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Original Article

Edge Computing Performance Amplification

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Abstract - *Edge computing can be defined as an emerging technology that uses cloud computing to leverage edge data centers to process, store and analyze data close to the source. Traditional cloud computing architectures are not designed for latency-critical applications such as AI (Artificial Intelligence) and IoT (Internet of Things) because they rely on low data volumes generated by applications running near highly-populated areas. When volume grows beyond 50 miles from the population center, networks experience higher latency and packet loss rates which impacts application performance. Since everyone's life is equipped with more and more IoT devices by the day, decisions should be made in a split second in edge computing. It is really crucial to perform at an optimum level; some devices, especially medical wearables, deal with patient life, and any delay in decision-making will result in disaster. Similarly, modern-day autonomous self-driving vehicles where late decisions that can endup in accidents and really, there is no room for errors. This paper provides a new approach to improve the performance of edge computing by having two identical computing systems in which one system will act as primary and another as reserved or secondary. This system will be available in the local environment of the IoT device and not in the cloud. The secondary system will be reserved for mission-critical requests. Whenever the primary system breaches the latency threshold for the response, the request will be rerouted to the secondary system. Both systems will sync data in the background and can also serve as backup computing systems in case of any failure of one of the systems. Traditional edge computing systems will have a singular computing system on the device and low capability to process data or user requests since it still relies on transferring data to the cloud to compute and make decisions. With multiple high-capacity computing systems on the device and automatic rerouting and balancing of the requests, edge computing performance will be more reliable. It will also ensure high availability, low latency and a highly dependable edge computing architecture. This method is scalable; based on the volume and complexity, the architecture can be extended to additional sub-systems to add more computing power and to handle additional requests on demand. The proposed method of multiple computing systems at the local environment or device will result in a highly responsive system, provide the much needed support to process data or user requests in a fraction of a second, and result in life-saving decisions. This solution also opens the door to multiple possibilities like tagging multiple IoT devices to the same computing system, the ability to include AI (Artificial Intelligence)/ML (Machine Learning) models and processing locally, and learning from previous decisions to enhance future computing, self troubleshooting and healing process etc which will further advance the existing technology.*

Keywords - *Edge computing, Performance testing, Performance engineering, Cloud computing, Edge computing infrastructure, IoT.*

1. Introduction

When Akamai introduced CDN, which stands for content delivery networks, in the late 1990s to increase web performance and speed, this was when edge computing first emerged. To cache and prefetch the internet content, CDN utilized nodes at the edge, which are located near the end users. The information can be changed in a variety of ways by these edge nodes, for as by inserting localized advertising. CDNs are especially helpful for video content because caching can dramatically reduce bandwidth usage. (Satyanarayanan, M., 2017). Edge computing revolutionizes the public cloud by introducing distributed and decentralized infrastructure, elevating it. By bringing them closer to the target applications, it provides the fundamental foundations of the cloud, including computing, memory, and the network. The latency needed to reach conventional cloud structures is drastically decreased with just one tag to the information center. Edge computing improves the user experience by reducing the need for a full journey to the cloud. (Janakiram MSV., Jun. 2017)

There is a misunderstanding that edge computing is designed mainly for the IoT. But edge computing is all set to turn into the most desirable structure for running data-driven, sophisticated intelligence-based applications. Though edge computing is perfect for IoT solutions, it provides enormous value for the departmental and conventional positions of

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business applications. (Janakiram MSV., Feb. 2017). As the amount of information we are processing continues to expand, and we have understood the limitations of cloud technology in some places. Edge computing is introduced to rectify most of these issues by resolving the slowness incurred by computing in the cloud and transporting information to be processed in the data center. It will reside "on the edge," which is near to where the computing needs to be performed, because of which edge computing may best suit to work with time-critical information in remote places with no reliable connectivity or very limited connectivity to the centralized position. In such places, edge computing in itself will be like mini data centers.

Even though edge computing has a great reputation in the industry for being really fast, the current architecture does have limitations. Sometimes external factors such as computing capacity, software glitches, and high-volume processing off requests will add high additional overhead to the computing process, which will deteriorate the overall response time. This study presents an alternative approach to computing that results in better performance. By adding an additional system to compute critical requests for the infrastructure, we will be able to distribute load and improve performance drastically; the second system will be reserved for only mission-critical requests and also serves as a disaster recovery system in case of primary system failure. The objective of this study is to elucidate the infrastructure enhancements necessary for edge computing, to improve system stability and performance. Implementing these improvements is expected to catalyze progress in the fields of IoT devices and computing systems, providing support for high-volume processing and decision-making, two vital components for developing new capabilities and innovations. By enabling these advancements, we can pave the way for improved productivity and efficiency in various domains.

The remaining sections of this paper are organized as follows. Section 2 outlines an adequate background about the topic through review of literature. Section 3 methodlogy describes how cloud and edge computing infrastructure is hosted and explains the proposed enhanced edge infrastructure for better performance. Section 4 provides the results. Section 5 concludes with remarks and summarises the study. Section 6 dicusses the limitations and directions for future research.

2. Literature Review

An important study (Gartner, 2018) provides valuable insights into the growing significance of edge computing in enabling low-latency applications. But it does not venture into the specific limitations or challenges associated with adopting and implementing edge computing. The research by (Satyanarayanan et al. 2017) proposes a three-tier architecture for edge computing, which effectively distributes the workload across different tiers. However, the study does not extensively address scalability issues or the potential bottlenecks that may arise in this architecture.

(Li et al., 2018) present a fog computing framework that enhances edge computing capabilities by leveraging nearby resources. While this framework extends the benefits of edge computing, the study does not thoroughly explore the trade-offs or performance implications of incorporating fog computing into edge environments. The study by (Zhang et al. 2019) highlights the application of edge computing in healthcare for real-time monitoring and analysis of patient data. However, it may not comprehensively discuss the limitations or challenges related to data privacy, interoperability and the integration of edge computing solutions within existing healthcare systems.

(Yi et al., 2020) discuss the use of edge computing in smart cities and its role in efficient resource management. However, the study may not extensively address potential challenges associated with the scalability and interoperability of edge computing solutions in large-scale smart city deployments. (Shi et al. 2021) explore the application of edge computing in industrial automation for real-time monitoring and control. Despite that, the study may not extensively address the challenges of integrating edge computing with legacy industrial systems or the potential impact on network infrastructure and reliability.

The research by (Fouad et al. 2021) proposes a solution for managing distributed resources through fog-based containerization. However, the study may not thoroughly address the limitations or performance trade-offs of containerization approaches in edge computing environments. (Mao et al. 2017) propose offloading workload algorithms to address the challenge of resource orchestration across edge and cloud environments. Still, the study did not comprehensively discuss the potential overhead or complexity introduced by these algorithms in real-world edge computing deployments.

(Dey et al., 2022) highlight the importance of secure communication protocols and access control mechanisms in edge computing environments. However, the study may not extensively address the limitations or challenges associated with implementing and managing these security measures in diverse edge computing scenarios. While all the mentioned studies provide valuable insights into various aspects of edge computing, it is important to consider their limitations and the need for further research to address the challenges and complexities associated with adopting and implementing edge computing solutions.

3. Methodology

An edge device is referred to a device that is located outside of a data center. Edge computing "is a new paradigm in which large processing and storage capabilities are placed at the edge of the Internet, in close proximity to mobile devices or sensors," which is referred to as the source. Your current mobile phone could be considered an edge gadget. Security cameras may be located across the city, and banks, also regarded as edge devices, are self-driving automobiles. Thus they do not even need to be small. These gadgets make capturing real-time and location-based information simpler and more common. In addition, a lot of these gadgets produce actual data like pictures and movies. The enormous volume of data being produced is one of the issues with the proliferation of edge computing devices. Consider a security camera, for example, with a 10 Hz frame rate that can transmit data upward of 250MegaBytes each second. A standard airliner with an Internet connection creates data as high as 5 TeraBytes per day. Each day, a self-driving car produces data worth 4TeraBytes and is only for single devices. Consider the volume of traffic that would result from several of these devices attempting to deliver their unprocessed data to a single server. According to Gartner, by the year 2025, In contrast to centralized data centers, 75% of data generated by enterprises will be generated elsewhere. The cloud structure is impractical due to issues with bandwidth and latency for devices that need near real-time processing. Energy use is still another issue; a single bit traveling across the Internet uses 500 microjoules of energy; with edge computing, this energy usage can be significantly decreased.

As shown in Figure 1, a report from grand view research predicts that the market for edge computing on a global scale was assessed in 2021 for USD 7.43 billion, and it is projected to further increase by 38.9% CAGR from the year 2022-2030 (Grand View Research, 2022).

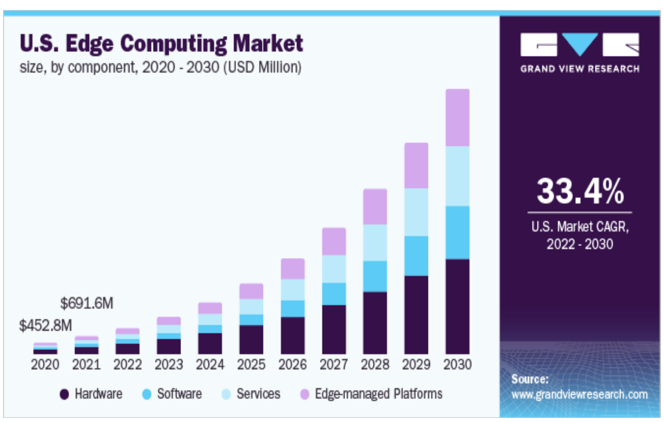

Fig. 1 U. S. edge computing market report

3.1. How Edge Computing Differs from Cloud Computing

It is really important to understand how edge computing is different from cloud computing before effective performance enhancement is presented. Traditionally software applications always had all infrastructure (servers) on-premises, and most of the time, the infrastructure was underutilized, not easily scalable, and incurred a high maintenance cost. Cloud computing solves this problem by centralizing the infrastructure in a distributed model where one can rent or reserve the required space for operation. It only pays based on utilization or for reserved standalone space. This resulted in easy scalability, high uptime and reduction in cost. Due to the long journey to the server, the likelihood of attacks on the data is greater in cloud computing than in edge computing. The top cloud service providers currently are Amazon Web Services (AWS), Azure from Microsoft and Google Cloud. Edge computing, on the other hand, is introduced because of the rise of IoT (Internet of Things) devices which require faster processing, data security and minimum latency. An additional layer of edge node is installed closer to the device, which processes requests and controls the device. Table 1 shows the comparison between cloud computing and edge computing (J. Pan and J. McElhannon, 2018).

Table 1. Cloud computing characteristics comparison to edge computing

Characteristics	Cloud Computing	Edge Computing
Major applications	Mainstream applications	IoT, VR (Virtual Reality, AR (Augmented Reality), Smart Homes, Smart Vehicles, Smart Devices etc
Proximity of services and resources for data processing	Far from the end user, in a remote location	Closer to the user, at the edge
Network bandwidth	A high amount of data transfer is needed	Low, as data processing is done on the edge node
Availability	A small count of data centers which are largely sized	A large count of data centers which are largely sized
Slowness/ Latency	High, because of the distance	Low, because of the proximity
Security	Low	High
Scalability	Scalable at data centers in the cloud	Scalable at data centers, at the edge

3.2. Edge Computing Infrastructure

In today's digital age, privacy and security are more important than ever, particularly when it comes to using cloud services. Organizations that handle sensitive data, such as hospitals, must ensure they take every possible measure to protect their users' privacy and avoid security breaches. As a result, it has become increasingly important to carefully consider how data is transferred to cloud platforms and how it is managed once it is there. Cloud platforms offer a wide range of benefits, such as scalability, cost-effectiveness and accessibility, but they can also be vulnerable to cyber threats. Due to the large attack surface of cloud services, the risk of data breaches is higher, particularly if sensitive information is being transferred in its raw form.

For this reason, institutions like hospitals have to be very cautious when sending raw data to cloud platforms. To avoid these risks, organizations can adopt security measures such as encryption or data masking to secure the data while it is being transmitted or stored. Encryption is a technique that involves encoding data so that it can only be accessed by someone with the appropriate decryption key. It provides an additional layer of security that can help prevent unauthorized access to the data in transit or storage. Data masking, on the other hand, is a technique that involves obscuring parts of sensitive information while still preserving the consistency of the data for analysis. This can help minimize the risk of data breaches while maintaining data usability. There must be some kind of edge-level preprocessing involved. A simplified 3tier edge computing infrastructure is showcased in Figure 2.

Figure 3 (B. Varghese et al., 2016) shows that typical Edge computing has 3 layers.

- Edge Devices: These are devices used at the base level, which can be any device like a smartphone, smartwatch, thermostat, smartplug etc
- Edge Nodes: These are the devices that control base devices and also collect and process data like routers, small base stations or data centers, which are installed closer to the device
- Cloud: Even though Edge nodes can independently control local devices, when additional communication is required from different parts of the world, process and analyze data that is not critical, or update software or security, the cloud will be used.

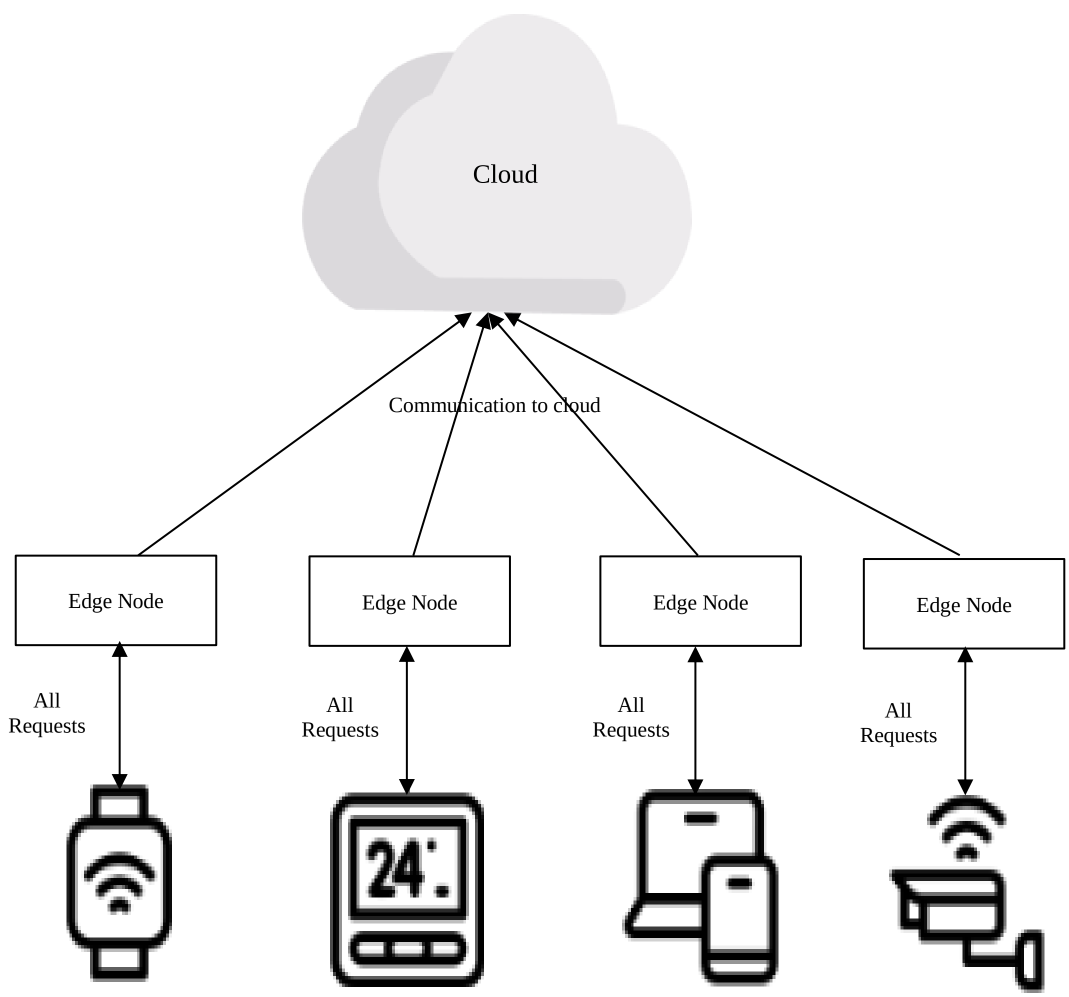

Fig. 2 Edge computing infrastructure

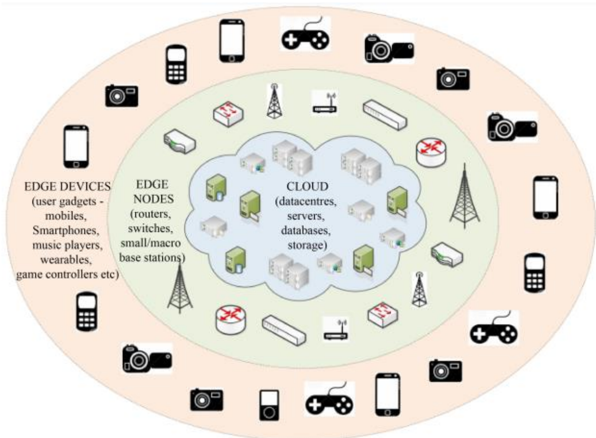

Fig. 3 Edge computing layers

As evident from the infrastructure setup, any disruption on the edge node will result in the failure of the IoT system, and it is not equipped to handle such a situation. This clearly indicates a need for infrastructure modification which will enable higher availability and performance for edge computing, which is the exact goal of this study and will be explained in detail in the next section.

3.3. Enhanced Edge Computing Infrastructure

As we have established the limitation with the current edge computing infrastructure, the proposal is to have an additional computing system or edge node which will co-exist with the current computing system or edge node. We will consider the existing edge node the primary node and the newly added node the secondary node. Whenever the primary node fails, is not available or has high latency, the secondary node will be active. It will process mission-critical requests to ensure the IoT device can continue operating.

In Figure 4, it is showcased that each IoT device will talk only to the primary node for regular requests and processing and critical requests are either directly sent to a secondary node or when the primary node fails or is non-responsive. Both the edge nodes will be in-sync with near-zero latency if there is any need for data sharing for request processing. This can be achieved by tagging the request as critical so that it can appropriately be sent to the primary or secondary node when routed.

4. Results

To elaborate on the proposed enhanced infrastructure advantage, we will consider 3 different scenarios. Response time numbers used are not actually tested numbers, and it is for the purpose of a better demonstration of the proposed method. In general, for interactive applications, reaction delays of less than 150 ms are typically regarded as acceptable; however, fast-paced engagements cannot tolerate delays of more than 70 ms (Premsankar, G. et al., 2018).

4.1. Scenario 1: Primary Node is Active

This is the happy path, as shown in Figure 5, when the primary node actively processes all requests and has no latency impact. In this scenario, the primary node will continue to process requests, and the secondary node will be in standby mode. Only when the primary node breaches the latency threshold is the request killed and resent to the secondary edge node for processing. The latency threshold is a variable value and can be set based on the criticality of the process; as a ballpark number, any request that does not receive a response beyond 100ms can be considered redirected.

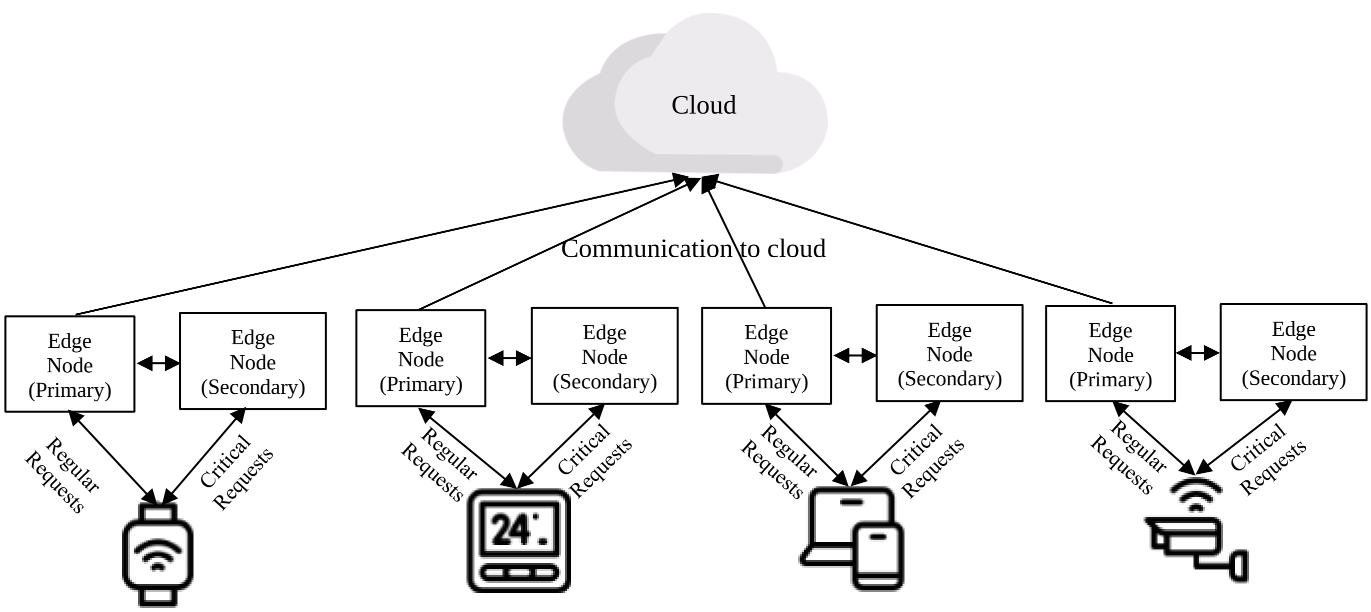

Fig. 4 Enhanced edge computing infrastructure

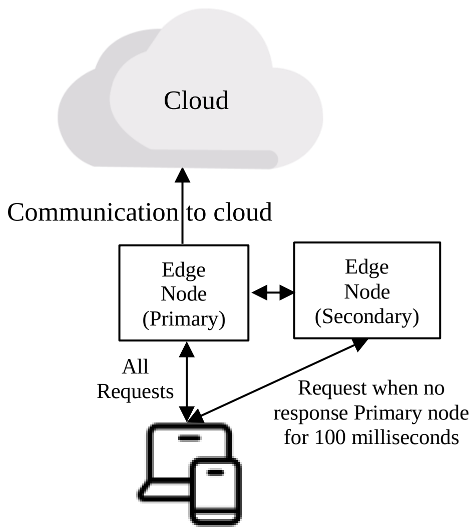

Fig. 5 Scenario 1 - Primary node is active

4.2. Scenario 2: Primary Node and Secondary Node are Active

As shown in Figure 6, in this scenario, we will balance the requests for enhanced performance by routing critical requests only to the secondary node. All other majorities of non-critical requests will be sent to the primary edge node. By doing this, we will ensure that mission-critical requests are always served without any latency, which will drive customer satisfaction and prolonged service to the devices. This is a better approach compared to Scenario-1 because we will be utilizing both nodes for optimal performance.

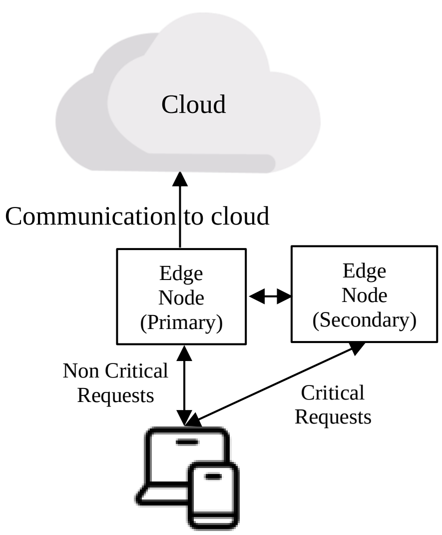

Fig. 6 Scenario 2 - Primary node and secondary node are active

4.3. Scenario 3: Primary Node is Inactive

When the Primary node fails to process any requests, this could be due to many reasons like memory issues, software glitches, security or software updates processing etc. Then the secondary edge node will act as a disaster recovery system, meaning it will take the burden of processing all the requests to serve the IoT device to have no impact on the service. Here the secondary node will, in turn, become the primary node till the actual primary node is available to process requests again. This scenario is shown in Figure 7.

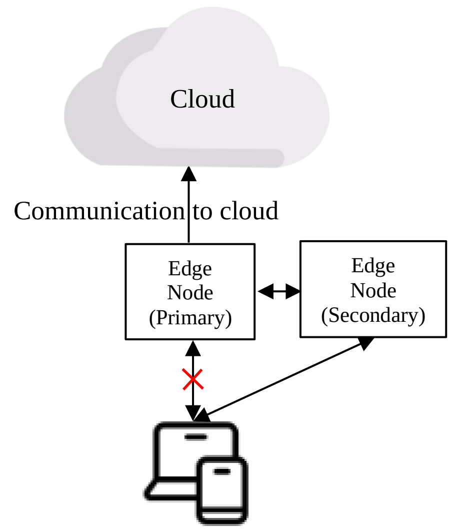

Fig. 7 Scenario 3 - Primary node is inactive

In Table 2, the different scenarios are listed, mapping to the status of primary and secondary nodes along with the type of request which is expected to be processed by the secondary node. This gives a comprehensive view of the edge nodes' expected activity when the proposed infrastructure is implemented.

Table 2. Edge Node status and secondary node request process type

Scenario	Primary Node Status	Secondary Node Status	Secondary Node Request Process Type
Scenario 1: Primary Node is Active	Active	Inactive	Critical requests on demand only
Scenario 2: Primary Node and Secondary Node are Active	Active	Active	Critical requests only
Scenario 3: Primary Node is Inactive	Inactive	Active	All requests

5. Discussion

Edge computing is considered to be the key transformer for a number of developing technologies, such as augmented reality, 5G, vehicle-to-vehicle communications and the Internet of Things (IoT), by connecting the end users to cloud computing resources and services (Khan, W.Z. et al., 2019).

Even though enhanced infrastructure will have higher edge computing capacity, there are some limitations related to the additional cost involved in setup secondary edge node; data sync between both primary and secondary edge nodes at near-zero latency can be challenging, and actual setup and testing are required to solidify the proposed solution. Physical maintenance is another aspect of edge computing that cannot be ignored. Unlike the cloud, the edge systems which do computing close to the devices should be maintained physically over time. Security of physical devices is also another area of edge computing that is vulnerable. In General, there is an increase in data breach incidents, and more hackers are coming into play daily, be it On-prem, Cloud, Hybrid or Edge Infrastructure. In one such incident, Uber company data was recently hacked.

The development of edge computing has presented researchers with many new areas to explore and problems to solve. One of the most significant issues facing edge computing is the difficulty in finding the optimal cost-to-performance ratio. Cost and performance are two critical factors in the decision-making process for implementing edge computing, and finding the right balance can be a challenging task. To help address this issue, future research can focus on testing secondary and additional edge nodes. Researchers can explore the deployment of additional edge nodes, their effectiveness in handling requests, and the cost-to-performance ratio of each additional node. This can involve setting up edge node clusters and experimenting with different configurations to find the optimal setup. Additionally, researchers can test and explore how secondary and additional edge nodes can connect to multiple devices and how data is routed between the edge node.

6. Conclusion

Now that we have IoT, we have reached the post-cloud age, when there will be a lot of edge apps deployed and a lot of high-quality data generated by devices that are part of our daily lives (Shi, W. et al., 2016). IoT will be the most crucial component of big data production because it is the supply of enormous amounts of data. IoT must therefore upload vast amounts of data to edge or cloud storage. Of course, the quick upload time is one advantage of using edge-based storage (Yu, W. et al., 2017). Incorporating edge computing with 5G technology has the potential to be extremely beneficial for the healthcare industry, as it will promote advancements in remote operations and diagnostics as well as the tracking of patients' vital signs and statistics. Doctors can operate surgical instruments remotely from a location where they feel secure and comfortable in order to save lives (Hassan N. et al., 2019). On the other hand, edge systems do create a lot of data that may not be required to be stored or transferred to the cloud; consider medical devices which continuously monitor patients' vitals; most of the time, the stable measurement can be ignored and only when the readings are at the critical level are most important.

As edge computing continues to gain momentum, it is critical to design infrastructure that can effectively handle any scenario, operate within network limitations, route requests intelligently, minimize reliance on large cloud computing systems and be highly reliable. With the current infrastructure setup for most IoT devices, it is nearly impossible to rely on a single edge node or computing system to handle all requests effectively. Increased latency can significantly impact operations, leading to potential disruption. Thus, this study has identified the limitations of current edge computing infrastructure. We have developed and proposed an enhanced infrastructure that addresses these limitations to ensure reliable and fast processing. The enhanced infrastructure includes additional edge nodes that can compute critical requests or serve as backup computing systems in the event of a disaster, ensuring uptime and reliability. If effectively implemented, this enhanced infrastructure will offer several benefits in terms of fast response times, high uptime and reliability which can help drive innovation in the edge computing ecosystem by inventing new devices and high processing units. This innovation can make cutting-edge concepts like the metaverse a reality much sooner. For developing and adopting Internet of Things (IoT) devices, creating efficient and reliable edge computing systems is important. It is also equally important to ensure that the systems are designed to meet the increasing demands of efficient and secure computer systems. Potential benefits for both businesses and society are great, making this a worthwhile investment for further exploration and development.

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