their location to make smart decisions [9]. Using its position recognition feature, these decisions can be more effectively enforced in fog.

5.3 Mobility

Mobility support can be seen from two different viewpoints. It needs to have a penchant from the point of view of the customer to gain access to services anywhere at any time, without any constraint it handles the allocation of resources from one location to a new one and the relocation of objects. When an object passes across the network, another neighboring fog node will be assigned to this object as it leaves the coverage of a fog node. This service transfer eliminates service interruption and ensures continuity of service [2]. Upper access points support communication with mobile devices at the application level. This protocol specifies a LISP router mechanism for encapsulating endpoint identifier (EID) addressed IP packets for transmission through a network infrastructure that uses Routing Locators (RLOCS) for routing and forwarding.

6 5G 3 Tier Architecture Computing

5G technology is the best and most important infrastructure in IoT applications which has more speed than other communication channels. This section, first, has to consider the computing model for 5GPPP architecture for multi-tier for which a 5G network is presented. Now a day as related to current setups like 4G, Fifth Generation networks is the finest one to get the finest development in the network era. Also, the number of devices and better energy cradles [25, 26] is used for communication channels used in connected mechanisms.

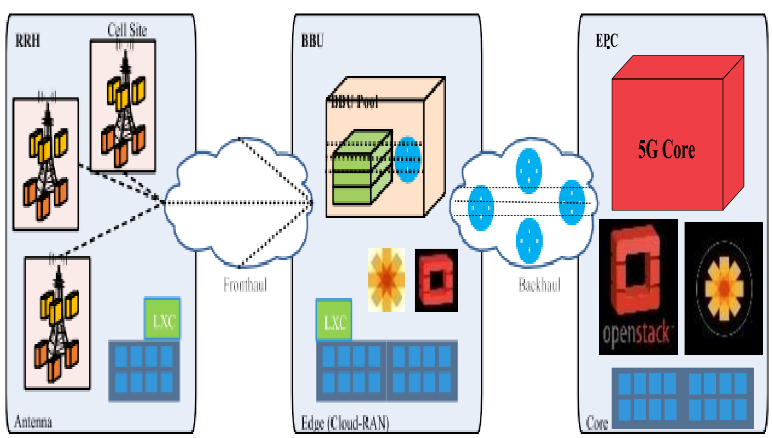

Fig.6 A multi-tier computing model in 5G [26]

From the above figure, a multi-tier model regarding computing is adopted from the 5G PPP architecture. To overcome the solution of speed and Communication Bridge it needs to expand the performance of fifth-generation channels. Also concerning efficiency by energy, enable wireless communications like direct device which is used to upkeep the mounting era of networking functions, virtualization, and control intelligence by parting off a network. 5G will use the sources and latest trends of the central cloud, RAN's cloud mechanism, and network verge by cell-level dispersed mobile cloud. This may have many chances for mobile firms to recruit or enhance many actual facilities that cannot be brought on the current mobile node with the addition of wireless networks [27].

Mostly C-RAN incorporates cloud-based computing into the source of RANs. Though, the application in which radio signal processing functions are stored is consolidated under the behavior of cloud computing servers in the fifth generation 5G core. The content which is downloaded in the form of packets is directly gripped from the main content source deprived of reaching the backhaul assistance mechanism.

Distributed 5G mechanism is very next to IoT devices and mobile devices and is also the finest method to get the marginal end-to-end issues regarding latency. The minimal latency required in creating low latency solicitations such as machines with remote control handling techniques and independent schemes is used to configure the latency constraints. With the help of fog-based computing, architecture like C-RAN and fifth-generation (5G) based functions can also be provoked to get the full benefit of native stations like the processing of radio signals. Other mechanisms in edge devices and cooperative radio resources include management distributed and storing capabilities [28].

Cloud and fog computing components are combined to make a separate mechanism regarding server quantum. Due to this, the existing phenomena of users and running applications depends on mutual cooperation regarding business, management operation, and assigned tasks by the user. Some of these processes are very suitable and efficient which results in the formation of cloud centralization, while other processes which are running at the back end are better to combine to perform the results at the fog level [30, 31].

6.1 Computing Architecture with IoT & IEC

An organization named as International Electro-Technical Commission (IEC) is working on different architectures. ISO has made an architecture in which IoT-based components are used to define various materials in an IoT mechanism. As it is known that in IoT-based running applications, different fog-connecting nodes are also connected to different devices which may collect data from other sources. And then it stores them in a certain position where certain information and data are processed manually in the form of value ability [32, 33]. When IOT-based functions are used to collect the data, their performing request should be sent to the matching fog nodes with the help of many components like time and delay. Thus, the best coordination from the user side and other processes are required to process this.

7 IoT Security and Privacy Issues

7.1 Latency in IoT

The event in a cloud computing environment when the signal is causing a delay and not being sighted is known as network latency in IoT. In past, significant work has observed that network latency causes information disclosure [34, 35]. Indeed, the information leakage is also dependent on network topologies e.g., the star topology does not disclose information.

7.2 Bottlenecks (Delay) in IoT Technology

Emergent requests that involve delay can host different tasks elsewhere unbiased expectancy desires. Suppose in the method of application manufacturing of networks, it contains thousands of network sensors that are arrayed inside a mechanism. In such situations, it is very difficult to assure networking. Furthermore, several instruments are organized in strict situations that the majorly meditative and absorptive technique works on the phenome in signal transmission, for example, if it take a metal pipe or injection molding machine, then it creates a suitable mechanism to work on the selected node [36, 37]. At last, all the nodes are not inevitably related to power provisions, then it need to create a suitable environment.

7.3 Security& Privacy Issues

To ensure the reliability of IoT it must be secure, private, and trustworthy. Unauthorized access, personal information disclosure, leakage of private data, and data corruption are some of the problems that occur due to security breaches of IoT. The new algorithms are being developed to make IoT more secure on regular basis. Confidentiality, access control, privacy, RFID security, and secure routing are five difficult sections of IoT security. Many communications channels have a major threat to their security. The connectivity of high intelligent objects like home appliances and other connections leads to many security challenges, which are not part of the latest security problems and their solutions. In general, security challenges mean data leakage from some external sources like attacks from different hackers using different techniques like brute force, DOS & DDOS attacks, eavesdropping, Sybil, and by stealing data packets used in the source of networks [38, 39]. To overcome this solution, a Security shield for the Internet of Things is used which was identified in the year 2014 by DARPA (Defense Advanced Research Projects Agency). As it knows that in IoT, all the people and connected devices are joined with each other to perform a strong communication platform. Many devices that are connected to the internet are not much secured as their security mechanism is not much efficient. To fulfill this issue, some basic requirements are needed to prevent the network from malicious attacks. For a secured network following are the capable measures which have to be taken.

8 Conclusion

Throughout this research paper, detailed scrutiny of different challenging domains including fog, edge, mobile edge, and the cloud was studied with pros and cons. Moreover, the research on the nomenclature of cloud, edge, and fog computing respectively was carried out that discussed various domains (Networking, Security and privacy, software, application heterogeneity, infrastructure) along with research aspects, technologies, and framework. A detailed examination of fog computing framework assessments is presented in this paper. These architectural viewpoints explained physical and logical components and modules in an edge and fog computing environment and their roles in IoT. Few addresses network architectures' point and few pay attention to application and software level architecture. Similar technologies need to be adopted and developed consistently and vigorously to take full advantage of edge and fog computing in IoT, some are already taken place. The recommended architectures were assessed and compared based on many domains and criteria. Finally, a survey on research issues and each subject domain directions were carried and main challenges were investigated and directions on further research were provided. The findings of this research paper survey would enable researchers to refrain from attempting to resolve the current gaps to help bring this technology to perfection.

9 References

[1] S. Yi, C. Li, and Q. Li, ‘‘A survey of fog computing: Concepts, applications, and issues,’’ in Proc. Workshop Mobile Big Data, New York, NY, USA, 2015, pp. 37–42.

[2] S. Yangui, P. Ravindran, O. Bibani, R. H. Glitho, N. Ben Hadj-Alouane, M. J. Morrow, and P. A. Polakos, ‘‘A platform-as-a-service for hybrid cloud/fog environments,’’ in Proc. IEEE Int. Symp. Local Metrop. Area Netw. (LANMAN), Jun. 2016, pp. 1–7.

[3] O. Salman, I. Elhajj, A. Kayssi, and A. Chehab, ‘‘Edge computing enabling the Internet of Things,’’ in Proc. IEEE 2nd World Forum Internet Things (WF-IoT), Dec. 2015, pp. 603–608.

[4] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, ‘‘Edge computing: Vision and challenges,’’ IEEE Internet Things J., vol. 3, no. 5, pp. 637–646, Oct. 2016.

[5] P. Hu, S. Dhelim, H. Ning, and T. Qiu, ‘‘Survey on fog computing: Architecture, key technologies, applications,

and open issues,'' J. Netw. Comput. Appl., vol. 98, pp. 27– 42, Nov. 2017.
[6] C. C. Byers, ''Architectural imperatives for fog computing: Use cases, requirements, and architectural techniques for fog-enabled IoT networks,'' IEEE Commun. Mag., vol. 55, no. 8, pp. 14–20, Aug. 2017.
[7] R. Mahmud, R. Kotagiri, and R. Buyya, ''Fog computing: A taxonomy, survey, and future directions,'' in Internet of Everything. Singapore: Springer, 2018, pp. 103–130.
[8] C. Mouradian, D. Naboulsi, S. Yangui, R. H. Glitho, M. J. Morrow, and P. A. Polakos, ''A comprehensive survey on fog computing: State-of-the-art and research challenges,'' IEEE Commun. Surveys Tuts., vol. 20, no. 1, pp. 416–464, 1st Quart., 2018.
[9] R. Kumar Naha, S. Garg, and A. Chan, ''Fog computing architecture: Survey and challenges,'' 2018, arXiv:1811.09047. [Online]. Available: http://arxiv.org/abs/1811.09047
[10] A. Yousefpour, C. Fung, T. Nguyen, K. Kadiyala, F. Jalali, Niakanlahiji, J. Kong, and J. P. Jue, ''All one needs to know about fog computing and related edge computing paradigms: A complete survey,'' Syst. Archit., vol. 98, pp. 289–330, Sep. 2019.
[11] A. Shawish and M. Salama, ''Cloud computing: Paradigms and technologies,'' in Inter-Cooperative Collective Intelligence: Techniques and Applications. Berlin, Germany: Springer, 2014, pp. 39–67.
[12] I. Sahu and U. S. Pandey, ''Mobile cloud computing: Issues and challenges,'' in Proc. Int. Conf. Adv. Comput., Commun. Control Netw. (ICAC- CCN), Oct. 2018, pp. 247–250.
[13] S. H. Mortazavi, M. Salehe, C. S. Gomes, C. Phillips, and E. de Lara, ''application execution in mobile cloud computing: Motivation, taxonomy, and open challenges,'' J. Netw. Comput. Appl., vol. 52, pp. 154–172, Jun. 2015.,'' in Proc. 2nd ACM/IEEE Symp. Edge Comput. (SEC), vol. 20, 2017, pp. 1–20.
[14] E. Ahmed, A. Gani, M. K. Khan, R. Buyya, and S. U. Khan, ''Seamless application execution in mobile cloud computing: Motivation, taxonomy, and open challenges,'' J. Netw. Comput. Appl., vol. 52, pp. 154–172, Jun. 2015.
[15] M. Satyanarayanan, ''A brief history of cloud offload: A personal journey from odyssey through cyber foraging to cloudlets,'' ACM SIGMOBILE Mobile Comput. Commun. Rev., vol. 18, no. 4, pp. 19–23, Jan. 2015.
[16] W. Shi and S. Dustdar, ''The promise of edge computing,'' Computer, vol. 49, no. 5, pp. 78–81, May 2016.
[17] J. Pan and J. McElhannon, ''Future edge cloud and edge computing for Internet of Things applications,'' IEEE Internet Things J., vol. 5, no. 1, pp. 439–449, Feb. 2018.
[18] D. Sabella, A. Vaillant, P. Kuure, U. Rauschenbach, and F. Giust, ''Mobile-edge computing architecture: The role of MEC in the Internet of Things,'' IEEE Consum. Electron. Mag., vol. 5, no. 4, pp. 84–91, Oct. 2016.
[19] P. Habibi, S. Baharlooei, M. Farhoudi, S. Kazemian, and S. Khorsandi, ''Virtualized SDN-based end-to-end reference architecture for fog networking,'' in Proc. 32nd Int. Conf. Adv. Inf. Netw. Appl. Workshops (WAINA), May 2018, pp. 61–66.
[20] S. Sarkar, S. Chatterjee, and S. Misra, ''Assessment of the suitability of fog computing in the context of Internet of Things,'' IEEE Trans. Cloud Comput., vol. 6, no. 1, pp. 46– 59, Jan. 2018.
[21] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, ''Internet of Things: A survey on enabling technologies, protocols, and applications,'' IEEE Commun. Surveys Tuts., vol. 17, no. 4, pp. 2347–2376, 4th Quart., 2015.
[22] R. Vilalta, V. Lopez, A. Giorgetti, S. Peng, V. Orsini, L. Velasco, R. Serral-Gracia, D. Morris, S. DeFina, F. Cugini, P. Castoldi, A. Mayoral, R. Casellas, R. Martinez, C. Verikoukis, and R. Munoz, ''Tel- coFog: A unified flexible fog and cloud computing architecture for 5G networks,'' IEEE Commun. Mag., vol. 55, no. 8, pp.36–43, Aug. 2017.
[23] C. Byers and R. Swanson, ''OpenFog consortium, OpenFog reference architecture for fog computing,'' OpenFog Consortium Archit. Working Group, Fremont, CA, USA, Tech. Rep. OPFRA 001.020817, Feb. 2017.
[24] M. S. de Brito, S. Hoque, T. Magedanz, R. Steinke, A. Willner, D. Nehls, O. Keils, and F. Schreiner, ''A service orchestration architecture for fog- enabled infrastructures,'' in Proc. 2nd Int. Conf. Fog Mobile Edge Com- put. (FMEC), May 2017, pp. 127–132.
[25] M. Shafi, A. F. Molisch, P. J. Smith, T. Haustein, P. Zhu, P. De Silva, F. Tufvesson, A. Benjebbour, and G. Wunder, ''5G: A tutorial overview of standards, trials, challenges, deployment, and practice,'' IEEE J. Sel. Areas Commun., vol. 35, no. 6, pp. 1201– 1221, Jun. 2017.
[26] T. X. Tran, A. Hajisami, P. Pandey, and D. Pompili, ''Collaborative mobile edge computing in 5G networks:

New paradigms, scenarios, and challenges,'' IEEE Commun. Mag., vol. 55, no. 4, pp. 54–61, Apr. 2017.

[27] B. Blanco, J. O. Fajardo, I. Giannoulakis, E. Kafetzakis, S. Peng, J. Pérez-Romero, I. Trajkovska, P. S. Khodashenas, L. Goratti, M. Paolino, E. Sfakianakis, F. Liberal, and G. Xilouris, ''Technology pillars in the architecture of future 5G mobile networks: NFV, MEC, and SDN,'' Comput. Standards Interfaces, vol. 54, pp. 216–228, Nov. 2017.

[28] J. C. Guevara, L. F. Bittencourt, and N. L. S. da Fonseca, ''Class of service in fog computing,'' in Proc. IEEE 9th Latin-American Conf. Commun. (LATINCOM), Nov. 2017, pp. 1–6.

[29] Z. Hao, E. Novak, S. Yi, and Q. Li, ''Challenges and software architecture for fog computing,'' IEEE Internet Comput., vol. 21, no. 2, pp. 44–53, Mar. 2017.

[30] AsadUllah, M., Khan, M. A., Abbas, S., Athar, A., Raza, S. S., & Ahmad, G. (2018). Blind channel and data estimation using fuzzy logic-empowered opposite learning-based mutant particle swarm optimization. Computational intelligence and neuroscience, 2018.

[31] Khan, M. A., Umair, M., Saleem, M. A., Ali, M. N., & Abbas, S. (2019). CDE using improved opposite based swarm optimization for MIMO systems. Journal of Intelligent & Fuzzy Systems, 37(1), 687-692.

[32] Saleem, M., Khan, M. A., Abbas, S., Asif, M., Hassan, M., & Malik, J. A. (2019, July). Intelligent FSO link for communication in natural disasters empowered with fuzzy inference system. In 2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE) (pp. 1-6). IEEE.

[33] Fatima, A., Adnan Khan, M., Abbas, S., Waqas, M., Anum, L., & Asif, M. (2019). Evaluation of planet factors of smart city through multi-layer fuzzy logic (MFL). The ISC International Journal of Information Security, 11(3), 51-58.

[34] Khan, A. H., Hasnain, S. A., Siddiqui, S. Y., Irshad, M. S., Sajid, M., & Iqbal, S. (2020). Analytical Method to Compute the Cloud Computing Data Security Issues by Using Encryption Algorithms. EAI Endorsed Transactions on Scalable Information Systems, 7(28), e3.

[35] Alhaidari, F., Almotiri, S. H., Al Ghamdi, M. A., Khan, M. A., Rehman, A., Abbas, S., & Khan, K. M. (2021). Intelligent software-defined network for cognitive routing optimization using deep extreme learning machine approach.

[36] Abbas, S., Khan, M. A., Athar, A., Shan, S. A., Saeed, A., & Alyas, T. (2022). Enabling smart city with intelligent congestion control using hops with a hybrid computational approach. The Computer Journal, 65(3), 484-494.

[37] Hussain, S., Naqvi, R. A., Abbas, S., Khan, M. A., Sohail, T., & Hussain, D. (2021). Trait based trustworthiness assessment in human-agent collaboration using multi-layer fuzzy inference approach. IEEE Access, 9, 73561-73574.

[38] Khan, A. H., Siddiqui, S. Y., Irshad, M. S., Ali, S., Saleem, M. R., & Iqbal, S. (2019). Analytical Method to Improve the Security of Internet of Things with Limited Resources. EAI Endorsed Transactions on Internet of Things, 5(18).

[39] Hussain, S., Abbas, S., Sohail, T., Adnan Khan, M., & Athar, A. (2019). Estimating virtual trust of cognitive agents using multi layered socio-fuzzy inference system. Journal of Intelligent & Fuzzy Systems, 37(2), 2769-2784.