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EXPLORING THE HYBRID APPROACH OF INTEGRATING EDGE COMPUTING WITH CLOUD INFRASTRUCTURE

Sandeep Kumar Guduru
gudurusandeep@gmail.com

Abstract

The issues on modern computing platforms, including IoT, 5G, and real-time applications, should be addressed by the integration of edge and cloud computing. Edge computing utilizes slow latency as it works on data at a point of need while cloud computing supports scalable resources and shared infrastructures. This study aims to determine how the edge and cloud paradigms merge and discovers that they work in tandem to provide safe processing and real-time data processing with low latency and high bandwidth. A new architecture is proposed, which encompasses the features in the flamboyant edge computing that can perform computations where the data is generated and the muscle power that cloud computing offers. Features including latency control, data coherency and compatibility are discussed in relation to the current developments and uses. The present review demonstrates the enormous potential of hybrid edge-cloud solutions across various domains, such as IoT, 5G, and industrial automation and explicates the theoretical and methodological contributions that outline how to enhance the suggested distributed architecture's scalability, performance, and dependability in further studies. Several directions for future research have been suggested in this study for future hybrid architecture refinement across the industries are shown below.

Keywords: Edge Computing, Cloud Computing, Hybrid Edge-Cloud Architecture, Internet of Things (IoT), 5G Networks, Real-Time Data Processing, Distributed Systems, Data Synchronization, Resource Optimization, Scalability, Low Latency.

I. INTRODUCTION

Edge computing is very innovative in the field of distributed computing which is intended to process the big data artifacts near to them like at sensors, IoTs, local servers etc. The importance is realized from the ever-increasing demand to process data in real-time manner since this protocol assists in minimizing the distance that data has to travel. Although the edge computing notion is getting more recognition daily, some edge aspects require it to connect with defining cloud computing[1]. A novel approach that combines cloud and edge computing into a hybrid network addresses the lack of such a paradigm. This is especially so because while cloud computing offers cheap, flexible, fast ICT utilities that can be accessed on demand, edge computing offers near real-time data processing to reduce delay time.

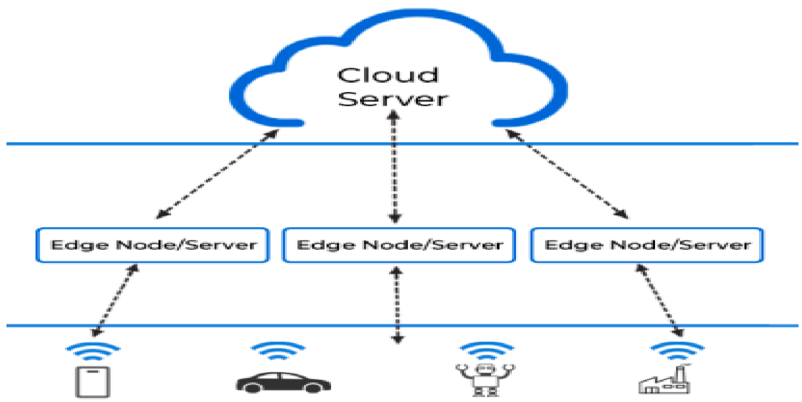

Fig.1. Integration of cloud and edge computing

This is referred to as "cloud-to-edge". An example of where a given business needs extensive analysis of voluminous data, then needs real-time analysis and low latency then this strategy may be feasible. The edge-to-cloud operating paradigm analyses data before it is sent and stored in the cloud for the following step, allowing for a flexible flow at the network edge. This approach may be useful for businesses that need to analyze a lot of data, but it is not appropriate for processing and analyzing data in real time.
To tackle these limitations, the edge computing paradigm appears as the secondary one that shifted the data processing logic closer to the data creation point. Because of this proximity, the model of a centralized cloud does not require as much because processing and decision-making can occur more rapidly[2]. Another strategy that works well for managing IoT data is the hybrid method, which combines cloud and edge computing. The combination of cloud and edge computing demonstrates how data for the Internet of Things might be improved. First, discussion of the integration's theoretical framework, the state-of-the-art approaches, and the practitioners' experience. The primary objectives are to understand how cloud and edge computing are combined, to state the pros and cons that arise from this integration, and to focus on the major usage cases showing how efficient integration is in practice [3].

A. Organization of the paper

This paper is organized as follows: These make up part II, which concentrates on the fundamental ideas of cloud and edge computing. The integration of the hybrid edge-cloud strategy is covered in Section III. Section IV outlines the main challenges since the integration, such as security and latency. In section V, authors present a literature review and developments. Recommended strategies of this study and other recommended interventions It is important to realize that section VI of this paper provides important information on some key findings and directions for future research.

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II. FUNDAMENTALS OF EDGE COMPUTING AND CLOUD INFRASTRUCTURE

Cloud computing and edge computing are two cutting-edge approaches of managing data and information. Cloud computing, in contrast, combines data analysis, whereas edge computing analyses data close to its source.

A. Edge Computing Overview

Edge computing can be understood as the computing assets, including servers, storage, applications, and connections, as well as networks and other software, that are positioned at the periphery of the enterprise. Transfer of edge computing Applications, services, and computational data are moved to the network edge from the cloud server. Large bandwidth processing, extremely low latency, and real-time network data access are all capabilities of edge computing that may be used to a wide range of different applications.
Edge computing is becoming more popular in various industries because of such benefits:

- Low Latency and Fast Response: Edge computing is a technique that dials down the time it takes to perform data processing away from data centers or cloud. This is crucial for some high real-time applications For instance, industrial security and control systems.
- Local Data Processing and Bandwidth Savings: Many crucial calculations may take place close to the device thanks to edge computing, which only relays important and relevant data to the cloud or data center. This results in lower data transmission costs since it lessens the strain on bandwidth availability for system use.
- Better Data Security and Privacy: The processing of data in close proximity to the event itself thereby improves data protection and privacy. Additionally, there is no requirement to move it to a data center or cloud, which may be compromised or have leaks while being moved.

1) Components of edge computing:

Edge computing functions in sync with three main components. Let's discover the pivotal role each one of these plays in shaping the edge infrastructure [4]. Figure 2 depicts the components of Edge computing discussed below:

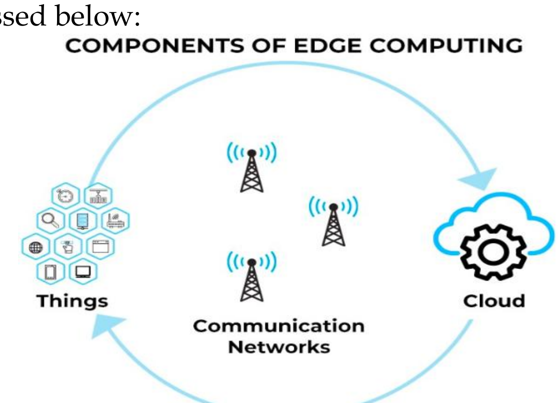

Fig. 2. Component of Edge computing

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- Internet of Things (IoT): It is noteworthy, however, that the use of IoT devices has grown rapidly only in recent years. The almost boundless applications of IoT have elicited high expectations among many businesses. IoT has played a very significant role in driving computing to the edge in many ways. Edge computation is mostly found in IoT domain where results are stored in a remote location far from the central server[5].
- Communication networks: The advancements in the telecom industries are highly propelled by 5G, it has created ways for various innovations. However, the appearance of new, wireless devices such as IoT, becomes a problem for the network, which hinders to handle the large amount of virtual data[6]. The integration of edge computing and 5G is creating the foundations for the digital transformation that forms the basis of today's organizations.
- Cloud computing: The predecessor of the edge is called cloud computing, which is a massive means of storing and processing computer resources in a central computing center. On the other hand, edge computing is a decentralized architecture model that will be applied by those applications and connected devices seeking fast response times, real-time data processing, and core insights.

B. Cloud Infrastructure

Cloud solutions refer to the physical and logical systems through which cloud services are accessed and used. Then, the service paradigm called cloud computing enables customers to access resources like servers, storage, and apps via the Internet. SaaS does not require the necessary physical facilities, additional IT investments and infrastructure, as consumers can access these services at their convenience [7]. There are also several benefits of cloud computing, which also make it crucial for many companies or organizations including:

- Scalability and Flexibility: Depending on business requirements, Cloud computing makes it simple for users to increase or decrease their resource capacity. By only paying for the resources they utilize, users may reduce operating expenses[8].
- Operational Cost Savings: Businesses can avoid paying high costs for the acquisition and upkeep of physical infrastructure by utilizing cloud services. Cloud service providers handle all infrastructure requirements, freeing up companies to concentrate on their primary business operations.
- Enhanced Security and Compliance: Cloud service companies often adhere to a number of industry rules and have strict security standards. The danger of data loss or theft is decreased since cloud data is additionally safeguarded by a number of security measures, including firewalls and encryption[9].

1) Cloud computing Architecture

The two components that comprise the architecture of cloud computing are the front-end and the back-end.

- Front End: A variety of apps and interfaces required for distinct cloud-based services are included in the front-end cloud computing area. This was created with client-side applications, such as web browsers like Internet Explorer or Google Chrome. Cloud infrastructure includes many hardware and software components, such as servers, virtualization software, and data storage. Additionally, end users can do their tasks via a graphical user interface.

- Back-end: It is responsible for monitoring every program that runs the front-end application. The resources are required for the back end to manage cloud computing services. Numerous information repositories, servers, security services, deployment patterns, and traffic management strategies are all included[10]. Below is the architecture of cloud computing in Figure 3.

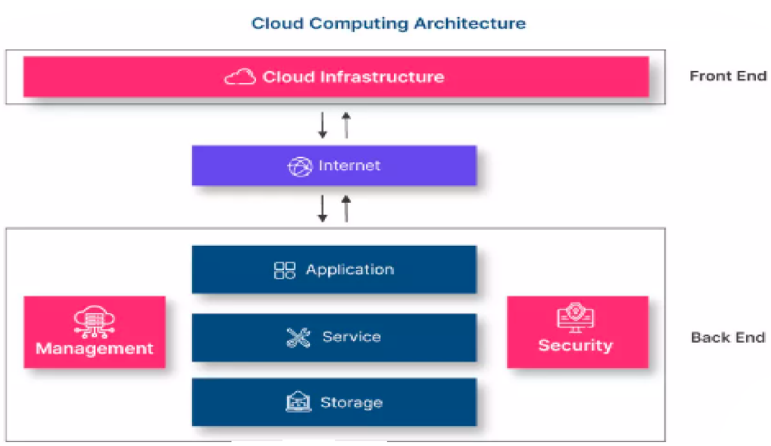

Fig. 3. Architecture of cloud computing

Following are some cloud computing components

- Application: The application is nothing but a software/platform accessed by the client.
- Storage: This component is useful for storing large amounts of information in the cloud. e.g. Oracle Cloud Storage.
- Management: Management is primarily helpful in handling all the components like applications, infrastructure, storage, runtime cloud as well as services. It also takes diverse security problems that arise in the cloud.
- Internet: By using the Internet, the front-end section of cloud architecture and back-end section can communicate with each other. It is a communication medium between them.
- Services: Taking the client's demands into account Cloud computing provides a wide range of services, such as infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). Services are the primary component of cloud computing.

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III. THE SYNERGY OF EDGE AND CLOUD COMPUTING: A HYBRID APPROACH

The hybrid edge cloud is an enterprise edge deployment model that combines infrastructural elements of both private cloud (provided by CSPs' own infrastructure) and public cloud (provided by HCPs infrastructure) environments. It's an evolution of the partner edge, where resources, expertise and value are shared between both players and where network functions and enterprise applications run seamlessly across a single hybrid infrastructure shown in Figure 4 [11].

- Private cloud: To refer to products that simulate cloud computing on private networks, several companies have used the phrase "private cloud." An organization's internal corporate data center is where it is configured. In the private cloud, cloud customers may share and utilize the virtual apps and scalable resources that the cloud vendor has pooled together.
- Public cloud: The phrase "public cloud" describes cloud computing in its widely accepted, traditional sense, which uses web apps and web services from an off-site third-party provider to dynamically distribute fine-grained, self-serviced resources via the Internet. Public clouds are less secure than other cloud models because of the additional burden of ensuring that all programs and data accessed on the cloud are not susceptible to malicious attacks.

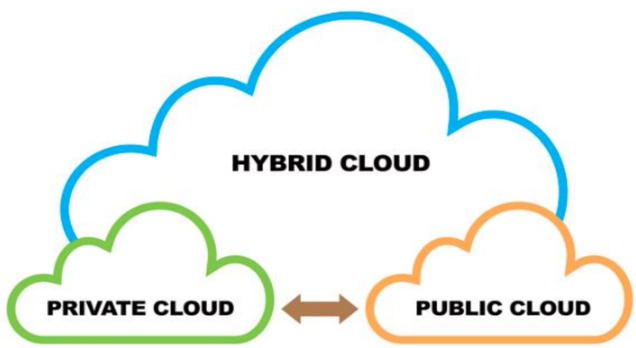

Fig. 4. Hybrid cloud in infrastructure

A. Integration of Hybrid Edge-Cloud Approach

Because they recognize the complementary nature of edge and cloud computing, many businesses choose hybrid architectures that combine the benefits of both paradigms. By combining Edge devices with cloud services, businesses can balance local processing and centralized control while optimizing resource allocation based on workload characteristics and operational needs[12]. There is no need for hybrid cloud and edge computing to clash. There is a noticeable rise in hybrid systems as a result of cleverly allocating computation to combine the benefits of cloud and edge computing [13].

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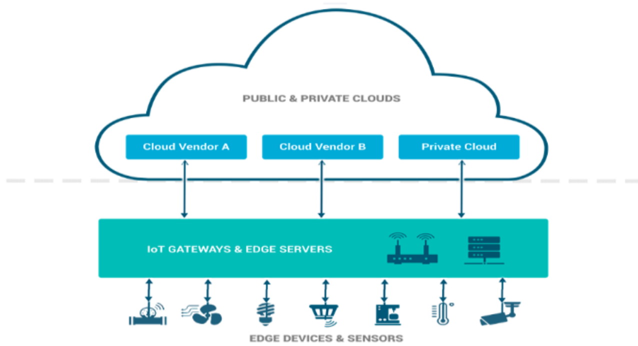

Fig. 5. Hybrid Edge-cloud Approaches Architecture

As seen in Figure 5, the Hybrid Edge-Cloud architecture highlights the smooth transition between edge and cloud computing for effective data processing and flow [14].

1) Cloud layer

The Hybrid Edge-Cloud architecture relies on both private and public clouds for support. Private and public organization-specific infrastructures can handle a variety of computational demands. Public cloud vendors such as Cloud Vendor A and Cloud Vendor B feature controlled flexibility and distribution of resources that efficiently switch according to the workload requirements. Meanwhile, the private clouds secure enhanced control through in-prem home service infrastructures set for particular organizations. Both of them work in sync to perform a variety of big-data-related functions, ML, long-term storage, and consolidated management of all IT aspects, enabling the organizations to function and utilize resources together free of obstacles [15].

2) Edge Server layer

IoT gateways and edge servers are essential for tying edge sensors or devices to the cloud and enabling seamless communication and data transfer. At the edge, they are responsible for real-time data preparation, aggregation, and processing, which eases the burden on cloud infrastructure and guarantees quick response times. Furthermore, the servers and gateways connect to the cloud and ensure secure connections for data transfers. By encrypting data exchanges, the system becomes more efficient[16].

3) Edge Devices & Sensors

Internet of Things sensors, vision equipment, and actuators used in real-world environments for data collecting and immediate feedback make up the large population of devices and sensor equipment known as smart peripherals. These gadgets are crucial for gathering environmental data and enabling real-time decision-making[17]. For example, use of robots in industries, traffic cameras in smart environment of a city, smart meters in energy management systems and medical devices in patient monitoring to enhance responsive operations of the management systems[18].

IV. CHALLENGES IN INTEGRATING EDGE COMPUTING AND CLOUD

Edge computing technologies also raise important concerns about data security and privacy that may be managed at the network edge. Because edge devices are more common and have fewer security measures, they are more frequently the target of cybersecurity threats. There are some factors to take into account while integrating edge computing with cloud infrastructure.

- Latency Management: Keeping data processing real-time at the edge while at the same time being interoperable with the cloud.
- Data Synchronization: Maintaining consistency of data across edge and cloud, especially when it is necessary to work with elements of a system that may only periodically have access to each other [19].
- Security Concerns: Addressing edge and cloud level issues, which are some of the following: data encryption, funny access control, and threat detection.
- Network Reliability: They called for ways of handling interferences in network connectivity between the edge devices and the cloud, as this affects the performance of the system.
- Scalability: Designing for systems, which can effectively manage the fluctuations in the workload at the edge and the cloud.
- Interoperability: Being able to guarantee that multiple types of hardware and software platforms popular in the edges as well as in the clouds are compatible.
- Resource Allocation: Interedge is defined as the process of how the edges and the Clouds divide the computational and storage resources[20].
- Regulatory Compliance: In addition, where such data is processed locally at the edge adhering to regional data privacy and security rules.
- Cost Management: Mitigating the costs incurred with deploying, managing and growing edge devices and cloud infrastructure.
- Complexity in Orchestration: overlapping of processes in both edge and cloud platforms especially when working with multiple systems and different protocols.
- Energy Efficiency: Managing the power consumption of edge devices while ensuring they perform efficiently.
- Limited Edge Device Capabilities: Addressing limitations such as restricted processing power, memory, and battery life in edge devices.
- Data Governance: Establishing clear ownership and management of data processed at the edge compared to the cloud [21].
- Latency-Sensitive Applications: Making sure that applications that need near-instantaneous responses (like IoT and autonomous vehicles) are not slowed down by integration issues [22].

V. LITERATURE REVIEW

This section covers earlier studies on the hybrid approach of combining cloud infrastructure and edge computing with cloud computing and the IoT.

In this study, Hamadi et al. (2022) suggest an innovative method for offloading computing duties from devices to possible edge computers that possess sufficient computational power. The edge computers are grouped according to their hardware specs in the suggested method. Rethinking how data is handled, processed, and distributed across a large, diverse network is the goal of edge computing, or EC. The edge computer that is anticipated to respond the quickest to each job is finally selected. According to the experiment data, our suggested method works better than[23].

In this study, Alamouti, Arjomandi and Burger, (2022) Describe the hybrid edge cloud (HEC), a unique architectural solution to cloud decentralization that uses less network bandwidth, communication latencies, and smart device resources to concurrently reduce the burden on server farms and other centralized computer resources. Consequently, the current centralized cloud infrastructure is no longer viable or effective. Utilizing both private and public clouds, HEC leverages computational power by combining the advantages of emerging network technologies like 5G and WIFI 6[13].

In this study, Chen et al. (2019) essential component of edge-cloud-hybrid systems is the Internet of Things concept. In an edge environment, a number of IoT-data-intensive services will come together to form a service combination. This leads us to suggest a new heuristic approach for deploying IoT-data-intensive service components in edge-cloud-hybrid systems. According to the experimental findings, the iDiSC method performs better and is more efficient when it comes to handling Problems with the deployment of data-intensive service components in hybrid edge-cloud settings[24].

In this study, Sandeep and Thangam, (2021) Identify duplication and stop it using this methodology to make effective use of cloud storage. While some processes are expected to be necessary to provide safe information capacity and recovery, the majority of them face certain drawbacks that diminish the common sense of cloud computing. A half-breed cloud strategy is examined in this paper for effective information capacity and security[25].

In this study, Schäfer et al., (2018) Present a hybrid scheduling strategy. In addition to centralized scheduling on the remote edge and cloud resources, we offer an ad hoc scheduling method on nearby edge devices. When choosing between an execution in the cloud or on the edge, our context-aware scheduler takes into account both alternatives as well as the task's characteristics. We assess the hybrid scheduler on an actual testbed and incorporate our method into an already-existing distributed computing system[26].

In this study, Riane and Ettalbi, (2018) a multi-cloud setting, provide a novel method for deploying composite infrastructure services. The deployment of composite infrastructure services across various clouds is complicated, and an automated method is needed to satisfy user objectives like high dependability and low deployment costs. On-demand Internet access to various cloud services is made possible by cloud computing technologies[27].Table I provides the comparison on their key points, focus area and also discuss finding the insights.

Table I. Literature Review Review on Hybrid Approach of Integrating Edge Computing with Cloud Infrastructure

References	Key Topic	Focus Area	Findings/Insights
[23]	Edge Computer Offloading Technique	Computational task assignment and resource optimization in edge computers	suggests allocating jobs to edge computers that are anticipated to respond the fastest and grouping edge computers according to hardware requirements. The results of the experiment demonstrate that the suggested strategy performs better.
[13]	Hybrid Edge Cloud (HEC)	Cloud Decentralization	suggests HEC as a cutting-edge method for maximizing smart device resources, minimizing network bandwidth use, and lowering communication latencies. Improves the efficiency of both private and public clouds by combining 5G and WiFi 6 technologies. Highlights inefficiencies of centralized cloud infrastructure and presents HEC as a sustainable alternative.
[24]	Implementation of Data-Intensive IoT Service Elements	Deploying IoT data-intensive services in hybrid edge-cloud environments	provides instructions for installing IoT-data-intensive service components using the iDiSC heuristic, which enhances the effectiveness and performance of edge-cloud-hybrid systems.
[25]	Efficient Cloud Storage and Duplication Prevention	Hybrid cloud approaches for secure and efficient data storage	Proposes a model to identify and prevent data duplication to optimize cloud storage usage. Addresses security and recovery challenges in hybrid cloud systems.
[26]	Hybrid Scheduling Approach	Context-aware task scheduling across edge and cloud resources	Introduces a context-aware hybrid scheduler integrating ad-hoc scheduling on nearby edge devices and centralized scheduling on remote resources. Evaluation in a real-world testbed shows effective task distribution.
[27]	Multi-Cloud Deployment of Composite Infrastructure Services	Composite infrastructure services are automatically deployed across several clouds	The difficulty of installing composite services is addressed by an automated method that ensures high dependability and low deployment costs in multi-cloud systems.

VI. CONCLUSION AND FUTURE WORK

The hybrid integration of edge and cloud computing enables low latency, real-time data processing and the scalability of cloud infrastructure, offering an innovative solution to meet the demands of modern distributed systems. This study examined the foundational ideas, hybrid architecture, difficulties, and developments in this field. Optimizing operational efficiency, especially in IoT and 5G applications, has been made possible by the convergence of edge and cloud technology.

Despite its potential, several challenges remain, including data synchronization, security, and resource optimization. Future research should focus on developing standardized frameworks to address interoperability issues, improving energy efficiency in edge devices, and enhancing security mechanisms for data exchange. Additionally, advancements in AI and machine learning can further optimize hybrid systems by enabling intelligent resource allocation and predictive analytics. The ongoing development of hybrid edge-cloud computing will spur industry-wide breakthroughs and open the door to distributed computing solutions that are safe, scalable, and effective.

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