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A COMPARATIVE ANALYSIS OF CLOUD, FOG & EDGE COMPUTING

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ABSTRACT

This paper presents a complete comparative analysis of Cloud, Edge, and Fog Computing, describing their architectures, capabilities, and applications. Tremendously growing need for low latency, efficient data management, and real-time processing hasgiven rise to the emergence of these computing paradigms. This paper explores prospective integration strategies and synergies to optimize computing resources in a varied range of applications.Edge computing is a distributed technology architecture in which client data is processed at the edge of the enterprise network, as close to the producing source as possible.Fog computing is taking the benefits of cloud computing to the edge of the network. It specifies non centralized computing resource located between the devices that produce data and the cloud. Tasks like computing, storing, and networking between devices and data centers of cloud computing are being provided by Fog computing. Decentralization and flexibility are the primary differences between Fog computing and Cloud computing. Reduced latency, comfiture network bandwidth, reduced operating costs, improved security, and enhanced reliability are primary advantages of Fog computing. Various applications of Fog computing aresmart electric grids, smart transportation networks, autonomous connected cars, smart citiesand real-time analysis, etc., This paper shows a comparative study of Cloud, Fog, and Edge Computing.

Key-words: Cloud computing, Fog computing, Edge Computing, Internet of Things, Distributed, Data security.

INTRODUCTION

Needs for efficient, fast, and reliable computing systems are growing with great pace. With the extensive increase of the IoT and the increasing number of smart devices, traditional cloud computing is facing several new challenges. Fog computing and edge computing have now emerged as better solutions to such challenges and problems. Fog, and edge computing offers ways of processing and analyzing data in real-time.

Cloud computing is the deliverance of computing services and IT resources over the Internet with pricing model of pay-as-you-go. Consumers can get technology services like storage, databases, and processing power from a cloud vendor eliminating the requirement of buying maintaining and operating on premises' physical data centers and servers.

Edge computing is a computing architecture [1] that has the objective of bringing computing closer to the device where data is produced. It has the idea of processing data at the edge of the network as opposed to in the cloud or in a centralized data center. Edge computing is reducing the amount of data that needs to be transmitted to the cloud or a centralized server for processing by which network latency is reduced thereby overall performance is improved.

Fogging [3] is a technology that extends cloud computing and services to the edge of an enterprise's network. It is a decentralized computing model that is designed to complement edge computing. It

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extends the capabilities of edge computing by providing a layer of infrastructure (fog layer) of computing between the cloud and edge devices.

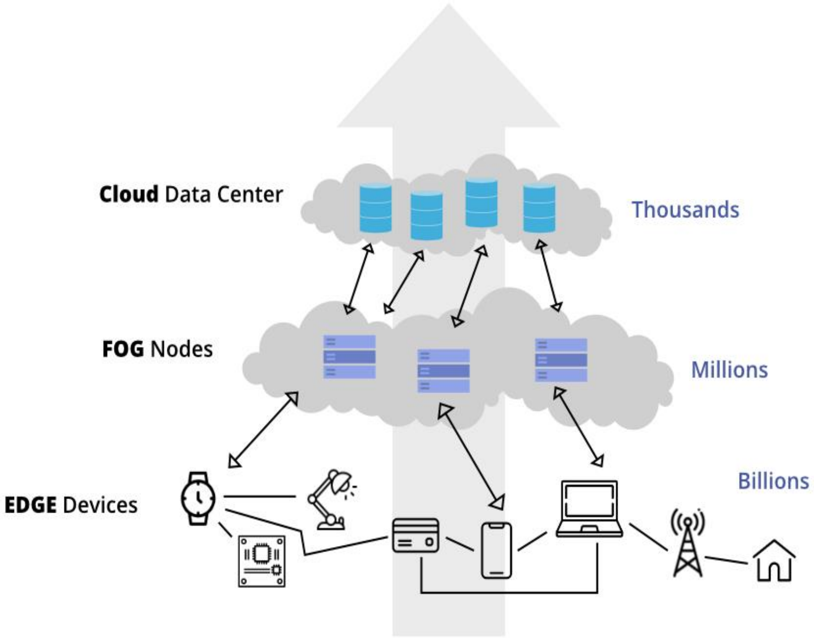

Figure 1: Layer of infrastructure (Fog layer)

MAIN DRIVERS BEHIND FOG, CLOUD, AND EDGE COMPUTING:

Cloud computing

- **Client-Server Architecture and Mainframes:**Computing primarily relied on mainframe systems and later evolved into client-server architectures before advent of cloud computing. However, these models had various limitations in terms of flexibility, scalability and cost-effectiveness.
- **Up rise of the Internet:**Adoption of the Internet has a crucial role in the development of cloud computing. Internethas provided the connectivity needed for remote data access and collaboration.
- **Server Virtualization Technology:** Server virtualization has allowed multiple virtual machines to run on a single physical server. This breakthrough enhanced resource utilization, the ability to quickly provision computing resources, and scalability.
- **Pay-as-You-Go Pricing Model:** Cloud computing offered a pay-as-you-go model that enabled organizations to pay only for the resources they use. This shift from capital-intensive investments to operational expenditures contributed to significant cost reduction.
- **Resource Optimization:** Cloud services permitted better resource utilization, reducing the requirement for over-provisioning and enabling organizations to scale up or down their infrastructure as per requirements.
- **Scalability:** Cloud computing offers a great deal of scalability, enabling organizations to scale up or down their infrastructure dynamically. This flexibility is vital for businesses facing workloads of variable nature.

Edge computing:

- **The growth of IoT Devices:** The enormous growth of end devices, sensors, and IoT applications producedhuge amounts of data. Edge computing evolved to process the data closer to the source, minimizing latency and bandwidth use.

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- **Demand for reduced latency:** Applications needing real-time or near-real-time processing, such as virtual reality, augmented reality, and self drivingvehicles, required a paradigm shift toward edge computing.
- **Bandwidth Optimization:**With the increasing volume of data generated, sending all data to central cloud servers became impractical. Edge computing tackles this challenge by processing data locally, minimizing the requirement for voluminous data transfer.
- **Decentralized and Distributed Computing:**Edge computing provides a shift from a centralized computing model to a decentralized approach. This change improves reliability and scalability by distributing computing resources geographically.
- **Edge Devices' Increased Computing Power:** The enhanced processing power of edge devices, such as gateways, routers, and edge servers, enabled more sophisticated computations to be performed very closer to the data source. Edge devices equipped with embedded AI capabilities and analytics allow for on-device processing and decision-making.
- **Privacy and Data Sovereignty Concerns:** Privacy regulations and concerns about data sovereignty made organizations to process sensitive data locally, within specific regions. Edge computing offers compliance with these regulations. Data processing at the edge reduces the requirement for data to travel long distances, reducing exposure to potential security risks during transmission.
- **Emergency Response and Public Safety:** Mission-critical applications, such as emergency response systems, benefit from the low-latency and high-reliability aspects of edge computing.
- **Future Connectivity Technology (5G Networks):** The 5G technology further supports edge computing by providing low-latency, high-speed connectivity. This combination opens up various new possibilities for applications that need ultra-fast response times.

Fog computing:

- **Expanding IoT:** The swift growth of IoT devices and applications, originatinghuge amounts of data, necessitated a paradigm that could efficiently process and analyze this data closer to the source.
- **Real-time Processing Requirements:** Applications like industrial automation, and augmented reality needing low latency demanded a computing paradigm that could provide localized and fast processing.
- **Bandwidth Efficiency:** Fog computing evolved as a solution to minimize the load on centralized cloud infrastructure by processing data much closer to the edge, reducing the need for huge data transfers.
- **Distributed Computing Resources:** Fog computing extends the cloud paradigm by bringing computing resources closer to the edge. This distributed architecture improves response-time, scalability, and reliability.
- **Seamless Integration with Cloud and Edge Computing:** Fog computing complements both cloud and edge computing by providing an intermediate layer, forming a seamless continuum. This integration optimizes the distribution of computing tasks based on resources and requirements.

COMPARISON OF CLOUD, EDGE, AND FOG COMPUTING:

Table 1: Comparison of cloud, fog, and edge computing

S.N.	Performance Metric	Cloud	Fog	Edge
1	Data Processing distance	Far from the source of information	Close to the source of information	Very close to the source of information
2	Number of nodes present	Thousands	Millions	Billions
3	Operational cost	Low	High	Very high

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4	Architecture	Centralized	Distributed	Distributed
5	Analysis	Long term	Short term	Instantaneous
6	Attack on data enroute	Very likely	Less likely	Very rare
7	Communication with devices	From a distance	from the edge	From the device or edge
8	Capacity	Does not provide any reduction in data while sending or transforming data	Reduces the amount of data sent to a centralized server	Reduces greatly the amount of data sent to the fog layer or a centralized server
9	Computing power	Higher	Lower	Lowest
10	Connectivity	Internet	Various protocols and standards	Device-to-device communication
11	Latency	High	Low	Very low
12	Delay jitter	High	Low	Very low
13	Location awareness	Partially supported	Yes	Precisely
14	Mobility	Limited	To some extent	To large extent
15	Real-time interactions	Supported to some extent only	Supported	Supported to a very large extent
16	Responsiveness	Low	High	Very high
17	Scalable	Very High scalable	High scalable	Very less scalable
18	Bandwidth Requirement	Very high	The bandwidth requirement is high. Data originating from edge nodes is transferred to the cloud.	The bandwidth requirement is very low. Because data comes from the edge nodes themselves.
19	Privacy	Less	High	Very high

FINDINGS FROM THE COMPARATIVE STUDY:

- **Overview of Computing Approaches:**
    - **Cloud Computing:** Cloud computing is acentralized model that provides resource virtualization, scalability, and diverse services. Appropriate to applications without strict latency demand.
    - **Fog Computing:**Fog computing is a layer between cloud and edge that minimizes latency by processing data closer to the source of data. It is suitable for applications that need low to moderate latency and distributed processing.
    - **Edge Computing:**Processing closer or at the data producing device, reducing latency and minimizing reliance on centralized infrastructure. It is ideal for real-time, latency-sensitive applications.
- **Latency and Response Times:**
    - **Cloud Computing:**Cloud computing has higher latency due to data transmission to or from central servers. Not necessarily satisfy stringent latency demands of real-time applications.

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- **Fog Computing:** Fog computing provides moderate latency because data is processed nearer to the source. It is suitable for applications with medium real-time processing requirements.
- **Edge Computing:** Minimal latency since data processing is done locally i.e. at the device itself. Ideal for applications demanding quick response times and very low latency.

- **Bandwidth Utilization:**
  - **Cloud Computing:**Cloud computing requireshigh bandwidthdue to data transmission to or from central servers.
  - **Fog Computing:**Because data processing is done locally so bandwidth requirement is low and amount of data transfers is reduced enormously.
  - **Edge Computing:** Minimizes bandwidth usage as processing occurs at or near the edge device.
- **Resource Utilization:**
  - **Cloud computing:**Resources are used efficientlyin cloud computing. But cloud computing may face challenges in optimizing sporadic workloads.
  - **Fog Computing:** Fog computing modifies resource usage by distributing tasks near to the edge. It providesadaptability and scalability for variable workloads.
  - **Edge Computing:** Localized resource usage, avoiding extensive cloud infrastructure. It is efficient for localized tasks.
- **Industry-Specific Applications:**
  - **Cloud Computing:** Well-suited for general-purpose applications, processing, and data storage.
  - **Fog Computing:**Fog computing can be applied to industries like healthcare, manufacturing, and smart cities where localized processing is important.
  - **Edge Computing:**Best suited for applications in manufacturing, IoT, and real-time analytics where edge data processing is mandatory.
- **Synergy and Integration:**
  - **Cloud-Fog Continuum** Fog computing complements cloud computing as an intermediary layer. Fog computing enables optimized distribution of operations based on needs.
  - **Fog-Edge Integration:** Fog and edge computing get united to form a continuum, optimizing computing resources across layers.
- **Forthcoming Trends:**
  - **Cloud Computing:**There is continually growth focused on special services and improved AI capabilities in cloud computing.
  - **Fog Computing:** Fog computing has growing integration with edge and cloud computing, further optimization for variable workloads.
  - **Edge Computing:**Expanding applications with 5G advancements, increased device capabilities, and improved interoperability.

CONCLUSION

Based on various metrics and functionalities we can infer that the choiceamongst cloud, fog, and edge computing depends on the specific needs of the application, considering factors like bandwidth, security, speed, and resource usage. The union of these approaches is a trend now, permitting organizations to utilize the strengths of each for optimized computing solutions. Fog computing, and Edge computing are two harmonizing computing models created to address the challenges of processing and analyzing data in real-time. Edge computing takes computing near to the device that generates data, while fog computing expands the abilities of edge computing by providing extra

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services, and computing processing to edge devices. Both computinghas many practical uses in digital world and plays an increasingly significant role in the future of computing.

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