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Edge computing: an evolution and paradigm shift in the realm of cloud computing and IOT

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Abstract

Nowadays, the Internet of Things (IoT) is an increasingly popular technology that generates a vast amount of data. By applying data analytics techniques to discrete data through Cloud Computing, valuable and precise information can be obtained. However, when it comes to traditional applications and IoT applications such as environmental monitoring, smart navigation, and smart healthcare, there are specific requirements to consider, including mobility, quick response, and real-time capabilities. Unfortunately, the conventional cloud computing architecture falls short in meeting these requirements due to the distributed processing of data across various physical locations of IIoT devices worldwide. Consequently, the concept of edge computing has emerged, enabling data storage and processing at the network's extreme end, closer to the data collection sources than cloud storage. This approach enhances computational efficiency and location awareness in applications. Nevertheless, the integration of edge computing with IoT devices presents several security and privacy challenges in the realm of data analytics.

Keywords: Cloud computing, IOT, Edge Computing, Edge devices, IOT.

Introduction

Data Computing Concepts are constantly evolving due to technological advancements and the changing requirements of individuals. One particular concept that has emerged is edge computing, which involves a distributed IT architecture. In edge computing, client data is processed at the network's edge, near the source that generates the data. In today's world, IoT devices and sensors can collect a significant amount of real-time data. The effectiveness of this data depends on its ability to provide quick responses [https://www.techtarget.com/searchdatacenter/definition/edge-computing, https://www.redhat.com/en/topics/edge-computing/what-is-edge-architecture]. However, the sheer volume of data collected presents challenges for traditional computing methods that rely on centralized data centers. Processing real-time data from sensors, IoT devices, and smart phones in a centralized facility can result in issues such as limited bandwidth, latency problems, and network disruptions [Bilal et al., 2014].

To overcome these challenges, IT professionals are adopting edge computing architecture. This approach involves moving some storage and computing resources from central data centers to locations closer to the data source. While cloud-based processing has its advantages, the exponential growth in data volume and the need for real-time processing capabilities have exposed its limitations. Consequently, there has been a significant increase in investment in edge computing in recent years. By leveraging technologies like 5G, edge computing provides new opportunities for various industries. It brings together computation and data storage, enabling improved data control and seamless, efficient operations [ttps://proxybros.com/edge-servers].

Applications of Edge Computing

Edge computing is a distributed computing paradigm that brings computation and data storage closer to the location where it is required. This approach is gaining prominence due to the proliferation of Internet of Things (IoT) devices, the need for real-time data processing, and the demand for low-latency applications. Here are some notable applications of edge computing [https://infohub.delltechnologies.com/en-US/p/edge-computing-in-the-age-of-ai-an-overview]

IOT (Internet of Things)

Edge computing is extensively utilized in IoT applications where a significant number of devices generate data that requires real-time processing. By deploying edge computing nodes in close proximity to IoT devices, latency is reduced, and bandwidth consumption is optimized.

Smart Cities

Edge computing is employed in smart city applications to enable real-time processing of data from various sources such as sensors, cameras, and traffic signals. This aids in optimizing traffic flow, managing public transportation, monitoring air quality, and enhancing overall urban efficiency.

Industrial Internet of Things (IIoT)

In industrial settings, edge computing enables real-time monitoring and control of equipment, predictive maintenance, and process optimization. It reduces latency, improves reliability, and enables faster decision-making in manufacturing, energy, and other sectors.

Autonomous Vehicles

Edge computing plays a crucial role in autonomous vehicles by processing data from sensors (such as LiDAR, cameras, and radar) in real-time to make split-second decisions. By reducing latency and enabling faster response times, edge computing enhances the safety and efficiency of autonomous vehicles.

Healthcare

In healthcare, edge computing facilitates the collection and analysis of patient data from wearable devices, medical sensors, and monitoring equipment in real-time. This enables remote patient monitoring, personalized healthcare interventions, and timely alerts for healthcare providers.

Retail

Edge computing is utilized in retail environments for real-time inventory management, personalized marketing, and enhanced customer experience.

Essential Elements and Parties Involved in Edge Computing

It involves a variety of elements that contribute to the architecture, operation, and utilization of edge computing systems. Here is an overview:

Key Components

Edge Devices

These physical devices are located at the network's edge, such as sensors, actuators, mobile phones, IoT devices, edge servers, and gateways. They generate, collect, and process data locally before transmitting it to the central data center or cloud.

Edge Computing Nodes

These computing resources are deployed at the edge of the network infrastructure, closer to the data sources. Edge computing nodes may include micro data centers, edge servers, or cloudlets. They provide computing, storage, and networking capabilities to process data locally and reduce latency.

Edge Software Stack

This encompasses the software components deployed on edge computing nodes to enable various functionalities, including data processing, analytics, security, orchestration, and management. The edge software stack may consist of operating systems, middleware, containerization platforms (e.g., Docker, Kubernetes), edge computing frameworks (e.g., OpenStack, AWS IoT Greengrass), and application-specific software modules.

Connectivity Technologies

Edge computing relies on diverse connectivity technologies to establish communication between edge devices, edge nodes, and central data centers or cloud platforms. These technologies may include wired connections (e.g., Ethernet, fiber optic), wireless protocols (e.g., Wi-Fi, Bluetooth, Zigbee, LoRa), cellular networks (e.g., 5G, LTE), and satellite links.

Data Processing and Analytics Tools

Edge computing systems incorporate data processing and analytics tools to derive insights and actionable information from the data generated at the edge. These tools may include real-time stream processing frameworks (e.g., Apache Kafka, Apache Flink), machine learning algorithms, predictive analytics models, and database management systems [https://www.pubnub.com/guides/iot-edge-computing].

Edge Devices

(Sensors, IoT Devices)

Edge Gateway

Edge Computing Nodes
(Edge Servers, Micro Data Centers)

Sensor Processing | Data Analytics

Edge Software Stack | Connectivity Technologies
(OS, Middleware, Security) | (Wired, Wireless, Cellular)

Application Layer | Management and Orchestration
(Edge Applications)

(Deployment, Monitoring, Scaling)

Architecture of Edge Computing

General architecture of Edge Computing has three layers:

- Edge Device Layer(EDL)
- Edge Service Layer(ESL)
- Cloud Server Layer(CSL)

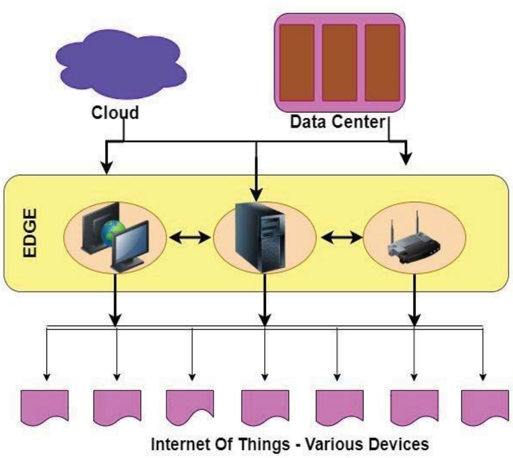

Figure1: Architecture of Edge Computing

Edge Device Layer (EDL)

Edge devices are electronic devices that are deployed at the edge of the network. These devices function in the physical world and are utilized for sensing, activating, and controlling the environment. Microcontrollers (MCU) are responsible for controlling these edge devices. The low-level software, also known as firmware, is programmed in the MCU to manage the hardware devices connected to it. All functions such as sensing and controlling are carried out by this firmware. Edge devices can be categorized into two types: IoT devices and mobile devices.

IoT devices are small electronic devices connected to the network through wireless protocols like 4G/5G, WiFi, and Bluetooth. They operate on lightweight real-time operating systems like FreeRTOS and RT-Thread. Examples of IoT devices include health monitoring devices, smart home devices, and smart warehouse carts used in Industrial IoT (IIoT). On the other hand, mobile devices are equipped with advanced and preemptive operating systems such as Android. This allows programmers to develop their own applications on these operating systems. Examples of mobile devices include tablets, smart phones, central controllers of smart vehicles, and smart homes.

Edge Server Layer (ESL)

The Edge Server Layer is structured hierarchically, with multiple layers. Each layer is comprised of several Edge servers. These Edge servers exhibit increasing computational power as you move from the bottom layer to the top layer. The lowest sub layer of Edge Servers consists of wireless base stations and Access Points (AP's). These wireless base stations receive data from various edge devices and send control flows back to the edge devices through different wireless interfaces. Upon receiving data packets from the edge devices, these base stations and AP's transmit the data to the edge servers situated in the upper sub layer. The servers in the upper layer handle data computations.

If the complexity of the computation is high, these servers transfer the data to higher layer edge servers that possess greater computational power [Pace et al, 2019]. Once the data computation is complete, these edge servers transmit the computed data back to the base stations and AP's, which then send it to the relevant edge devices. The tasks performed by the edge servers include authentication, authorization, computation, data analytics, task offloading, and data storage.

Cloud server Layer (CSL)

The Cloud Server Layer operates centralized cloud servers and data centers. Cloud servers handle the most complex computations and integration of tasks received from edge servers. Meanwhile, cloud data centers are tasked with storing vast amounts of data produced by edge devices and edge servers. Both cloud servers and data centers are comprised of clusters of highly powerful computing machines [Pace et al, 2019, Ren et al., 2019].

Real-Time Response of Edge Computing

Real-time response is a critical benefit of edge computing, allowing for quick processing and decision-making in close proximity to the data source. Edge computing achieves real-time response through various means:

Reduced Latency

By processing data locally, near where it is generated, edge computing minimizes the time it takes for data to travel to processing infrastructure. This results in faster response times due to lower latency.

Localized Processing

Edge computing devices and infrastructure can process data locally without relying on distant cloud servers. This immediate processing of data streams enables real-time analytics, inference, and decision-making.

Distributed Architecture

Edge computing utilizes a distributed architecture, deploying computing resources at the network edge. This setup allows for parallel processing and load balancing across multiple edge nodes, enhancing real-time responsiveness.

Data Preprocessing and Filtering

Edge computing can preprocess and filter data at the edge, reducing the amount of data that needs to be sent to centralized servers. This selective transmission of relevant data optimizes bandwidth usage and speeds up response times.

Edge Intelligence

Leveraging machine learning models and AI algorithms, edge computing enables real-time data analysis and decision-making at the edge. Intelligent edge devices can autonomously detect patterns, anomalies, and events in streaming data, facilitating immediate actions or alerts.

Local Caching and Storage

Edge computing devices can cache frequently accessed data or store relevant information locally, eliminating the need to retrieve data from remote servers. This local caching and storage enhance responsiveness by providing quick access to commonly used data.

Event-Driven Architecture

Edge computing often follows an event-driven architecture, where edge devices or applications respond to events or triggers in real-time. This architecture allows for immediate reactions to events, contributing to real-time response capabilities [Escamilla-Ambrosio et al., 2018].

Edge Computing vs. Cloud Computing

[Mittal et al, 2017; Mittal et al., 2017**]**

Edge computing and cloud computing represent two distinct computing paradigms, each with unique characteristics, benefits, and applications. Here is a comparison between the two:

Definition

Edge Computing

Edge computing involves processing data closer to the source or the network edge, often on local devices or infrastructure. Its goal is to decrease latency, bandwidth consumption, and reliance on centralized cloud services.

Cloud Computing

Cloud computing provides computing services, such as storage and software, over the internet on a pay-as-you-go basis. It depends on centralized data centers to offer scalable and on-demand resources.

Location

Edge Computing

Edge computing resources are situated at the network edge, near where data is generated or used. This can include sensors, IoT gateways, or small data centers located close to users or devices.

Cloud Computing

Cloud computing resources are centralized in remote data centers managed by cloud service providers. Users can access these resources over the internet, regardless of their physical location.

Latency

Edge Computing

Edge computing reduces latency by processing data locally, close to its origin. This is especially useful for applications requiring real-time or low-latency processing, like IoT, gaming, and autonomous vehicles.

Cloud Computing

Cloud computing introduces latency as data must be sent over the internet to remote data centers for processing. While efforts are made to minimize latency, it may not be ideal for applications with strict latency needs.

Bandwidth Usage:

Edge Computing

Edge computing minimizes bandwidth usage by processing data locally and sending only relevant information to centralized cloud services. This helps optimize network bandwidth and reduce costs related to data transmission.

Cloud Computing

Cloud computing relies on internet connectivity to transfer data to and from remote data centers. This can lead to higher bandwidth consumption compared to edge computing.

Edge Computing: Improving Customer Satisfaction within Banking Systems

One sector where Edge Computing is widely utilized is the Banking Sector. Banks today are highly interested in delivering exceptional and personalized customer service. Customers are increasingly using smart phones or tablets to access banking services. Banks are keen on leveraging new technologies to effectively serve their customers and offer personalized services. This era is characterized by data-driven banking, which has placed pressure on banking IT infrastructure to analyze the vast amount of data generated in real-time every hour.

Edge computing has emerged to assist banks in improving the customer experience. By allowing banks to analyze data in close proximity rather than transferring it to a cloud center for analysis, edge computing has enabled faster decision-making and real-time service offerings. This proximity processing of data by edge computing is helping banks to bring analytics closer to customers.

Customized Customer Proposal

Upon a customer's arrival at a bank, the utilization of facial recognition technology enables the 'edge' to promptly present loan offers and relay pertinent information to the staff. Through the collection of data derived from customer interactions and the application of real-time analytics, banks can further personalize their offerings. For instance, when a recently married couple enters a bank, suitable options such as home loans, car loans, or saving plans can be extended to them.

Detection of Fraudulent Activities

If an individual attempting to commit fraud tries to manipulate an edge computing ATM, the ATM may stop responding. If additional attempts are made, the ATM will eventually shut down. It is crucial to have real-time fraud detection in place for online transactions in order to take prompt action. By implementing edge computing, banks can establish a real-time fraud detection system that analyzes each transaction in real-time.

Conclusion

In the current landscape, numerous services are being shifted from the Cloud to the Edge of the network. This is primarily due to the fact that processing data at the edge enables quicker response times and therefore enhances reliability. Additionally, by analyzing a large amount of data at the edge instead of uploading it to the cloud, bandwidth can be utilized more efficiently. Managing data at the edge of the network would be highly efficient. In this document, we have introduced the concept of edge computing and provided a concise overview of its architecture. Edge computing is a permanent fixture and requires our attention. Now, let's discuss the future prospects of Edge Computing. Considering the ongoing research and investment in this field, it is poised to become the optimal choice for various industries. In the coming years, approximately 70% to 75% of enterprise-related data will be generated and processed on edge devices themselves, leading to a significant reduction in the reliance on the Cloud. Many organizations and companies, such as RedHat and Cloudera, are actively engaged in research to overcome the challenges faced in Edge Computing today. The capabilities of the edge empower us to address tomorrow's issues by enabling faster and smarter decision-making when time is critical.

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