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Utilization of Fog and Cloud Computing with IoT for Real-Time Applications: A Combined Study

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***Abstract*—The Internet of Things (IoT) is changing our way of life and work by enabling objects from daily life to connect over internet. The Cloud Computing and Fog Computing with the IoT is revolutionizing real-time applications by instant analysis and response to data as it is produced. Data gathered from sensors and devices is immediately processed to prompt actions or decisions without any significant delay which is essential for applications where precise timing is vital such as in healthcare, emergency response systems, predictive maintenance, and real-time traffic management. This paper explores how Cloud Computing and Fog Computing are enabling real-time data processing in IoT environments. Cloud Computing provides extensive computational power and scalability but due to centralized data processing it frequently encounters latency and bandwidth challenges. In contrast FC enhances cloud capabilities by bringing processing nearer to the network periphery thereby lowering latency and improving real-time responsiveness. Further due to its decentralized nature of resources load balancing is very critical. Effective load balancing and task scheduling reduce latency and improve system performance, ensuring high throughput and reliability in Cloud-Fog environments.**

***Index Terms*— IoT, Cloud Computing and Fog Computing.**

I. Introduction

The Internet of Things (IoT) consists of two parts: Things and Internet. 'Things' are physical objects that collect and transmit data about themselves or their environment. The 'Internet' part provides the infrastructure needed to connect these objects and allow them to communicate with each other and with users[1].

With the perspective of International Telecommunication Union, Internet of Things is “a global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies” [2].

Internet of Things (IoT) consists of sensors, devices, actuators, network connections and additional elements that work together to gather and exchange data. This synergy enables the establishment of smart systems that can monitor and control various aspects of our daily lives. To create a smooth and automated experience a smart home system for example uses sensors to observe humidity temperature, and light levels. These parameters are then modified based on the data obtained using actuators.

The researchers face significant challenges because to the vast data collected by IoT devices. IoT data comes from many sources in a variety of formats that includes scripts, photos and videos and is characterized by volume and generation rate.

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Efficient storage, processing, and analysis are necessary for managing this volume of data. Considering the limited resources (power, storage, processing capabilities) of small IoT devices like smartphones and wearables data scientists face substantial challenges in acquiring, integrating, gathering, processing, and studying IoT data. This emphasizes how cloud computing which offers resources and on-demand services that let the management of data must be integrated with the IoT.

II. OVERVIEW OF CLOUD COMPUTING

A. Cloud Computing

With the perspective of NIST, Cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [4].

B. Integration of IoT -Cloud

The IoT encounter challenges like storage, performance, security, and privacy because of its limitations in storage capacity and computation. These limitations can be overcome by integrating IoT with a technology called Cloud computing technology. This integration brings numerous benefits to various IoT applications.

C. Cloud-IoT Based Architecture

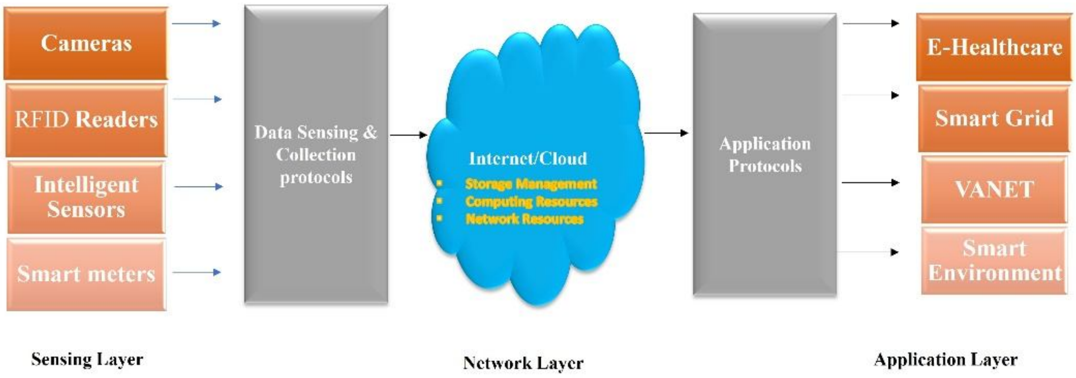

Fig.1 Cloud -IoT Based Architecture [4]

Sensing Layer: The Perception layer consist of physical objects with sensors. This can also be referred to as the 'Device Layer'[7]. This layer uses sensors like RFID, barcodes, or infrared to recognize objects and collect environmental data. This layer primarily emphasizes on gathering and recognizing specific information from objects using sensor devices [7]. The sensors can detect things like temperature, humidity, motion, and vibrations. The layer also has actuators that perform tasks based on the collected data, like cooling or slowing down. The Device Layer also sends the collected data to the next levels in a safe and reliable way where it can be used for further processing and analysing large amounts of information.

Networking Layer: Also known as the 'Transmission Layer. It is responsible for safely exchange of data between sensor devices and data processing system (Cloud Layer). Both wired or wireless methods can be used to transmit data using technologies such as UMTS, WiFi, Bluetooth, infrared, 3G, Z-Wave, or ZigBee, depending on the sensor devices [7]. The Network Layer enhances energy efficiency and performance by assigning the appropriate bandwidth to each device and maintaining high quality of service. The Network layer essentially makes it possible for data to be transmitted from the Perception layer to Cloud [6].

Application Layer: This is the uppermost layer in the Cloud-IoT based architecture which handles the delivery of services and interfaces to the end-users. It provides interfaces like dashboards and control panels for users to manage IoT devices remotely. The Application Layer enhances security by implementing user authentication and authorization mechanisms [7].

D. Benefits of Computation on Cloud

Computation on cloud gives access to a wide range of computing resources via the internet. These resources include networking tools, physical servers, virtual servers, data storage options, application development platforms, software solutions and AI-powered analytics.

Its flexible pricing approach, which lets customers pay for just the resources they use, is one of cloud computing's most notable benefits. Due to this configuration, enterprises may readily scale up or down resources based on their requirements without needing to make large upfront investments in infrastructure or hardware [3].

E. Limitations of Cloud Computing

The term "latency" describes the interval of time that passes between the start of a data transfer and its receipt. In the context of cloud computing and the Internet of Things, latency becomes an essential issue since it reduces the efficacy and responsiveness of applications. Because there are multiple network hops involved, transporting data from devices to the cloud for processing may take longer than expected. This is particularly problematic for time-sensitive applications, including disaster relief and healthcare, where even a one-second delay could have detrimental consequences. Due to the longer time it takes for data to be processed and actions to be taken, high latency may potentially lessen the effectiveness of connected devices in emergency situations[1].

Latency (L) can be expressed mathematically as:

Latency= $T_{request} + T_{processing} + T_{response}$[1]

Where:

- $T_{request}$ is the time consume to send the request from the device to the cloud.
- $T_{processing}$ is the time consume to process the data in the cloud.
- $T_{response}$ is the time consume to send the processed data back to the device.

Bandwidth: Limited bandwidth of transmission channels results in network congestion due to massive overflow of data, causing delays, packet losses, and reduced overall performance. Additionally, it gets harder to safeguard the data's integrity and weed out irrelevant or superfluous information, which raises the possibility of cyberattacks and data breaches[1].

Privacy and security: Cloud-based IoT enables data transfer from physical devices (real world) to the Cloud for computation and storage. A major unresolved issue is setting up the right rules and policies to make sure that sensitive data can only be accessed by authorized users.

This is vital for protecting privacy of user and ensuring data accuracy. Concerns about service level agreements (SLAs), physical data storage locations, and service provider confidence can arise when important Internet of Things applications are moved to the cloud.

Multi-tenancy (where multiple users share the same resources) can lead to risks of sensitive information leakage if proper isolation is not maintained. For some IoT devices due to their limited processing power makes it difficult to use advanced encryption at all levels.

Cloud-IoT distributed systems are susceptible to a number of threats, including side-channel, SQL injection, cross-site scripting, and session riding. Serious vulnerabilities such as virtual machine escape and session hijacking are also a cause for concern [4].

Big data: Managing Big Data in Cloud-IoT computing is challenging because of the huge amount, fast speed, and different types of data produced by IoT devices. Traditional data processing systems can struggle to handle the fast-growing and varied data from IoT sources like sensors, wearables, and industrial machines. Preserving, processing, and interpreting this data in real-time is complicated and needs flexible cloud systems and advanced tools. It is also very important to keep the data accurate and reliable when dealing with such large amounts of information[4].

Data processing and cleaning: Data preservation and acquisition in Cloud-IoT systems indeed require preprocessing and cleaning. This includes merging data from different sources, filtering out irrelevant information, ensuring consistency, and optimizing data for efficiency.

Cleaning and processing data is hard due to the many different sources of data. The difficulty lies in cleaning large volumes of data and assessing the reliability of such data and how to determine whether such data are reliable since they might have errors, extra irrelevant information (noise), or missing parts[11].

Performance: A significant amount of bandwidth is required in order to transfer large data from IoT devices to the Cloud. So, the main issue is ensuring good performance network for data transfer, since broadband speeds aren't increasing as fast as storage and computing technology.

In many cases, services and data need to be delivered quickly. Delays can occur due to unexpected issues, and real-time applications are highly sensitive to how well system performance is managed[4].

Heterogeneity: Big data is diverse because it comes from various devices and includes different types of formats like visuals, videos, audio recordings, and textual information.

Before storing data in a warehouse, it must be processed and cleaned, which presents difficulties in handling big data.

Merging and organizing unstructured data for reports is very difficult, particularly when done in real-time [11].

Energy efficiency: IoT devices' energy is quickly depleted by modern cloud-based IoT applications that regularly transfer data from the devices to the cloud.
Therefore, improving energy efficiency in data processing and transmission is still a major challenge. To resolve this issue, several approaches have been proposed, including technology for data compression, effective data transfer strategies, and data caching strategies for reusing data that isn't needed immediately[4].

III. Fog computing Overview

A. Definition of Fog Computing

Fog computing was first defined by Cisco in 2012 as a system that provides networking, storage, and processing services between end devices and conventional cloud data centers, which are often located at the edge of the network [8]. In simpler terms, Fog computing spreads out resources and services from the cloud to devices, speeding up processes and improving efficiency.

B. Integration of IoT-Fog

Fog computing expands upon cloud computing by placing storage, computing, and networking functions near to the network edge, rather than centralizing them in cloud servers. Cisco introduced fog computing in 2014 to distribute workloads and services to edge devices, reducing reliance on cloud transmission[5]. This approach addresses limitations of traditional cloud computing, specifically in contexts requiring high bandwidth, low latency as well as real-time data processing.

C. Characteristics of Fog Computing

Fog computing in the IoT aims to make systems more efficient, improve performance, and cut down on the quantity of data sent for cloud processing and preserving. Instead of transferring all the data gathered by sensors to cloud servers, it is first sent to nearby edge devices for coputaion and finite duration storage. This approach reduces network traffic and delays.
Proximity to End-Users: Fog computing focuses on being close to the data sources and users. This helps process data faster and cut down on delays by minimizing the distance the data required to travel [9].
Real-time Data Processing: By executing data processing at the network periphery, fog computing supports real-time analysis. This aspect is crucial for applications that need quick responses, like smart sensors and autonomous systems [9].
Low Latency: In fog networks, latency refers to the duration required for data to be transmitted, processed, and for results to be returned. Fog computing handles processing data near to the point where data generated, therefore cutting down on this time. [6].
For applications that need to avoid delays, it's best to use local edge devices or fog devices near the periphery of the network. These devices can handle data processing more quickly than centralized cloud servers, which are better suited for tasks needing a lot of processing power [6].
Bandwidth Optimization: The necessity for continuous data transport to the central cloud is decreased when data is processed and filtered locally at the edge. This helps optimize bandwidth and decrease network congestion [9].
Enhanced Privacy and Security: Fog computing improves security by processing and analyzing data locally, which reduces the risk of sensitive information being exposed during transit to remote data centers [9].
Scalability and Flexibility: The distributed design of fog computing allows for adding more fog nodes as needed to handle increased workloads and various applications [9].
Energy Consumption: When setting up a project, it is important to consider the number of sensors, their range, and data transmission rates. These factors affect energy use, especially for battery-powered devices [6].
Resource Utilization: Efficient use of resources is key in fog computing. It ensures systems work well without overloading or wasting resources. Fog computing manages resources by using virtual machines (VMs) or containers to handle real-time IoT applications. Since IoT devices have limited resources, fog devices may fully or partially offload tasks. Using lightweight container-based virtualization helps handle applications that need quick responses, improving efficiency and reducing waste [7].
Mobility and Geographic Distribution: Mobility is crucial for modern IoT applications, like intelligent vehicles and transportation. Fog computing uses a few intelligent gateway devices at the network periphery to control many IoT devices spread across different areas. This setup allows for real-time data processing, such as health status or other important information. It also supports dynamic resource management as IoT devices move. Fog and edge devices connect directly with IoT devices, making the system adaptable to changes and ensuring effective data handling as devices move around [7].

Fog computing handles nodes spread across various locations and can work with many devices, even in remote or tough conditions. It can process data from devices whether they have wireless access or not [5].
Reducing Latency and Load Balancing: Fog computing aims to ease the burden on data centers and lower delays, especially for real-time tasks. Key challenges include balancing the load and scheduling tasks to maintain high performance and reliability in both cloud and fog systems.

D. Layered Architecture of Fog Computing

Fog computing involves connecting cloud servers and smart IoT devices. To achieve this it uses distributed networking, storage, and computation connection. It distributes tasks across nodes, providing low latency from end devices. The three-layer hierarchy of IoT, fog nodes, and clouds makes up the fundamental architecture of fog computing [5]. This is an overview of these layers:
Layer 1: The lowest layer includes IoT devices like sensors and actuators, which is present in gadgets like watches, tablets, and cell phones. These devices are used all over the world and may come with GPS to track their location. The data through sensors is collected by this layer primarily and then it is transmitted to the middle layer for processing. For making more precise assessments and spotting unusual patterns one must be knowing how these devices work, especially their ability to detect and send real-time data. Actuators in this layer react to their environment based on the commands they receive from the middle layer [5],[15].
Layer 2: This includes various devices such as mobile phones, tablets, desktops, laptops, and edge devices like routers, switches, modems and gateways[6]. These dispersed fog devices, often termed fog nodes, are equipped with restricted processing and storage capacities. Data is received by this layer directly from edge devices and stores it locally for a short period. Fog devices process this data intelligently and can handle small, delay-sensitive tasks on-site or distribute them among nearby fog nodes. For more intensive computations or data requiring longer processing, the tasks are offloaded to cloud data centers[6]. The fog devices try to process user requests locally to reduce latency and improve performance. However, when local processing is insufficient or to balance the load, fog devices may offload some of their data or processing tasks to nearby fog devices. This helps in optimizing latency by distributing the workload more efficiently. Aggregating fog nodes in this layer are responsible for efficiently handling and transferring data to Layer 3 for further processing [5].
Layer 3: The third layer includes cloud data centers with various types of cloud servers for processing data and cloud warehouses for long-term data storage. Most advanced IoT applications that essential to analyze vast historical data are best suited to be transferred to the cloud data center since they have large processing and storage capabilities. The processed and analyzed data at the fog or IoT device level, Sending significant findings or information to the cloud warehouse for long-term preservation. This ensures that valuable data is preserved and accessible for future use. This layer is unaware of where edge devices are located[5].

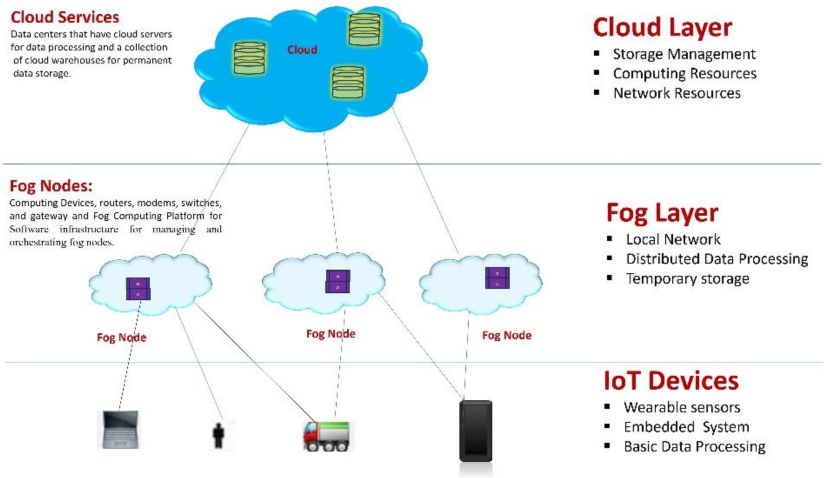

Fig.2 Fog Computing Layered Architecture

E. Working of Fog Computing

Fog nodes are placed positioned close to IoT devices to collect data directly from them. These nodes then transmit the data to the most appropriate location for analysis. Data that requires immediate attention is processed and analyzed directly at the fog nodes[5]. This enables the nearest fog nodes to swiftly detect any issues or failures and promptly send responses to the actuators to address them. Fog nodes are designed to seamlessly work with both sensor devices and cloud systems. They act as intelligent controllers, and their numbers can reach millions, ranging from basic routers to sophisticated embedded servers. Data that is less urgent undergoes processing with functions such as aggregation or summarization before being forwarded to other nodes. These nodes consolidate and summarize local data prior to forwarding it to the cloud. Non-urgent data is sent to the cloud for long-term preserving and analysis, where it can be retained for extended periods, potentially months or even years. The cloud encompasses numerous data centers that perform tasks like big data analytics, machine learning, and parallel processing [5]. Consequently, fog computing enhances cloud computing by introducing a hierarchical layer that optimizes the overall system's performance.

IV. UTILIZATION OF CLOUD-FOG COMPUTING

Using both cloud and fog computing together offers several benefits. Fog computing helps reduce delays by processing data close to where it's generated, which is vital for real-time activities like video calls. This setup speeds up responses by minimizing the distance data travels between users and the cloud. It also improves bandwidth usage by managing data locally, so less data is essential to be sent to the central cloud, which cuts down on network congestion and only transfers necessary information.

Security and privacy are enhanced because fog computing eliminates potential hazards during transmission by processing sensitive data closer to the source, improving security and privacy. Techniques like anonymizing and encrypting data at the edge provide extra protection. Additionally, the distributed nature of fog computing makes it easy to scale up or down based on need, ensuring stable performance even during high-demand periods, and it has built-in redundancy to handle device failures.

Cost savings are another advantage, as fog computing reduces data transfer costs and uses local resources more efficiently, decreasing the reliance on cloud resources. It also supports real-time applications across different industries, like enabling fast consultations and monitoring in healthcare, facilitating instant data analysis and machine communication in manufacturing, and improving management of traffic and public safety in smart cities through local data handling[9].

V. CONCLUSION

In conclusion, this study underscores the transformative impact of integrating cloud and fog computing with the IoT for real-time applications. By leveraging the strengths of both cloud and fog computing, we can achieve a balanced approach to processing and managing extensive amounts of IoT data. Cloud computing offers robust, centralized resources ideal for handling extensive, resource-intensive tasks and long-term data retention. In contrast, fog computing enhances real-time processing by distributing resources nearer to the network edge, thus decreasing latency and enhancing responsiveness for time-bound applications.

The combined approach of cloud and fog computing addresses critical challenges in IoT systems, such as scalability, bandwidth optimization, and efficient resource utilization. Proximity to data sources characteristics of Fog computing ensures faster processing and lower delays, while cloud computing's centralized power supports complex analytics and large-scale storage. This combined approach not only optimizes performance and reliability but also supports very extensive range of uses, including industrial automation and smart cities. As IoT continues to evolve, the integration of fog-cloud will be pivotal in delivering efficient, scalable, and responsive solutions, driving advancements in real-time processing and enhancing the overall IoT experience.

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