Edge Computing: Applications & Challenges: A Short Review

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Abstract Edge computing is distributed computing system in which Edge devices are used to process data locally, at the point of generation. Compared to alternative computer architectures, it offers higher latency as data processing and analysis are completed on the premises. Input-output ports, memory, storage, CPUs, and other components are integrated into edge computing tools. On these devices, data processing and analysis programs are installed at the location of data creation. A distributed computing paradigm known as "edge computing" improves reaction times and conserves bandwidth by bringing processing and data storage closer to the point of demand. Low latency, real-time processing, and the capacity to handle data at the edge of the network are important features. Edge computing is useful for many applications, including Internet of Things (IoT), virtual and augmented reality, smart cities, and driverless cars. Local data processing lowers latency, making it appropriate for applications where timely decision-making is essential. This study is to focus applications and challenges of edge computing along with tools which imparts key part of the edge computing. These tools and techniques can lead a better way to improve edge computing challenges. Hence this study recommends few research direction for research with regard latest development. This paper is review in the field edge computing.

Index Terms: Edge computing, Cloud Computing and IoT

1. INTRODUCTION

Edge computing [1] is distributed computing system in which Edge devices are used to process data locally, at the point of generation. Compared to alternative computer architectures, it offers higher latency as data processing and analysis are completed on the premises. Input-output ports, memory, storage, CPUs, and other components are integrated into edge computing tools. On these devices, data processing and analysis programs are installed at the location of data creation. For instance, to reduce wait times and CO2 emissions at danger-zone intersections, an Israeli firm called No Traffic, working with NVIDIA Metropolis Project, installed thousands of edge devices with computer vision applications to monitor vehicle movement. By eliminating the need to transfer data over a network to cloud servers, it guarantees data security. The goal of edge technology is to move cloud resources—more especially, network, storage, and computation—closer to edge devices, or smart gadgets that generate and use data. As of right now, edge analytics is unable to fully support the analytical methods. Advanced and complex analytical algorithms cannot be performed by edge devices because to a number of limitations, including small memory sizes, limited power supplies, and limited resources. The detail paradigam of Edge computing with Datacenter, cloud and IoT is show in figure 1 below:

In order to guarantee the dependability and robustness of the infrastructure of smart cities, edge computing is essential. Cities may lessen the effect of network interruptions and prevent a single point of failure by spreading computing resources among several edge nodes. Edge devices can process and store data locally in the case of a network outage or lack of connectivity, guaranteeing the continued operation of vital services. Furthermore, edge computing frees edge nodes from the dependency on a centralized cloud infrastructure, allowing them to operate independently and make choices in real time. The resilience and dependability of smart city applications like environmental monitoring, public safety, and emergency response systems are improved by this dispersed intelligence.

The goal of edge computing, a recently developed technology, is to locate processing power close to Internet of Things (IoT) devices [2] like sensors, smartphones, and many other cutting-edge gadgets [3]. The process of developing, gathering, and evaluating resources in real-time for Internet of Things devices that offer information. When using edge analytics [4], the data is transferred to the following stage, where further data is collected and examined before taking non-delaying actions. Edge computing is renowned for its real-time or software application performance. Edge computing [5] aims to solve issues with IoT devices like data management, latency, and network congestion. The edge computing technique is also applied in the field of computer vision. Edge computing uses computer vision processing to lower the price.

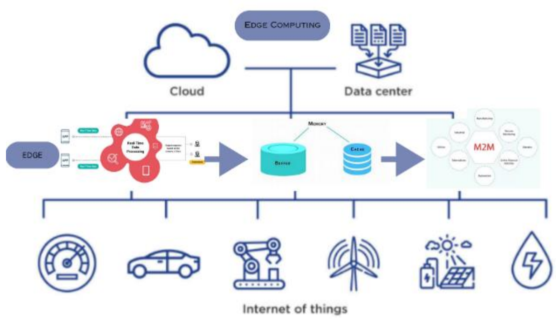

Figure 1 EC Scenario with Data center, Cloud & IoT

2. LITERATURE REVIEW

A distributed computing [6] paradigm known as "edge computing" improves gives conservation of bandwidth to bring with point where source of data is need to collect. Low latency, real-time processing, and the capacity to handle at edge. EC is useful for many applications [7], and driverless cars. Local data processing lowers latency, making it appropriate for applications where timely decision-making is essential. Although edge computing topologies differ, centralized cloud servers, edge devices, and edge nodes are often used components. Implementing edge computing solutions is made easier by frameworks like Mobile Edge Computing (MEC) [8] and Fog Computing [9]. Security concerns, resource limitations, scalability, and edge device management are topics that are frequently covered in literature. The creation of effective algorithms, security standards, and edge orchestration strategies are necessary for solutions. Because edge equipment may be more susceptible to physical assaults and illegal access, security [10] is a major concern. When sensitive data is processed closer to its source, privacy concerns emerge, necessitating careful consideration of data governance. Numerous research endeavors center on enhancing the performance of edge computing systems by taking into account variables including workload distribution, resource distribution, and energy efficiency. Common frameworks and standards for edge computing are established in part by standardization organizations such as the OpenFog Consortium and the European Telecommunications Standards Institute (ETSI). Case studies of edge computing deployments in several sectors are found in the literature; these case studies illustrate real-world situations and lessons discovered. Topics including the development of edge-native apps, 5G networks, and the integration of artificial intelligence (AI) are frequently brought up in discussions on the future of edge computing [8].

The detailed of the relevant literature review is discussed in table 1 below:

Table 1: Literature review of Edge computing

S.No	Author & Year	Objective	Outcome	Technology	Limitation
1	X. Zheng, M. Li, and J. Guo (2023)	Smart cities and edge computing paradigm	Designed a circular buffer queue at the lower edge layer	Smart cities, IoT & Cloud Computing	This can be better if machine learning model added for prediction
2	K. T. Putra (2024)	To propose edge computing framework named federate compressed learning (FCL)	The results shows reduction of data consumption by 95% having error rate of below 5% .	FCL, Edge computing, WSN	In addition IoT based devices can better with addition ML model
4	B. Khan (2024)	Healthcare predictive analysis	Model comparison as performance of RF 88.32% average accuracy, 2.96 ranked value, SVM 87.99% average accuracy & 3.83 RV	Big data, Machine learning techniques named SVM, j48, RBF, RF, HMM, CDT, KNN, AIDE, NB	The comparison can be performed on two or more dataset which can give variations in model training predictions
5	L. Cui (2022)	To provide a detailed survey of health analytics in edge computing with IoT and Machine leaning	Results shows a comprehensive review of papers having detailed model, challenges and application based information	Research survey	The study can add more details like challenges and technologies related to IoT and machine learning which help to improve health analytics

6	Morghan Hartmann (2019)	To survey current and emerging edge computing, Health analytics, architecture & applications	A comprehensive review material focused for the domain of emerging edge computing architecture and applications are discussed	Edge computing provided detail	Edge computing can be more clear paradigm if IoT and WSN technologies added in Survey
7	L. Liu (2021)	To provide a Vehicular edge computing challenge and opportunities	To provide a comprehensive detail review of vehicular edge computing	Edge computing, vehicular network	In addition few vechicular edge computing network solution and few research papers can be added in survey
8	S. Hamdan (2020)	To conduct detailed survey Edge computing architecture for IoT	This study provided for the detailed survey of edge computing and IoT	ECAs – IoT, Data placement, orchestration services and Big data	However architecture designed for IoT can be extended further if few different types of data devices added to collect text, image and video data
9	McEnroe (2020)	To study impact of edge computing in UAV Technical Aspects	Detailed study regarding UAV technical aspect with edge computing applications	UAV & Edge computing	In addition few challenges in UAV with edge computing can give better explanation
10	Garima Nain (2022)	To study edge computing in manufacturing industry perspective	The study presented a detailed survey of past present and future of industry 4.0 also called intelligence manufacturing with	The progress in I4.0 following the PDP loop and bring intelligence to the EC	Cloud technologies should be added for better understanding of Industry 4.0

			edge computing technology		
11	Liang (2022)	To study and survey multi – access edge computing technologies	The study provided a detailed multi – access Edge computing (MEC) survey which focused on recent frameworks, concepts and capabilities.	The tools studies Software defined network, Network function virtualization, information centric Networking, cloud radio access network etc	Edge computing technologies like IoT, Cloud computing and Machine learning aspects can be added for better added smartness.
12	Wei Xu (2023)	To study practical distributed Edge learning	The study presented first mathematical model for goral oriented entropy as an optimization problem	Wireless communication system, B5G	Distribute edge aspects with Few prediction models can give better implementation logic for smart results
13	Hua, H. (2023)	To study edge computing challenges, limitation of Traditional approaches of EC, AI optimization results in other fields	This study provided a detail overview of EC architecture and optimization solutions regarding AI based approaches different fields perspective	AI based tools for EC optimization	AI and Edge Computing are good combination and it can be better further to add AI solutions in prespective of IoT architecture and cloud computing challenges
14	Acheampong, A (2023)	To study EC offloading and resource allocation in perspective ML model implementation to find out challenges	This study provides a ML based approaches for offloading techniques evaluation with challenges and issue in EC	Supervised, unsupervised and Reinforcement Learning also Non-machine learning approaches like Non-optimization, game theory etc	ML and EC

15	Chen, J (2023)	To focus Mobile edge computing approaches in ML based model proposed as game model for computation offloading	The results shows that the proposed model named QCOG-DG and QCOG-SG. From which QCOG – DG model can find NE solution in the MEC Scenarios.	MEC	MEC
16	Orfanos, V. A (2023)	To study MEMS performance improvement with integration of WSN and IoT for Machine to machine communication	This study focuses on tiny devices communication performance improvement with integration of IoT and WSN Modules with data integrity, cost factors and other technical characteristics.	EC, IoT, WSN and MEMS	Cloud computing aspects is not added in their study which is crucial part of IoT, WSN and EC
17	[11]	To propose a AI based model with EC results optimization	This study focuses AI and EC tradional approach for performance optimization witih limitation and challenges	AI – Machine learning and Edge computing	The study only focuses limitation and challenges while it is better to add applications and each application AI solution
18	[12]	A survey on Edge computing	Edge computing infrastructure, design, resource Management, and Optimization Approaches	Mobile edge computing (MEC) with auto scaled and proactive MEC-NFV infrastructure	There could be many other applications like IoT and challenges like cloud storage infrastructure
19	[13]	To implement digital network in forest ecosystem	Edge computing for IoT to monitor forest by applying real time	IoT sensor environment	However it is just for the digitization of forest but few of

			sensing system and energy harvesting		the investigation regarding water, soil and weather should be clearly need to be discussed
20	[14]	Crop health assessment	To implement IoT based system with machine learning to assess crop health with prediction	UAV and IoT	The data storage medium should be added to process and store health assessment data

Edge computing tools: An edge device is any equipment, such as internet routers, Internet of Things [15] sensor devices, smartphones, etc., that has the ability to process and transmit data. The majority of edge computing devices have an Ethernet interface, input/output ports, memory, storage, and a processor. To gather data and perform on-site processing and analysis, edge devices are linked to peripheral input devices like cameras and sensors. On the edge device, the data processing and analysis program or script is installed. To convey the inference and collected data, the devices are subsequently linked to an output device or cloud platform. The NVIDIA Jetson series, the Lenovo Think Edge, and the Raspberry Pi are a few well-known examples of edge devices. A number of auxiliary devices are designed with edge device integration in mind. Pi cameras are designed to operate with Raspberry Pi, offering high-definition photography and recording capabilities. Using sensors and stereo vision, Intel's RealSense Depth cameras determine the depth of surfaces that they have photographed.

Cloud Platforms: The majority of well-known suppliers of Edge device toolkits also combine cloud services [16] with Edge. using user-friendly interfaces, cloud platforms facilitate communication between developers and users using edge devices. They serve a variety of purposes, including data collection and inference by Edge, application deployment updates, edge device monitoring, and more. Consider the NVIDIA Jetson platform, Google's Distributed Cloud Edge, and Amazon's Green grass. Edge computing with cloud and end device logical view is given in figure 2 below:

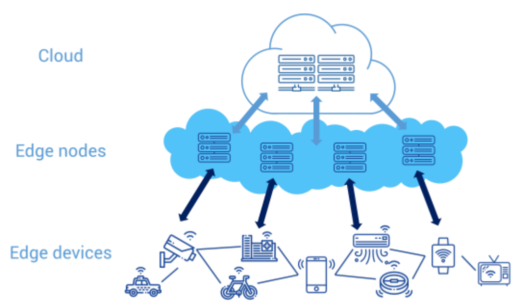

Figure 2 Edge Computing with Cloud, End Nodes and Edge devices

Edge Networks: Communication protocols including Bluetooth, Ethernet, WiFi, NFC (near-field communication), Zigbee, and others are used to link edge devices to edge gateways. These technologies allow communication at distances ranging from less than 4 cm to up to 100 meters. Nodes serving as gateways between edge devices and the core network, which is where most data processing takes place, are called edge gateways. Communications methods like Z-wave, Bluetooth Low Energy, etc., for shorter distances up to 100 meters, and LTE-

A (Long-term Evolution Advanced) for long-distance communication >1 km are used to connect edge gateways to the core network.

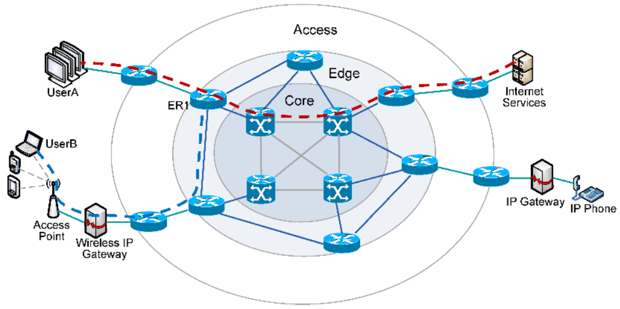

Figure 3 Edge Computing Network Paradigm

The above figure 3 shows logical view of the edge computing network logical structure view.

Applications of Edge Computing: Edge computing covers broader range applications in real time scenarios. Few of important applications are discussed below in detail:

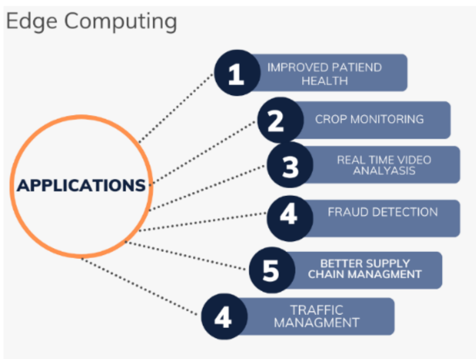

Figure 4 Applications of Edge Computing

The above Figure 4 shows complete depiction of edge computing applications.

Improved patient health: Making the most of edge computing architecture to boost real-time processing, lower latency, and boost overall efficiency is the process of creating a better health application. Here are some essential characteristics and things to keep in mind while creating a better edge computing health application. The health analytics involves real time monitoring of patient, processing of local data, predictive analysis, edge to cloud integration, user friendly interface, common monitoring of edge devices and feedback mechanism. These factors are used to consider for better patient health improvement.

Crop Monitoring: Crop monitoring with edge computing involves leveraging edge devices to process and analyze data directly on or near the field, reducing the need for centralized cloud processing. This approach enhances real-time decision-making, reduces latency, and optimizes resource usage. Crop monitoring involves many factors of IoT includes sensors, actuators, automated machinery. These factors can be further involve in sensor integration, edge device selection, data ingestion, edge computing framework, data preprocessing, edge AI Model, local decision making and edge to cloud integration.

Real time video analysis: Here's a guide on implementing real-time video analysis in edge computing. Real-time video analysis reduces latency, increases privacy, and improves efficiency by dispensation video data nearby on edge devices, eliminating data to centralized cloud servers. The most important aspect in video analysis includes choosing suitable edge device, define use cases, select a framework, optimize models for edge computing, edge to edge computing, edge AI accelerator, low latency streaming and edge device management.

Fraud Detection: By putting computational power closer to the source of data generation, edge computing can be used to provide fraud detection by processing and analyzing transactions in real-time. This method improves the capacity to identify fraudulent activity and take swift action against it. This is a how-to for using edge computing for fraud detection.

Computer Vision: Computer Vision [17] in edge computing also known as Edge AI [18] makes it possible to get beyond the restrictions on data privacy in image processing because of the decentralized data processing close to the data source. Without the need to store or transmit data, sensitive and private visual data pertaining to intellectual property (IP), personal identifiers (PID), or personally identifiable information (PII) is examined in real-time. With distributed computer vision systems [19], AI vision may be scaled and delivered to any location without affecting latency, bottlenecks, robustness, or efficiency. Edge AI-based apps produce substantially less data while attaining far greater data quality because of the instantaneous processing. The following advantages are yours to enjoy when using Viso to supply computer vision for private video analysis, real-time and instantaneous video analysis Privacy are much less and better-quality data is produced with real-time AI processing. Automatic functioning also involves human intervention is not necessary. Applications for machine learning [20] on devices can operate continuously (always-on computer vision). Safeguard delicate images: Operate vision systems without storing or transmitting image or video data, and refrain from sending video streams to the cloud.

Federated Learning: Federated learning [21] is a machine learning approach that uses many decentralized edge devices or servers that store and share local data samples to train an algorithm. This approach is not the same as traditional centralized machine learning techniques, which call for the submission of each local dataset to a single server. Among the industries that employ it are pharmaceutics, IoT, telecommunications, and data protection.

Federated machine learning offers the following main advantages: Instead of uploading and storing the training data on a central server, FL enables smart devcies for development of shared model [22]. Takes model teaching to a new level by incorporating devices such as computers, cellphones, IoT, with even "organizations" have to follow to stern confidentiality commandments. Data nearby has advantage of security concerns. FL minimizes latency that arises from transmitting data which is in raw form for server. Subsequently returning the findings to the system.

Home IoT Appliances: In the past few decades, a lot of practitioners have concentrated on tying commonplace items—such as appliances, sensors, and actuators—to the Internet so that people may monitor and operate them from anywhere at any time [23]. The terms IoT and IoE were created during this transition, giving common things additional intelligence and the capacity to carry out [24]. WoOs support and represent intelligent aspects of real-world objects as online resources that can be accessed via lightweight Application Programming Interfaces (APIs).

Machinery Automation: Transportation businesses may easily distribute software and application upgrades to trains, aircraft, and other moving vehicles with considerably less human participation by automating difficult manual device setup operations. Teams may work on more useful, strategic, and inventive initiatives by doing this, which can also help save time and reduce manual configuration mistakes. Automating the installation and administration of devices is often a safer and more dependable way than doing so manually [18], analytics, and IoT into industrial production facilities and across activities [25]. Edge automation benefits are exemplified at the plant floor. On the assembly line, edge automation can assist in identifying flaws in produced components with the use of visualization algorithms. By spotting and warning to dangerous situations or prohibited behavior, it can also aid in enhancing the safety of manufacturing operations.

Smart Cities: By facilitating better data processing, real-time insights, higher dependability, and enhanced security, edge computing is revolutionizing smart cities [26]. It gives communities the ability to improve services, make data-driven decisions, and raise residents' quality of life in general. Edge computing opens the door to a more effective, safe, and sustainable urban future by putting computer power closer to the point of data production. Edge computing will continue to be at the forefront of technology development as smart cities develop, spurring innovation and improving urban living [27]. The capacity of edge computing to handle data locally and in real-time is one of its main benefits in smart cities. Cities can successfully manage high amount of data from various IoT based systems [28]. While reducing latency by placing edge computing infrastructure closer to the sensors, devices, and endpoints of network. Because of this close closeness, it is possible to analyze data, make decisions, and respond to citizen needs more quickly, which boosts operational effectiveness.

Edge AI Challenges: The proliferation of smart automobiles [29], smart household appliances [30] , and networked industrial machinery is producing data almost everywhere. In reality, as of 2022, there were over 16.4 billion Internet of Things (IoT) devices [31] linked globally. By 2025, that figure is predicted to soar to 30.9 billion. IDC projects that by that time, these devices would produce 73.1 zettabytes of data worldwide, a 300% increase from the not-so-distant 2019. Efficiently classifying and evaluating this data is essential for achieving the best possible application user experience and more informed business decisions. The technology enabling this is edge computing.

Network connectivity and reliability: In edge computing, establishing and sustaining dependable network connectivity [32] at the edge is a major difficulty. Obstacles include bandwidth restrictions, latency, sporadic connectivity, and the requirement for a strong network infrastructure [33]. Organizations can use technologies like edge caching, content delivery networks (CDNs), and network redundancy methods to get around these obstacles. Furthermore, dependence on continuous network connectivity may be reduced by utilizing edge computing frameworks that provide offline operation and local data processing.

Security and privacy: Edge computing poses new privacy and security issues. Because edge devices are dispersed, there is a greater surface area for attacks and possible weaknesses[30]. It's critical to safeguard sensitive data at the edge [34]. For the reduction of risks regarding security, enterprises should also give top priority to threat intelligence, rapid patch management, and constant monitoring. Consent management, data anonymization, and compliance with privacy laws are the best ways to handle privacy problems.

Data management and storage: Because edge devices have limited storage space and processing capability, managing and storing huge amounts of data created at the edge is a substantial difficulty. Organizations can use techniques like data aggregation, compression, and intelligent data filtering to enhance data management [35]. These methods lessen data quantities without sacrificing important information needed for analysis and judgment. The capacity to manage edge-generated data is made possible by leveraging edge-to-cloud or edge-to-data center designs, which provide smooth data flow and storage in scalable infrastructure.

Scalability and resource constraints: Due to resource limitations, scaling edge computing implementations to meet increasing workloads and user expectations can be difficult. Memory, computing speed, and energy capacity are frequently constrained in edge devices. Organizations may use edge orchestration frameworks, which improve resource consumption, provide smooth load balancing, and distribute workloads across devices, to tackle scaling difficulties. Furthermore, by utilizing cloud integration and fog computing [36], intense processing duties may be transferred to more potent infrastructure, freeing up edge devices to concentrate on crucial local calculations.

Deployment and management complexity: Complexity arises in the deployment and administration of edge computing devices and infrastructure. Software upgrades, edge application deployment, remote device administration, and monitoring are among the difficulties [37]. Streamlining these procedures is essential for effective functioning. Software deployment, device provisioning, and remote administration may be made easier with the use of edge management platforms and automation tools. Proactive maintenance and issue resolution are made possible by the insight that centralized monitoring and analytics systems offer into edge deployments. Adopting open-source technology and standardized frameworks may help streamline the deployment and development processes, promoting interoperability and cutting down on complexity.

CONCLUSION

On the whole this study present a complete detailed applications and challenges of edge computing along with tools which imparts key part of the edge computing. These tools and techniques can lead a better way to improve edge computing challenges. In the last recommends few research direction for research with regard latest development.

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