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Edge Computing: The Future Era of Cloud Computing-A Review

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Abstract— **Cloud computing has ruled the technical industry for almost more than 20 years and still an essential technology used in the IT industry. The major utilization of clouds was done during Covid-19 period where the entire 99% of the IT world worked from home. But as the world is progressing digitally very fast with the invention of 5G, augmented reality, generative artificial intelligence, automation; the requirement data availability and access is in high demand. With clouds the era of digital data evolved. A cloud provides service on demand based on the pay as usage through Infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS). Cloud works based on sharable resources and remote access depending on the user's time zone. Data storage and data accessibility are the two major concerns in the IT world. So, industry keeps evolving and edge computing started gaining popularity. Edge computing keeps the information handling and calculation on the boundary of the network nearer to the utilizer. So, the data will be available at the edge of the network itself irrespective of the zone. This feature of edge computing reduces the latency and mobility for the data access and search. The current work focuses on the comparison of cloud computing and edge computing highlighting their key areas of utilization. The article also provides a comprehensive study on edge computing and current application areas. The article tries to present a review of the fields of cloud and edge computing keeping the software industry as a viewpoint.**

Keywords: Edge computing (EC) security, artificial intelligence, CDN, fog computing, mobile computing.

I. Introduction

The introduction section of the article elaborates on edge computing, cloud computing, fog computing, mobile computing and design of EC. Edge computing has gained popularity in academia and industry, serving key enablers for innovative skills such as Internet of Things (IoT), Computer vision, 5G, Augmented reality and virtual reality through services of cloud computing to the end users. Edge computing has characteristics of processing the content near the source where content has been generated, hence faster processing and less response time compared to cloud computing. For the low latency-based applications edge computing, Cloudlets, Mobile edge computing is very suitable as it provides a low response time.

1.1. Defining Cloud Computing

Cloud computing brought the revolution of digitization into the world economy. Cloud computing delivers the services on demand over the internet. The services are categorized as Infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS). IaaS provides computation and storage services. PaaS provides environment to develop and deploy the applications. SaaS allows to access the software applications based on rental basis. The web service by cloud is provided through RESTful web services which is platform independent and stateless. The backbone technology support for cloud computing is given by virtualization which takes care of load balancing by creating the virtual copies of hardware and software. The storage mechanism employed by cloud is object storage which stores data in the form units called objects. Each object will have its own unique identifier which makes it easier to access and retrieve the data.

There are three types of cloud namely private, public and hybrid cloud. In private clouds the infrastructure and services will be owned by a single company and available to access only for the employees of that company. The public clouds will be owned by a third party and clients must pay for the service utilized. Famous examples are

AWS (Amazon web Services by Amazon), GC (Google Cloud by Google) and Microsoft Azure (by Microsoft). Hybrid clouds have the features of both private and public clouds. IBM owns a hybrid cloud called IBM cloud.

1.2. Edge Computing

Edge computing is a systems administration innovation that permits systems to handle information and perform activities continuously by moving information storage and registering nearer to the gadget or client. Edge computing decreases network latency and transmission capacity prerequisites by handling most information at the "edge" of the organization, like on the actual gadget or a close by server. This permits information to travel a more limited distance, bringing about better reaction times and quicker continuous bits of knowledge.

Edge computing is the arrangement of storage and processing assets where information is created. This makes the storage and processing reside at the same point as that of information source at the organization edge. For instance, some servers and some storage devices may be used at the edge of the wind turbine to gather and handle information delivered by sensors to inside of the actual turbine.

Many Edge computing models present with different architectures and paradigms, all of which aim to bring processing power closer to end users, devices, and data sources. By decentralizing computational activities and processing data closer to the point of production or consumption, edge computing emerges as a solution to the latency, bandwidth, and privacy issues that plague traditional cloud computing. There are many well-known edge computing models such as Cloudlets, Fog Computing and Mobile Edge computing (MEC) are present. Figure 1 depicts the general layered architecture of Edge cloud-based model. Lower layers have edge devices such as any IoT devices such as camera, mobile, smart devices capture the information based on the context and forward to the Fog nodes for processing. If the information is small in amount, then edge devices or fog nodes itself will process the data and return the inference. If there exists a huge amount of data, then data will be processed in the cloud environment and return the results to the end users. For the time stringent applications Edge computing / Fog computing will be feasible. If the application is delaying tolerant Cloud computing will be a better solution.

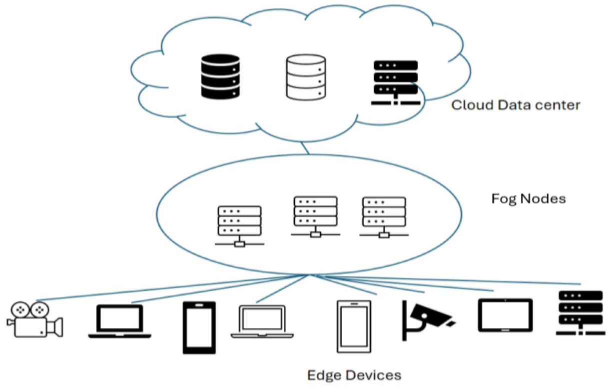

Figure 1. Edge-Cloud based layered model

Cloudlets: A cloudlet is a lightweight computing unit or small data center located at a network's edge. Cloudlets provide a link between the dispersed devices found in edge computing environments and the centralized resources of cloud data centers. By bringing cloud services closer to end users, these small data centers improve performance and lower latency for services and applications that require instantaneous response. They enable tasks to be offloaded from devices to neighboring cloudlets for processing, storage, and other computing needs by serving as a bridge between end-user devices and the cloud. By acting as an extension of the cloud computing infrastructure, cloudlets allow edge devices such as wearables, smartphones, and IoT devices to effectively access cloud services. These devices can be used in wide applications from augmented reality to Internet of Things applications, by hosting several services like computers, storage, and networking. Cloudlets provides a solution to the issues with latency-sensitive applications and the growing number of IoT devices. Hence Cloudlets help to maximize performance and resource consumption in the larger cloud ecosystem by keeping computing resources closer to end users.

1.3. Fog computing

Fog computing indicates a decentralized computing architecture having applications, data, computing, and storage which are distributed between the cloud and the data source. Fog computing enables shifting of cloud computing paradigm closer to the device where data is generated and required. The main aim of this solution is to solve the issues with latency, bandwidth limits, and privacy that may be present in cloud computing. As data presents near the network edge it eliminates the need to transfer all data to a centralized cloud server and enables quicker data processing and real-time analysis. Fog nodes perform data processing and storage locally, only transferring required data to the cloud for additional analysis or storage. The fog devices can be a router, switches to edge servers and IoT devices.

Fog computing is suitable for functions, for example autonomous vehicles, smart cities, and industrial automation which needs low latency and real-time responsiveness. This also reduces network congestion and increases the overall effectiveness of data transfer by managing data nearer to the resource. As sensitive data will be inside the local network, it reduces illegal access or data breaches and hence fog computing improves data security and privacy. Filtering and aggregating data locally before sending it to the cloud, Fog computing makes use of network capacity by reducing the quantity of data to be carried over the network.

1.4. Mobile Edge Computing

MEC enables deploying computing resources at the network edge, by bringing the cloud computing capabilities closer to mobile consumers and devices. In contrast to the centralized data center of cloud computing, MEC deploys computer infrastructure such as base stations, access points, and other network nodes at the periphery of the mobile network.

Dropping the latency and enhancing the user experience for mobile applications and services is the main goal of mobile edge computing. Through information handling and application execution closer to the point of need, MEC dramatically reduces the data transfer time between mobile devices and centralized cloud servers. Hence provides better performance, quicker response times, and improved support for real-time applications like gaming, streaming videos, and augmented reality.

MEC is appropriate for products which require high bandwidth connections, low latency, and real-time data processing. MEC architecture can also be used for application scenarios such as pedestrian detection, real-time traffic information to autonomous cars with the least amount of delay possible, enhancing road safety and productivity. Further MEC transfers processing responsibilities from centralized data centers to distributed edge devices, improving the scalability and flexibility of mobile networks. MEC also supports for edge analytics and data processing, which enables businesses to instantly derive useful insights from data created at the network edge. This kind of approach is useful for processing of huge data generated from distributed places. In the next part, origin and some of the work conducted on EC in different technological areas are discussed along with the top 10 companies using edge computing for their client's business.

II. Background and Review of literature

The section covers the origin, ongoing work happening in edge computing (EC) and top 10 industry work happening in EC.

2.1. Industry related survey on Edge Computing

The research works on edge computing was initiated in 1990s by the company Akamai by launching content delivery network (CDN) with the intention of keeping the resources close to the clients as much as possible by reducing the latency and response time in accessing the resources [1].

A team of authors with Odugu Rama Devi worked on cloud and edge computing focusing on the security of academic research area. The article addressed five security issues such as access to the network, key management, security guarantee, attack mitigation, and anomaly detection. The authors also worked on the security issues faced during edge registration [2].

A group of scientists worked with Haochen Hua and published an article on the responsibility of edge computing in artificial intelligence. The researchers listed the definition, benefits, and trials faced in edge computing. The role of artificial intelligence to improve the performance of edge computing using machine learning and deep learning algorithms [3].

Edge computing plays a significant part in the health care field. The inventor Morghan Hartmann and his team did extensive review work on the importance of edge computing in sign monitoring and fall detection. The article also presented a review on data operations covering the mechanisms such as communication, encoding, verification, division, reduction, and prediction. The authors suggested the future possible roles of EC in health care system [4].

A group of authors with Wazir Zada Khan did a study on edge computing research areas and applications. The article also explained the real scenarios of EC application and identifying open research challenges in EC area [5].

In 2020, KEYAN CAO and his team published a survey article on edge computing research areas and results. The topics presented in the article are comparison between cloud and edge computing, architecture, security, and privacy protection and summarizing the applications of EC [6].

In the year 2022, integrated framework of edge computing and machine learning for software sensor development was proposed by the author Pal Peter Hanzelik and his team. The study proposed an ML model to improve the quality of laboratory works [7].

An author named Wei Cui worked on the role of deep learning models in edge computing. The article described the function of AI in improving the performance of EC. The article concluded with the applications and future opportunities in edge deep learning models [8].

In 2022, an article was published by the author SALMANE DOUCH and his team which was based on the assessment of edge computing and it's supporting technologies. The article included a study on EC use-case scenarios, AI models in EC. The article concluded by emphasizing green energy and standardization [9].

In the year 2022, edge computing integrated role in ubiquitous power IoT (UPIoT) work was published by Dongqi Liu and his team of authors. The paper begins with the growth and building of UPIoT and its technical architecture. The article also discussed the disputes of edge computing in UPIoT, by means of policy challenges, market challenges, and technical challenges [10].

Sneha Lissy Sunny and the team published an article on the role of EC in the IoT field. This was a survey work which compared the performance of cloud and edge servers, real time applications of EC in reducing the latency and response time [11].

Table 1 represents the review of the top 10 companies working on edge computing, their products or application names.

Table 1: review of 10 companies working on edge computing and their business.

Sl. No	Company Name	Work Carried
1	Akamai	Akamai provides services on content delivery network, cybersecurity, DDoS mitigation, and cloud services. Edge applications such as EdgeWorkers, EdgeKV, Cloudlets, Vaccine Edge, etc. [12]
2	ProX PC	ProX PC works on AI and specialized computational hardware. One of the popular products is Micro Edge series powered by NVIDIA® Jetson™ etc [13].
3	Kyndryl	Edge and cloud networking services powered by AI. Kyndryl supports the automotive, healthcare, insurance, banking, media, government sectors [14].
4	AWS	AWS edge servers allow for data processing, analysis and storage closer to client's end points outside AWS data centers [15].
5	Siemens	Delivers edge services using SIMATIC controllers and HMIs [16].
6	Ericsson	Ericsson delivers the service to the clients by ensuring low latency, high bandwidth, improved security and storage from the support of edge computing [17].
7	Dell EMC	One of the leading companies offering services over edge. It has dedicated servers and micronodular data canters to run the edge applications [18].
8	CISCO	The company delivers products and services which support edge applications. The edge series devices offered by the company provides all in one cloud service [18].
9	EdgeConneX	The company has more than 12 years of experience in building and operating with data centers. It aims to deliver the services to the customers in a cost-efficient manner with high capacity and connectivity [19].
10	Sixsq	It is famous for its edge to cloud SaaS application called Nuvla. It helps customers in faster deployment, enhanced security and data access [19].

2.2. Industry Related Review on Cloud Computing [7]

Table 2 represents the review of the top 10 companies working on cloud computing, their business.

Sl. No	Cloud Service	Cloud business
1	Amazon Web Services (AWS) by Amazon	The largest cloud service provider globally with 300+ service offerings.
2	Microsoft Azure by Microsoft	The second largest cloud service provider with hybrid and intelligent cloud features with 600+ services.
3	Google Cloud Platform (GCP) by Google	The third largest cloud service provider with 100+ service offerings.
4	Alibaba cloud by Alibaba Group	The fourth largest cloud service provider with 100+ service offerings. It is the largest cloud service provider in China.
5	Oracle Cloud by Oracle Corporation.	Offers Oracle Cloud Software-as-a-Service (SaaS) and Oracle Cloud Infrastructure (OCI) services with a total of 150+ service offerings.
6	IBM cloud by IBM	Majorly offers IaaS services with a total of 170+ service offerings.
7	Tencent Cloud	Second largest cloud ser e provider in China.
8	OVHcloud	Europe focused Tencent Cloud which offers private, public and web cloud services.
9	DigitalOcean	Provides on demand platform and infrastructure services to smaller size companies.
10	Linode by Akamai	Provides platform and infrastructure services.

Table 2: List of top cloud services offered globally.

2.3. Research article survey on Edge Computing

Table 3 contains the research article survey on edge computing.

Table 3: Research article survey on edge computing

Sl. No	Author name(s)	Contribution
1	Francesco et al. in 2024	Performed a study on hybrid approaches using cloud and edge computing in Internet of Things [16].
2	Jorge Perez et al. in 2022	Performed a study on the role and advantages of edge computing in industries [17].
3	Daniel Alfonso Verde Romero in 2024	Implemented an Open IoT model using edge computing for monitoring energy consumption in buildings [18].
4	Yuwei Du et al. in 2023	Performed the study on the role of edge computing in gathering sports event data [19].
5	Deepak et al. in 2023	Presented a complete survey on edge computing research works, applications and opportunities [20].
6	Vakaliuk et al. in 2024	Presented the rapid growth and opportunities of edge computing in different areas [21].
7	Megha Sharma et al. in 2024	Reviewed the role of edge computing in industry 5.0, research challenges and solutions [22].
8	Prathyusha Nama et al. in 2024	Proposed an artificial intelligence framework embedded to edge computing for enhancing the data processing and decision-making using cloud services [23].

2.4. Research article survey on Cloud Computing

Table 4 contains the research article survey on cloud computing.

Table 4: Research articles survey on cloud computing

Sl. No	Author name(s)	Contribution
1	Rafia Islam et al. in 2023	Worked to provide better knowledge on cloud computing in research areas by covering the benefits and upcoming challenges of cloud computing [8].
2	Lewis Golightly et al. in 2022	Investigated the delivery method used by cloud and the challenges faced during adopting cloud as a business model [9].
3	Phenyo Modisane et al. in 2021	Performed the study on cloud computing benefits in small-medium and micro-sized organizations [10].
4	Paweł Lula et al. in 2021	Performed an investigation of impact of cloud computing in technical journals and the relationship between cloud computing and computer science network [12].
5	Siraj Munir et al. in 2020	Analyzed the research papers on cloud computing by considering the articles from 2016 onwards and reviewed the cloud computing working style [11].
6	Lei Zhang et al. in 2024	Introduced cloud concept to predict the wind power output [13].
7	Ke Yuan et al. in 2024	Improved the existing security feature of electronic health record (EHR) cloud system in keeping the medical records using multiple servers [14].
8	Neeraj Singla et al. in 2022	Presented the benefits and drawbacks of cloud computing. Even explained the use of IoT in cloud systems [15].

2.5. Level of Complexity

A. Complexity of Concepts:

Moderate to High, particularly for people who are unfamiliar with edge or cloud computing. The cloud, fog, and edge computing layers are introduced, and integration issues like latency, real-time processing, data offloading, and distributed computing are covered. It is conceptually rich since it covers a wide range of topics, including healthcare, smart cities, and the Internet of Things.

B. Complexity of Implementation:

It is high because of the requirement to maintain low latency, manage resources across many devices and networks, and handle security and privacy issues.

2.6. Cost of Computation (Architecture of General Edge Computing)

Computing duties are usually transferred from centralized cloud servers to decentralized edge devices (routers, gateways, etc.) by edge computing systems. Because data is handled closer to the source, latency costs are lower than with cloud computing.

A. Cost of distributed computation:

By managing partial workloads, each edge node lessens the strain on the central server. However, optimization is crucial due to resource limitations at the edge (such as restricted CPU/RAM).

B. Cost of Energy and Resources:

In general, edge devices use less power when performing limited tasks. However, when numerous devices process data simultaneously, energy usage may increase.

2.7. Statement of the Problem

Centralized data centers manage data storage and computational operations in the traditional cloud computing approach. Although this design is scalable and economical, it has several drawbacks for contemporary applications that require localized data processing, low latency, and real-time responsiveness. The delays incurred by transmitting data to remote cloud servers and waiting for a response are intolerable for applications like industrial IoT, smart healthcare systems, and driverless cars. Cloud computing thus loses its suitability for context-aware and latency-sensitive services.

Edge computing, a complementary paradigm that moves compute and data storage closer to the data source—such as sensors, mobile devices, and gateways—has arisen to address these issues. Although edge computing lowers latency and network congestion, it also brings with it several issues, such as a lack of processing power, a more sophisticated system, security flaws, and the challenge of overseeing many dispersed and diverse nodes. As a result, moving from centralized cloud to decentralized edge settings poses several operational and technical difficulties that require careful investigation.

2.8. Cloud Computing Research Issues

The centralized structure of cloud computing presents several research issues. When data must travel great distances between the user and the cloud, high latency and network delays are major problems. Bottlenecks may result from bandwidth restrictions, particularly as the amount of data produced by IoT devices grows. Since sensitive data is processed and kept on distant computers, protecting data security and privacy is a major concern. Further research concerns in cloud computing include attaining scalability while controlling operating costs, preserving service availability, and dynamic resource allocation.

2.9. Edge Computing Research Issues

The dispersal of computing resources in edge computing poses novel and intricate difficulties. Resource constraints are one of the main problems because edge devices usually have less memory, processing power, and energy capacity than cloud servers. It is challenging to standardize and interoperate devices due to their heterogeneity, which includes differences in hardware capabilities, software platforms, and protocols. As the attack surface grows with additional entry points, security and privacy become more complex. To decide which jobs should be handled locally and which should be transferred to the cloud, effective task offloading techniques are required. Other crucial research topics in the field of edge computing include facilitating device mobility, guaranteeing low latency, offering quality of service (QoS), and coordinating resource orchestration across dispersed nodes.

III. FUTURE SCOPE

As technology grows, expectations of customers also increase. Companies must adapt to the changes to deliver services in an effective and efficient manner. It is forecasted that edge computing will possibly and powerfully replace all the existing technologies and contribute towards automation. The emergence of 6G is said to boost the edge computing capability with higher frequency, capacity and lower latency. Gartner has forecasted that by the year 2025, EC will occupy the 50% market held by centralized data centers. According to the latest research it said to increase the market share by 25% in two years. Edge computing is gaining popularity from industrial and commercial servers.

IV. CONCLUSION

Edge computing is useful in manufacturing industries, content delivery, smart cities, self-driving cars, improving security and customer services. But its role is not limited to these. By embedding the features of AI with EC it can ease many of the human tasks like in building sensors for pollution check, traffic control etc. Cloud computing is still in existence, but edge computing has more advantages in terms of reducing the access time, data availability, improved security, low latency, no zone division as data is kept in the edge of the same network. Once the industry finds a way to reduce the cost of establishing edged servers, edge computing will start to rule over cloud computing.

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