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Deep Learning for Edge Computing Applications: A Comprehensive Survey

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Abstract - **Edge computing is a modern computer architecture that processes data quickly and efficiently close to its point of origin, hence avoiding slowdowns caused by network latency and capacity limitations. By moving processing power to the network's perimeter, edge computing decreases the load on central data centers and reduces the time it takes for users to submit data. Therefore, access latency may become a barrier, potentially negating the benefits of edge computing, particularly for applications that need a great deal of data.. Edge computing has some challenges, such as security, incomplete data, investment costs, and maintenance costs. In this research, we undertake a thorough analysis of edge computing, how edge device placement improves performance in IoT networks, compare various edge computing implementations, and explain various difficulties encountered during edge computing implementation. This study aims to promote creative edge-based Internet of Things security design by thoroughly examining existing Internet of Things security solutions at the edge layer and facilitate the dynamic deployment of edge devices.**
Keywords: **Security, IoT, Federated Learning, Edge Server, Edge Computing**

I. INTRODUCTION

One kind of distributed computing, called "edge computing," moves data processing and storage closer to the actual data sources. Distributed computing's "edge computing" idea relocates processing and storage facilities closer to information generators. Rather than a single technology, the word refers to architecture. With edge computing, data is processed and stored close to the users and apps that will use it. The ultimate result is a reduction in latency and protection from internet outages. With the use of edge computing architectures, advancements like,

1. Home networks
2. Self-driving vehicles
3. Robotics in medicine
4. Modern real-time games

Edge computing is an alternative architecture to cloud computing that may be used for applications that have stringent requirements for both speed and availability. This is because programs that exclusively use the cloud for data storage and processing become dependent on having access to the internet, which makes them vulnerable to its inherently unreliable nature. The entire application slows down or stops working when the internet is slow or unavailable.

In contrast to traditional data centers, edge computing is located closer to the point where data is being created or consumed. It involves a wide range of networks and devices located near or at the user's location [1]. Data processing is accelerated and scaled up at the edge, near the source, so that answers are available in real time. Most of today's computers is already used to analyze very sensitive data and power critical devices that must work safely and reliably. It already occurs in places like hospitals, factories, and retail outlets that are on the edge. For these regions, low latency, network-free solutions are required. Edge has the power to transform businesses in all industries and job categories, from marketing and customer service to production and back-office operations. Edge supports proactive and adaptive business processes, frequently in real-time, resulting in fresh, improved user experiences in every situation [2].

Edge enables businesses to combine the physical and digital worlds. incorporating web analytics and data into physical locations to improve the shopping experience [3]. Making intelligent settings that safeguard our security and comfort using technology that staff members can use to learn surroundings where staff can learn about machines. Edge computing, which enables businesses to operate applications with the most essential dependability, real-time, and data needs directly on-site, is what unites all of these cases. In the end, this enables businesses to innovate more swiftly, launch new products and services more quickly, and create opportunities for new revenue streams. Whether it's customer interaction and marketing or production and administrative tasks, Edge has the potential to completely transform a business, which is what makes it so fascinating [4].

II. REVIEW OF LITERATURE

Researchers in federated learning have already performed surveys using the edge computing paradigm, and those results are shown here. Readers are aided in their understanding of the study's findings by comparing them to results from earlier surveys. Finally, this part provides a concise summary of the survey's contribution.

A. Related Works in Edge Computing

By moving Cloud computing's services and utilities closer to the end user, edge computing aims to speed up the processing of data-intensive applications. In this article, they explored Cloud and Edge computing from the ground up, examining their most basic notions. Authors sorted the current divide the current state of the art in edge computing into a few different areas depending on the kind of workload they were designed to handle. Services in these domains include things like data analytics, resource management, and real-time applications. Also, they outlined critical conditions that must be satisfied to implement Edge computing. In addition, researchers reviewed a number of unanswered questions that remain in the field. The research team came to the conclusion that there are still several major hurdles to overcome before the Edge computing paradigm can reach its full potential. Compensating for these restrictions is possible via the provision of acceptable solutions and the fulfillment of criteria like dynamic charging [5].

Authors of [6] suggested the mobility-aware edge service placement strategy and used 2-dimensional regret to examine MAESP performance measures. The quantity of application demands for service from both new users and former users fluctuates often as a result of the nature of user movement.

Unstructured data has grown rapidly recently and is now primarily stored on cloud-based technology. Users that store their data in the cloud entirely relinquish control over it, increasing the danger of privacy breach. Solutions for privacy protection frequently about the technique of encryption. To solve this issue, an original three-layer fog computing-based storage technique was developed. The plan makes use of cloud storage while protecting user information. calculating the distribution percentage preserved in the fog, clouds, and local machinery; a Hash-Solomon technique was also developed.

The outcomes of the theoretical study supported the viability of the suggested plan. Schemes for allocating resources are frequently used in fog computing because they guarantee the best use of the available resources. These plans, however, are susceptible to both physical and digital attacks. An approach that protects privacy was suggested in order to solve this issue. The method relies on continuous message expansion. The technique helps to mitigate against smart gateway and eavesdropping attacks, which are frequently conducted against resource allocation algorithms, according to formal analysis results [7]. The suggested technique is also strong because it completely resists key compromise and satisfies user privacy concerns. Privacy-preserving. Fog-enabled aggregation is the name of the smart metering aggregation framework that [7].

The IDS is used to forecast hacked devices and continuously monitor the services provided to LDs [8]. This is how the proposed cybersecurity framework operates. When an attack is detected by an IDS, the detection phase for that edge device is then started when an attack alarm has been created. Markov 1 is given the name and classification of the attacked edge device; this establishes the likelihood of an attack on the edge device and its class. Choosing whether to change the edge device in the second stage to VHD, Markov 2 uses the data from Markov 1. In addition to continuously monitoring the edge devices that have been migrated to VHD, All of the devices that IDS has determined to be malicious are under the responsibility of VHD to preserve and maintain the log repository.

The results of the experiment indicate that faster response times are required for high accuracy. However, the crucial factors that affect response time, such as response cost and damage cost, are not considered. Despite the offered method's exceptional accuracy and low damage cost, the cost of reaction is high. As the total number of attacks rises and becomes more severe over time, the cost of responding will also rise. A method to safeguard the Cloud by using decoy information technology was put out by [9].

The authors introduced decoy. information technology to launch disinformation campaigns against nefarious insiders. Such assaults make it impossible for hostile insiders to distinguish between authentic, sensitive data and customer-generated phony data. Cloud services are more secure when user behavior analysis and decoys are used as security measures.

A popular method for determining the frequency, duration, and amount of a person's access to cloud-based data is user profiling. Always keep a close eye on the user's typical activities in order to identify any strange access to the user's data. The purpose of creating the decoy, which consists of meaningless information, is to fool and confuse an intruding individual into thinking that they have gotten the information of value. There are a lot of different methods to produce fake information, and some of those ways include using phishing mails, decoy papers, and honey files. In order to guarantee the safety of one's data stored in the cloud; one may make use of the decoy approach in combination with technology that profiles user behavior [10].

If an unauthorized user begins to utilize the service in an unusual manner, they will be provided a decoy that looks and feels just like the real thing. When the Cloud returns fake data, the legitimate user can quickly tell. It is possible to incorrectly identify unauthorized access by modifying the Cloud replies using various approaches, for example, a reaction to a problem posed by the cloud security system [11]. To evaluate false alarms and missed detections generated by the system, further research on the suggested security mechanism for fog computing is still necessary.

There are many reasons why businesses may start integrating edge computing technology into their network architecture. From better application performance and real-time AI data analysis to substantially lower operating costs and planned downtime. We'll examine a few edges computing IoT solutions. To learn more about how they enable next-generation network infrastructures, we'll examine what they are and how they operate.

B. Multi-Access Edge Computing

At the RAN edge, near to end users, MEC offers an environment with extremely low latency, high bandwidth, and immediate access to radio and network statistics [12]. IT and cloud computing skills are offered by this. By utilizing MEC, there is a chance to create a variety of fresh products and services, spark innovation, and launch fresh ventures. A customized mobile broadband experience can be provided through contextual data, tailored content, proximity awareness, and location awareness in particular.

MEC could help service companies by gathering more data on their clients' content and locations, to differentiate their service offerings in another way for profit. [13] The open radio network edge platform provided by MEC is capable of supporting several services and multitenancy, facilitating the flexible and on-demand launch of new enterprises, by permitting the storage and processing capabilities to be used by permitted third parties. By granting third parties' access to knowledge about RAN and network conditions in order to drive service innovation, following that, MNOs can offer cloud services and earn even more money from the broadband experience. Additionally, when vertical industries and services like energy utilities, the automobile industry, and smart city services are adequately established by M2M and IoT, MEC may use the cellular networks' vast coverage to act as the major enabler.

The development of additional IoT and 5G-enabled technologies and devices is expected to considerably increase network demands, and multi-edge computing enables users to manage this excessive traffic and resource needs more intelligently. Furthermore, it assists in setting the groundwork for the next intelligent and next-generation networks. The support for enhanced location, augmented reality, and Internet of Things services could also be provided by multi- or mobile edge computing. It offers those sectors time to catch up with new technology and a head start before 5G networks start to roll out.

C. Fog Computing

The framework is built on additive homographic encryption and the Fog computing architecture. By introducing concentrated Gaussian noise to their data, smart meters can use PPFA to encrypt the noisy output. As intermediate nodes are involved, PPFA ensures aggregator ignorance. The use of a two-layer encryption technique ensured robustness. While the second layer is utilized for authentication, the first layer aids in aggregator oblivion. The findings showed that PPFA preserves privacy by reducing network latency, reducing bandwidth bottleneck issues, and conserving a sizable amount of energy. To test the architecture for distributed applications, heterogeneous queries must still be taken into account [14].

In a Fog environment, [15] suggested a cybersecurity framework that makes use of the Markov model, virtual honeypot, and intrusion detection system (VHD). To distribute services to all edge devices and balance the strain on the resources of the fog layer, the use of a secure load balancer (SLB).

Fog and Edge Computing were described as new paradigms by researchers as an alternative to the Cloud. Combinations of these emerging paradigms have been the focus of contemporary system-building research, particularly in the agricultural sphere. In addition to highlighting the advantages and goals of the smart agricultural applications analyzed. It provided a comprehensive summary of the procedures followed and interim outcomes acquired during the identifying, screening, and determining phases. 55 main studies were chosen from 2788 preliminary studies retrieved from electronic sources to address research issues [16].

In order to move away from centralized cloud datacenters and enable a cloud computing architecture, Cisco first put forth the concept of cloud computing in the Fog, or "Fog Computing" "fogging" or fog networking which considers a significant number of widely scattered edge nodes as a distributed and cooperating cloud. Fogging, fog computing, or fogging are all terms used to describe a dispersed computer architecture [17].

The term "fog computing" refers to a kind of horizontal system architecture that distributes computing, storage, control, and networking resources and services along a continuum that extends from the cloud to objects. Fog computing provides the required technology to distribute, organize, manage, and secure resources and services that are shared across networks as well as those that are shared between devices that are located on the edge. The goal of fog computing is to reduce the quantity of data that must be sent to the cloud in order to be processed, analyzed, or stored. It does this by bringing cloud services and computation to the network's edge. The cloud regularly receives information collected by sensors and other Internet of Things devices for processing and analysis [15].

However, these gadgets are frequently geographically too far away to reply in a practical length of time. Fog computing enables rapid operations and analysis at the edge of a network, minimizing the quantity of information that has to be uploaded to the cloud once again. A fog node is capable of performing a wide range of functions, including networking, processing, accelerating, storage, and control. Wireless or wired connections can be used by fog nodes for communication.

Fog nodes also possess some generic computing capability. Configuring accelerator modules in order to improve computing performance, graphical processing units, field programmable gate arrays, and digital signal processors are being used. Especially important for fog nodes performing complex analytics. To preserve the crucial data integrity and dependability of the system, fog nodes require a range of storage options. In an application environment, the edge of the network frequently has a range of actuators and sensors. The fog node is connected to these sensors and actuators using a variety of interfaces, incorporating PCIe, USB, and Ethernet connections among others. A fog network's nodes may be connected in a mesh topology to provide load balancing, fault tolerance, data interchange, and minimum cloud connection, among other benefits. Interoperability in cutting edge data and network intensive applications like an open architecture that is built on fog computing makes the Internet of Things (5G), artificial intelligence (AI), tactile internet, virtual reality, and other technologies viable. IoT applications' unprecedented data generation has a number of advantages [18].

To address some issues about safety and privacy, A framework that is built on fog computing for face resolution and identification has been studied. In addition, the restricted fog makes it viable for emerging applications, like virtual reality, which require mobile networks capable of handling high data rates and low latency. For some applications that need network constraints, reduced latency, increased security, and real-time decision making, fog computing offers business value [19].

[20] claims that "Edge computing" is quickly becoming a game-changing technology that will usher in a new era in computing. In many use cases, from autonomous cars on the road to smart homes, offloading computation is essential for delivering on the promise. Energy efficiency, service reliability, and user satisfaction are only a few of the many benefits of offloading computing that are discussed. Furthermore, techniques for optimizing system performance and overheads while offloading computing are explored, including those based on game theory and heuristics.

Edge computing allows for the operation of numerous devices across a much smaller and more effective LAN Occasionally, network disruptions can aggravate traffic and even prevent some internet users from communicating with one another, making the Internet of Things useless when it is down, virtually eliminating delay and congestion. The raw data is gathered and secured locally, enabling local users to decide immediately before sending results, whereas the required edge analytics may be carried out by local servers, or at the very least, the data can be pre-processed and limited to the cloud or central data center [21].

In another research, [22] described current fog terms and associated subjects in addition to offering a more thorough definition. It is essential to develop a thorough fog platform and boost performance.

D. Cloudlets

[23] initially introduced the word "cloudlet" to describe the layer in the center of a three-tier architecture that also comprises an end device, a centralized datacenter, and an edge cloud platform. The purpose of Cloudlet is to provide consumer accessibility to cloud services from distant datacenters. According to experts, Cloudlet is a dependable node with a wealth of resources and reliable Internet connectivity that gives nearby mobile devices access to processing power as in addition to resources for access and storage It was proposed as a node on the edge of the cloud that could be positioned in busy places like train stations and convention halls as well as open places like coffee shops and shopping centers.

Mobile devices essentially operate as thin clients, which are lightweight workstations that heavily rely on distant connections to cloud servers to offload resource-intensive operations to speed up execution and reduce energy consumption [24].

Cloudlets just serve as a miniature data center that end users may access through Wi-Fi to install and manage their own virtual machines. Cloudlets provide two distinct methods using a VM-based strategy. Which is concentrates moving the end device's CPU, disk, and memory to the destination cloudlet, where execution is restarted from the precise state. The second choice instead of sending the aforementioned states considers a little VM overlay image. In this case, a VM basis has been used to prepare the cloudlet (OS). After combining the overlay image on top, the execution keeps going without interruption [25].

Additionally, cloud computing and cloudlets have some differences.

1. A cloudlet must be far more adaptable in terms of provisioning than cloud computing since connections to mobile devices are very dynamic and subject to significant churn because of user mobility.
2. When a user leaves the cloudlet with which they are currently associated to effortlessly move the services were transferred from the first cloudlet to the second cloudlet so they could be offloaded, a VM handoff solution must be used.
3. A mobile device must first find, choose, in addition to associating with the appropriate cloudlet among a number of users because cloudlets are tiny DCs that are geographically dispersed before it can begin provisioning.

E. Cloud Computing

It is not reasonable to make a comparison between edge computing and traditional cloud computing. It is a completely novel approach to computing, in which computations are carried out at the periphery of a network. Its primary objective is to move computing closer to the original source of the data. Edge computing is defined differently by different researchers. The notion of edge computing was first suggested by [26] who stated that computing at the network's edge is evolving into a new form known as edge computing. Cloud computing centers are characterized by the usage of the phrase "edge computing," which refers to the computing and network resources that are positioned between the data source and the route of the cloud. The Internet of Everything is represented by the uplink data, while the data that is sent downstream from edge computing constitutes cloud services. A new kind of computer model known as edge computing is responsible for the distribution of processing and storage resources. [27] claimed at the network's edge, closer to sensors or mobile devices. Based on the aforementioned definitions, [28] proposed: "In order to offer applications with computing, storage, and network services, Edge computing integrates resources that are nearby to the user, either physically or virtually." In order application intelligence, real-time business, data optimization, Connectivity, security, and privacy, as well as edge computing, are all essential components for satisfying the requirements of the sector's agility requirements. It is defined as "An open platform that combines fundamental capabilities including networking, computation, storage, and applications that offers edge intelligent services close to the network edge or the data source". In other words, edge computing involves creating and performing services and calculations there.

In order to suit the vital requirements of the IT sector in terms of Edge computing involves moving the network of clouds, processing, storage, and resource capabilities to the network's edge. This enables flexible connectivity, real-time commerce, data optimization, application intelligence, privacy, and security are among the topics that will be discussed. The low latency and high bandwidth need of the network must be met; it also offers intelligent services at the edge. Edge computing is a popular study area today [39].

F. Federated Learning

The design of edge computing topology that lays emphasis on a federated network is referred to as Edge devices are a roadblock for cloud computing and terminal devices, which are responsible for bringing cloud services closer to the network's perimeter. The characteristics of cloud-edge cooperation There are three layers total: the layer for cloud computing, the layer at the edge, and the terminal layer. The following are some parts that offer a short overview of the structure of the edge computing architecture as well as the functions that are associated with each tier.

According to our current knowledge, there does not seem to be any other thorough evaluation of studies on federated learning in edge computing. Anyhow The authors of [30] provided a thorough analysis of the applications of federated learning in smart city sensing, presenting illuminating perspectives on unanswered questions, stumbling blocks, and opportunities. In addition, they provided a survey study that covered the security risks and vulnerability concerns unique to federated learning systems and summed up the most common defensive measures taken with respect to federated learning. The quality of the main research was evaluated to extract the most reliable data. They used both forward and backward snowball methods to narrow down on the best answers. The authors also came to the conclusion that using only one kind of defense is not enough to guarantee safety against every type of assault. In a similar vein, Reference offered protocols and platforms for creating improved privacy solutions those badly in need of such solutions across a variety of sectors. However, the authors did not investigate how the hardware needs would be affected by using FL federated learning, opting instead to concentrate on the application. Moreover, the difficulties associated with incorporating federated learning into the edge computing paradigm were not considered. That other studies may take into account these consequences.

1. Terminal Layer

The terminal layer consists of all linked edge network gadgets, including smartphones and different Internet of Things gadgets. The gadget serves as both a data supplier and consumer in the terminal layer. minimizing the terminal service delay, just how each terminal device is seen, not the computer capabilities, is considered. Therefore, the hundreds of millions of terminal layer devices gather and upload various forms of raw data to the top layer, where they are calculated and stored [31].

2. Boundary Layer

In a three-layer design, the edge layer serves as the intermediate layer. It consists of edge nodes, which are scattered across the network's endpoints and clouds, and is located at the network's periphery. Common examples of hardware include repeaters, access points, routers, switches, gateways, and base stations. Downward access to terminal devices is made easier by the edge layer, as well as storing and processing data that is uploaded by terminal devices. Due of the edge layer's proximity to the user, data analysis in real-time and intelligent processing, which, compared to cloud computing, are more effective and secure, are better suited for it [32].

3. Cloud Layer

The cloud is still the most effective data processing center among the federated services that are offered by cloud-edge computing. The swiftly operating servers and storage gadgets that make up the cloud computing layer have strong computational and storage capabilities, and they can be useful in applications that call for extensive data analysis, like routine upkeep and guidance for business decisions. The cloud computing center has the ability to permanently store the edge computing layer's reported data, as well as to execute processing activities that combine global information and analytical tasks that the edge computing layer is unable to deal with in their entirety. Additionally, the cloud module can dynamically modify the edge computing layer's deployment strategy and algorithm in accordance with the control policy [33].

G. Edge Servers

Authors of [34] suggested ICLEDI, an edge data fidelity evaluation and corruption localization system with three features. First off, ICLEDI is a straightforward strategy that only slightly taxes edge servers' CPU resources. Second, it permits a service provider to simultaneously check every edge data replica. Thirdly, it enables service providers to instantly discover problems with data replication across a large number of edge servers, which is a significant benefit.

Memetic Algorithm-based batch application placement technique for dealing with work from several processes on suitable servers was presented for their exact and effective assignment. According to the statistics, the Weighted cost in bandwidth analysis shows a 65.5% improvement over the competition, while execution time in decision time analysis shows a 51.5% improvement over the competition [35].

H. Ubiquitous Power Internet of Things (UPIoT)

The emergence of the UPIoT has brought about numerous new difficulties. Despite being used in the UPIoT, present cloud computing cannot yet address the issues we list below [36]: Low latency requirements, network capacity restrictions, device resource limitations, and continuous connection to and communication with the cloud center, privacy protection, and data security are all factors that must be taken into consideration. Three crucial IoT technologies sensor, connectivity, In order to get beyond these obstacles and see UPIoT expand, and edge computing are essential components of its overall architecture.

The most crucial base technology for the UPIoT to accomplish real-time reaction, Edge computing is one of them, and it performs short-term data processing, several edge intelligent service types, and other tasks. utilizing the network, processing, and storage resources scattered among the pathways between the cloud computing center and data sources, using a new computer approach called edge computing, a piece of data is analyzed and processed. [37]. Due to its focus on real-time analysis and sophisticated processing, edge computing is better able to serve local business, short-term data analysis on the device's side.

In contrast to straightforward cloud computing, it has benefits including traffic pressure reduction, distributed computing, minimal latency, and great efficiency. It is also more secure. The following are the primary benefits of edge computing for UPIoT. With these all, it is possible to review and evaluate edge data in milliseconds in addition to being collected and sent to the cloud platform. Consider the smart grid's sophisticated measurement system as an example, which uploads the edge intelligent fusion terminal with user electricity consumption data rather than sending A cloud platform receives thousands of data files for examination. This data may be assessed in real-time by the edge platform's computing program, which will only upload combined or data processing to the cloud center, significantly reducing connection bandwidth, cutting down on the amount of time it takes for data to be transmitted, and improving system performance.

The suppliers of cloud platform services provide their customers with a broad selection of centralized data security and protection choices. However, if the data that is held centrally is compromised, there will be disastrous consequences. Edge computing eliminates the need to transfer data to the cloud, bringing processing closer to the device. This decreases the danger of sensitive data being hacked or destroyed during transmission down significantly.

In addition, it lessens the risk of attacks on the data center that stores the data in the cloud, which reduces the likelihood that all of the data would be lost. Edge computing has the potential to drastically reduce operating expenses if it is able to minimize data migration and restrict the amount of data that is migrated and sent, requirements for bandwidth, and lag times. Due to the fact that using cloud computing necessitates transmitting data to a cloud processing center, which bestows upon it the characteristics of bandwidth, latency, and data movement, the utilization of cloud computing may be rather pricey.

The edge uses the cloud to perform computing tasks at edge computing gateways, which have specialized computer resources that may offer a chance to partially alleviate the burden on the cloud. The edge doesn't just use cloud services and content. In the meanwhile, the gateway provides a distributed information computing service that processes massive volumes of data fast. It is also capable of processing vast amounts of data from a variety of terminals, smart devices, and end users of the power terminal layer. thousands of sensor nodes and power terminal devices have a variety of alternatives for connecting to the smart grid to sense or control the power grid [38].

The UPIoT can use edge computing to process massive volumes of heterogeneous data locally and to acquire signals, addressing challenges of prompt response and centralized service while simultaneously lowering the burden on the cloud and cutting down on communication overhead. In addition to being able to execute compute offloading, storing, caching, and processing data, the Edge may also convey requests and services from the cloud to consumers. Under certain conditions, this mode may fulfill the need for users and equipment connected to smart grids to deliver prompt replies. The internal architecture of the edge computing gateway is shown in [36]. Its software architecture is composed of a number of containers in addition to the host operating system. While the data is being sent from the cloud server to the edge computing device, the terminal node, the edge computing device, and the terminal node are required to comply with uplink and downlink data interaction instructions.

Active applications are contained inside the container systems. By encapsulating the application features as APPs that are loaded into the container, this may allow more sophisticated applications of smart grids, such as edge autonomy of smart substations, intelligent online monitoring, quick request distribution, and service delivery.

I. IoT Applications

In edge computing, location is the only consideration. a user's computer, which is a client endpoint, is where data is produced, in conventional enterprise computing. Data is sent across a WAN, such as the local area network of the company or even the internet and is then saved and processed by an application designed for use in an enterprise setting there. After that, the outcomes of that task are sent to the client endpoint. This client-server computing technique has been proved to be effective for the vast majority of the typical commercial applications time and time again.

However, conventional infrastructures for data centers are having trouble keeping up with the rise in the number of internet-connected devices and the volume of data that these devices generate and demand. By the year 2025, 75 percent of the data generated by businesses will be created in locations other than centralized data centers [39]. It puts a significant amount of strain on the world's internet, which is already frequently overloaded and disturbed, to carry so much data in circumstances where timing or disruption are regularly important.

IT architects are shifting their attention away from the primary data center and instead concentrating on the logical edge of the infrastructure. This allows them to move processing and storage capacity away from the data center and closer to the site where the data is created. The solution is straightforward: move the data center closer to the data if you are unable to transfer the data itself closer to the data center. These theories made the case that locating computing resources close to the desired location would be more reliable and efficient than relying on a single central site. The idea of edge computing is not new; rather, it is based on these theories. Computing at the edge locates storage and servers close to where the data is in order to collect and process it locally. For this to work on the remote LAN, often only a partial rack of equipment is needed [40].

In order to protect it against changes in temperature and humidity, The computers themselves are usually kept in shielded or protected containers. As part of processing, normalizing and assessing the data stream might include searching for business information.

During this time, the outcomes of the study are the only things that are sent back to the primary data center. There are a variety of potential concepts for business intelligence. For instance, in retail environments, it would be conceivable to link real sales data with video surveillance of the showroom floor in order to determine which product configuration or client demand is the most desired. Another example of a technology that may direct equipment maintenance and repair prior to the occurrence of actual faults or breakdowns is predictive analytics. Yet other instances frequently include utilities, like the production of electricity or water, in order to preserve the efficiency of the machinery and the standard of the output [41].

The architectures needed to do computing tasks must be appropriate for those tasks, and not all computing tasks require the same architecture. Edge computing has emerged as a major and beneficial architecture due to its ability to position compute and storage resources closer to being at their optimal location in close proximity to the data source. The ideas of working from home, setting up satellite offices, sharing server space, and storing data in the cloud have been around for some time, and distributed computing models are generally not very unique. But when departing from a conventional centralized computer architecture, decentralization can be difficult since it necessitates high standards of oversight and management that are readily disregarded. Because it effectively addresses new network issues related to transferring the enormous amounts of data that modern enterprises produce and use, Edge computing has becoming more significant [42].

It's not only a problem of quantity. Applications depend on processing and replies as well, which are getting more time concerns. Take the development of self-driving vehicles. They will rely on highly advanced systems for controlling traffic signals. Systems for managing traffic and vehicles will need to immediately generate, evaluate, and communicate data. The potential scope of the problems becomes more obvious when you multiply this requirement by a substantial number of autonomous cars [43]. A quick and responsive network is necessary for this. Three major network constraints bandwidth, latency, and congestion or reliability are resolved by edge and fog computing.

1. Bandwidth

A network's capacity for carrying data is measured in bandwidth, which is typically represented in bits per second. There is a limited amount of bandwidth available on every network, and wireless communication is subject to ever-tighter limitations. This indicates that there may be a limit placed on the amount of data that can be sent through a network as well as the number of devices that can do so. An increasing network capacity to support additional devices and traffic is possible, doing so can be expensive, there are still (higher) limiting constraints, and it only partially allays the worries.

2. Latency

Latency refers to the length of time it takes for data to move from one point to another over a network. Despite the idea that information should travel across networks at the speed of light, this isn't always the case due to factors such as physical distance, network congestion, and outages. As a result, a system's capacity for quick response is diminished, and all analytics and decision-making processes are slowed down. It even resulted in lives being lost in the driverless car scenario.

3. Congestion

The internet can be thought of as a huge network of networks. The volume of data generated by tens of billions of devices might overload the internet, producing significant congestion and necessitating time-consuming data retransmissions, despite having evolved to provide excellent general-purpose data transfers for the majority of routine computational operations, such as exchanging files or performing fundamental streaming. In the event that the internet of things is unavailable, network interruptions can often make devices more difficult to operate and even prevent some people from interacting.

J. Edge Security

In 2021, Edge computing, its applications, and the security threats associated with data analysis in the edge network were explored. They recommended both developing more edge based IoT security solutions and undertaking a thorough examination of the current IoT security options at the edge layer. The problems in the area of cutting-edge new technologies are not clearly stated by [44].

Important security objectives include session key agreement, anonymous mutual authentication, and secure communication, were said to be attained. The performance analysis of the suggested technique demonstrates that it is more effective. The proposed concept has yet to be put into practice in a number of applications, including telemedicine, smart homes, digital content distribution, and vehicular communication [45].

Researchers of [46] described the ideas behind edge computing and compared them to cloud computing. Then, after some quick introductions, a conversation discussing the applications of edge computing, keyword technology, security, and privacy protection was conducted. They still haven't specified what function they will serve in the Content Delivery Network (CDN).

The authors of [47] created a framework for the placement of hybrid cloudlets that is the most cost-effective alternative when compared to the framework for the installation of field cloudlets. Installing cloudlets in remote or remote-to-central office (CO) locations is best accomplished with a hybrid cloudlet installation framework based on TDM-PON. No other forms of CDM or FDM are discussed.

It is believed that an adaptive replica placement strategy would improve both the performance of cloud storage and the accessibility of data when applied to the setting of edge computing. Additional datasets were employed in the process of testing and validating the adaptive replica placement strategy that was proposed. They should also evaluate how the manufacturing of replicas is affected by other factors, such as the significance of the files to which the data blocks belong and the level of user authorization [48].

III. CONCLUSION

This paper presents a full introduction to the edge computing paradigm, covering its fundamental principles, architecture, major technologies, as well as aspects pertaining to security and privacy. Computing at the network's edge makes it possible to store and process data close to the network's edge as well as local Internet intelligent services. This helps a variety of businesses make the shift to digital technology and satisfies their requirements for data diversity. Research on edge computing is becoming more popular right now. As the Internet continues to evolve and become more complex, edge computing will play an increasingly important role in the future. Also, human civilization, and numerous businesses all continue to flourish into the future. It's used in a wide variety of fields, including video games, the industrial Internet, smart homes and transportation, and the Content Delivery Network (CDN).

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