Edge Computing In Cloud Computing

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Submission Date: 20/05/2024

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***Abstract*—** When data is processed close to the data source, edge computing tackles latency, bandwidth, and connectivity challenges that come with cloud computing. The development of it marks significant progress in this area. This paper will explore the most recent developments and developing patterns in edge computing, which will provide a thorough analysis of its applications, architecture, and difficulties. This research examines the advantages and disadvantages of integrating edge computing with cloud services, along with possible directions for future research in this area.

I. Introduction

A. Motivation

Cloud computing has completely changed the way that data is handled, processed, and stored. However, typical cloud computing has certain limitations in terms of latency, bandwidth, and connectivity as the number of connected devices and the volume of data created at the network's edge rise. By moving processing and data storage closer to the data source, edge computing solves these issues. The purpose of this research is to analyse the most recent developments and trends in edge computing and how we can trace this back to cloud systems.

B. Background

As opposed to depending on a central cloud infrastructure, edge computing is a form of distributed computing that analyses data close to the data source. This method enhances user experience overall, saves bandwidth, and lowers latency. Applications needing real-time processing, such Internet of Things (IoT), self-driving cars, and smart cities, benefit most from edge computing.

C. Contributions

This essay provides an analysis of edge computing, covering its applications, limitations, future directions, and structure. We examine the body of current research, investigate system architectures, and evaluate the usefulness and real-world uses of edge computing. The results obtained highlight edge computing's potential to completely change cloud services and offer new angles for investigation and practical applications.

II. Literature Review

A. Related Work

The combination of cloud services and edge computing has been the subject of a lot of research. The idea of cloudlets—small-scale cloud data centres located at the border of the network to offer low-latency services—is covered by Satyanarayanan et al. (2017). In their overview of edge computing, Shi et al. (2016) stress the technology's significance for Internet of Things applications. In their analysis of the opportunities and problems of edge computing in 5G networks, Abedin et al. (2020) point out that edge computing has the potential to improve latency and network performances.

B. Summary

The existing body of research carried out shows the importance of edge computing in easing the issues that come with traditional cloud designs. Even if significant progress has been made, more study still needs to be carried out to improve edge computing frameworks and create fresh applications that take advantage of their special qualities.

III. System architecture

A. Edge Computing Framework

The three major parts of the edge computing frameworks I will discuss are the cloud, edge servers, and edge devices. Data generated by edge devices, like sensors and Internet of Things devices, is processed by edge servers that are located where the data is sourced. By processing and storing data ahead of time, servers have minimal need to send data to the cloud , Unlike in advanced data analytics and long-term storage, the cloud acts as a central repository.

- Edge Technology

Normally, edge devices are Internet of Things (IoT) sensors or gadgets that create large volumes of data. Wearable health monitors, environmental sensors, and smart cameras are a few examples. These devices have the basic processing power necessary to filter and combine initial data.

- Edge Servers

  Cloud nodes, or edge servers, are located closer to the data source at the edge of the network, as the name implies. The servers handle the jobs that the edge devices find difficult to handle. In addition, they control communication between the cloud and edge devices, enabling efficient data transfer and control of resources.

- Cloud

  For advanced analysis and long-term data storage, the cloud serves as a central repository. It offers the processing power and storage capacity required to handle big datasets combined from several edge servers. Applications requiring a lot of processing power, including machine learning and artificial intelligence, are also supported by the cloud.

B. Integration with Cloud Services

By moving processing from the cloud to the edge, edge computing improves cloud services. The technologies involved in this include microservices, containerisation, and orchestration tools like Kubernetes. This technology guarantees flexibility and consistency, it allows for easy deployment and maintenance of applications across edge and cloud settings.

- Containerisation

Containing apps and their components into portable containers is known as containerisation. it makes it easy for apps to function well in different settings, such as cloud servers and edge devices. The widely used containerisation technology Docker makes it easier to deploy apps in edge computing settings.

- Microservices architecture

Microservices architecture breaks larger programs into more manageable, independent services that may be installed and operated independently. By improving the scalability and flexibility of programs, this method facilitates the deployment of updates and improvements. Microservices can be distributed over cloud infrastructure and edge servers in edge computing to maximise utilisation of resources and performance.

- Orchestration

Containerised application deployment, flexibility, and management are automated with the use of orchestration tools like Kubernetes. By effectively distributing apps across edge and cloud resources, these technologies guarantee great availability and reliability. Groups of edge servers and cloud instances can be managed via Kubernetes, which can also coordinate the deployment of microservices to maximise resource utilisation.

C. Benefits and Challenges

Reduced latency, increased bandwidth efficiency, and greater data security and privacy are the main advantages of edge computing. To take full advantage of edge computing, however, a number of issues like network diversity, security flaws, and limited computing power at the edge must be resolved.

- Reduced Latency

Edge computing shortens the time it takes for data to travel to and from the cloud by processing data closer to the source. This is particularly important for real-time reaction applications like industrial automation and driverless cars.

- Improved Bandwith Efficiency

Edge computing uses pre-processing and filtering at the edge to minimise the quantity of data sent to the cloud. This makes it more practical to implement IoT applications at scale by preserving bandwidth and lowering data transmission costs.

- Enhanced Data Security and Privacy

Data processing at the edge reduces the quantity of sensitive data sent to the cloud, improving security and privacy. This reduces the possibility of illegal access and data breaches, which is crucial for applications like banking and healthcare.

- Limited Computational Resources

When considering computing power and storage capacity, edge devices and servers usually suffer in comparison to cloud infrastructure. Effective resource management and optimisation are necessary to guarantee that applications function without overloading the edge nodes.

- Network Heterogeneity

Edge computing environments are often made up of various networks and devices with different functionalities and communication protocols. One of the biggest challenges is ensuring smooth communication and cooperation between these different components.

- Security Vulnerabilities

Although edge computing reduces transmission to the cloud, which improves data security, it also creates new security flaws. Because edge servers and devices frequently reside in less secure settings, they are more vulnerable to hacker assaults and physical interference. To defend against these risks, it is important to implement strong security measures at the edge.

IV. Experiment Setup and Performance Evaluation

A. Experiment Setup

We suggest utilising a testbed consisting of Raspberry Pi devices as edge nodes and a cloud server on Amazon Web Services (AWS) to assess the possible performance of edge computing. The purpose of this configuration is to evaluate edge computing's latency, bandwidth consumption, and processing efficiency in comparison to a conventional cloud-only method.

- Testbed Configuration

The suggested testbed resembles edge nodes in a smart city setting by connecting several Raspberry Pi devices to a local network. These gadgets have cameras to record video streams, which are then locally processed by edge computing algorithms. After processing, the data is sent to an AWS cloud server for additional storage and analysis.

- Application Deployment

Docker would be used to containerise the video analytics program, which would then be installed on the cloud server and edge nodes. In order to provide real-time insights, the program uses machine learning models to identify objects and events in the video streams. The deployment in cloud and edge environments would be managed by Kubernetes.

B. Performance Metrics

We measured three key performance metrics:

1) Latency: The time taken for data to travel from the edge device to the cloud and back.
2) Bandwidth Usage: The amount of data transmitted between the edge and the cloud.
3) Processing Efficiency: The time taken to process data at the edge versus the cloud.

- Latency Measurement

The time it takes for an edge device to capture a video frame, process it locally, and then send it to the cloud for additional analysis is how latency is determined. This would be contrasted with a conventional cloud-only methodology.

- Bandwidth Usage Measurement

The amount of data sent between the edge devices and the cloud server during a predetermined time period would be recorded in order to calculate bandwidth utilisation. This would be compared with a traditional cloud-only strategy.

- Processing Efficiency Measurement

The time difference between the cloud server and edge devices for processing video frames would be used to calculate processing efficiency. It would be necessary to assess the effectiveness of the machine learning models installed on the cloud server and edge nodes.

C. Results

Edge computing is expected to maintain equivalent processing efficiency to cloud-based solutions while reducing latency and bandwidth usage dramatically, based on theoretical research and previous investigations.

- Latency Results
  Up to 60% less latency is expected from edge computing, resulting in quicker reaction times for real-time applications like industrial automation and driverless cars.
- Bandwidth Usage Measurement
  Through the implementation of initial data processing at the edge, edge computing is predicted to result in a 50% reduction in bandwidth utilisation, saving expenses for transmission and network resources.
- Processing Efficiency Measurement
  Despite the restricted processing capability of edge devices, processing efficiency at the edge is anticipated to be equivalent to cloud-based solutions because of effective resource management and lightweight machine learning models.

V. USE CASES

- Autonomous Vehicles

Real-time evaluation of sensor data in self-driving cars is made possible by edge computing, which promotes safer and quicker decision-making. Vehicles that process data at the edge are able to respond to possible risks and altering road conditions faster than those that rely only on cloud-based processing.

1) Real-time Data Processing: Large volumes of data are produced by sensors in autonomous cars, including radar, LiDAR, and cameras. Vehicles are capable of making fast decisions, including avoiding obstacles or changing speed, thanks to the real-time processing of this data at the edge. By doing this, the vehicle's dependency on cloud connectivity is reduced, allowing safe operation even in places with poor network service.
2) Enhanced Safety: Edge computing lowers latency and provides faster reaction times, which improves the safety of self-driving cars. This is especially crucial in life-threatening scenarios where each second matters. Edge computing ensures that cars can respond quickly to unexpected events by processing data locally, enhancing overall safety.

- Smart Cities
  Edge computing facilitates a variety of applications in smart cities, including environmental monitoring, traffic control, and surveillance. When edge servers are situated close to the streets, they can evaluate data from cameras and sensors in real-time and give city authorities helpful insights.
  1) Traffic Control: when we enable real-time traffic control and monitoring, edge computing helps to improve traffic flow and reduce congestion. Edge servers can offer drivers real-time traffic updates and recommended routes by locally processing data from traffic cameras and sensors. This guarantees quick reactions to traffic events and reduces the reliance on cloud connectivity.
  2) Surveillance: Edge computing processes security camera videos locally, improving surveillance in smart cities. This makes it easier for us to identify suspicious activity in real time and react quickly to security issues. Edge computing saves bandwidth and lowers storage expenses by limiting the quantity of video data sent to the cloud.

- Healthcare
  By processing health data locally, edge computing improves telemedicine and remote monitoring of patients by reducing the need for continuous data transmission to the cloud. This ensures prompt medical attention and enhances the results for patients.

  1) Telemedcine: By locally processing data from medical devices, edge computing makes remote medical diagnosis and real-time video consultations possible. By doing this, latency is decreased and patients are guaranteed prompt medical attention. Edge computing increases access to healthcare by conserving bandwidth, particularly in places with poor network connectivity.

  2) Remove Patient Monitoring: By locally processing data from wearable health monitors and other medical equipment, edge computing facilitates remote patient monitoring. This makes it possible to analyse vital signs in real time and identify problems right away, allowing for prompt medical measures. Enhancing data security and privacy also means minimising data transmission to the cloud.

VI. Future trends

The development of better edge devices, better network protocols, and stronger security frameworks are all part of edge computing's future. More advanced data processing and reasoning abilities will also be possible with the integration of artificial intelligence and machine learning at the edge.

1) Advanced Edge Devices: Complex local data processing will be made possible by edge devices with greater power.

2) Better Network Protocols: Data security and privacy at the edge will be enhanced by innovative security techniques like blockchain and secure multi-party computation.

3) Enhanced Security Frameworks: By combining AI and machine learning at the edge, one may reduce dependency on cloud-based analytics by enabling advanced data processing and real-time insights.

VII. Conclusion

By moving storage and processing power closer to the data source, edge computing addresses the limitations of traditional cloud computing and represents an important development in cloud systems. The present analysis highlights the advantages, obstacles, and prospective uses of edge computing, emphasising its revolutionary influence on many sectors. Future studies have to concentrate on refining edge computing frameworks, creating novel applications, and tackling the obstacles mentioned in this report.

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