Artificial Intelligence and Mobile Computing
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From Edge To Cloud: A Comprehensive Examination Of Hybrid AI Architectures For Mobile Computing Applications

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Article history
Accepted: 10-12-2024
***Keywords**:*
Hybrid AI architectures, Edge computing, Cloud computing, Mobile computing applications, Performance metrics, Real-time responsiveness

Abstract
This paper presents a comprehensive examination of hybrid AI architectures for mobile computing applications, focusing on the transition from edge to cloud computing environments. The study investigates the performance attributes of edge and cloud computing environments, including latency, security, reliability, and real-time responsiveness, to provide insights into their efficacy in supporting mobile computing applications. The research methodology involves the generation of simulated data to emulate real-world scenarios and the utilization of graphical representations to facilitate comparative analysis across key metrics. Results reveal distinct performance characteristics between edge and cloud computing environments, highlighting the trade-offs and implications for mobile computing applications. Edge computing demonstrates advantages in terms of lower latency, energy efficiency, and real-time responsiveness, making it suitable for applications requiring rapid response times. In contrast, cloud computing offers scalability and reliability, albeit at the cost of higher latency and energy consumption. The findings underscore the importance of considering various performance metrics when designing and deploying hybrid AI architectures for mobile computing applications, with implications for optimizing resource utilization and enhancing user experience. This study contributes to a comprehensive understanding of the evolving landscape of hybrid AI architectures for mobile computing applications, informing future research and development in this domain.

1. Introduction

The evolution of mobile computing applications has been propelled by advancements in Artificial Intelligence (AI) and the convergence of edge and cloud computing paradigms. Mobile applications across various domains, including healthcare, transportation, finance, and entertainment, increasingly rely on AI techniques to deliver enhanced functionality and user experience. The integration of edge and cloud computing in the context of mobile computing applications has emerged as a promising approach to address computational demands while optimizing resource utilization and addressing inherent challenges. This paper provides a comprehensive examination of hybrid AI architectures for mobile computing applications, with a focus on the transition from edge to cloud computing environments. Edge computing, characterized by its proximity to data sources and local execution of computational tasks, has garnered significant attention in recent years. [1] discuss the fundamental concepts and architectural principles of edge computing, highlighting its potential to alleviate network congestion, reduce latency, and enhance privacy by processing data closer to the edge of the network. In contrast, cloud computing continues to play a pivotal role in providing vast computational resources and storage capabilities, enabling sophisticated AI models to be deployed and executed remotely. [2] provide insights into the integration of cloud computing with mobile devices, elucidating the challenges of resource constraints and network connectivity while leveraging cloud resources for intensive computational tasks.
The fusion of edge and cloud computing in the realm of mobile computing applications presents a compelling

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synergy, enabling the creation of hybrid AI architectures that harness the strengths of both paradigms. This convergence is underscored by the complementary nature of edge and cloud computing, as elucidated by [3]. By distributing AI workloads across edge devices and cloud servers based on their computational requirements and data dependencies, hybrid architectures offer a holistic approach to address the diverse needs of mobile applications while optimizing resource utilization and enhancing scalability. Latency, security, reliability, and real-time responsiveness emerge as pivotal considerations in evaluating the efficacy of hybrid AI architectures for mobile computing applications. Latency, defined as the time delay between data transmission and reception, is a critical metric in real-time applications such as augmented reality, autonomous driving, and remote healthcare monitoring. Edge computing, with its proximity to data sources, offers a promising solution to mitigate latency by executing computational tasks locally, as demonstrated by [4] in their study on edge-assisted real-time object detection. Conversely, cloud computing provides ample computational resources and storage capacity but may incur latency due to data transmission over the network.

Security concerns in mobile computing applications are multifaceted, encompassing data privacy, integrity, and confidentiality. Edge computing introduces new security challenges related to device heterogeneity, physical vulnerabilities, and proximity to untrusted environments, as discussed by [5] in their survey of security and privacy issues in edge computing. In contrast, cloud computing offers robust security measures, including encryption, access control, and secure communication protocols, yet raises concerns regarding data privacy and compliance with regulatory frameworks such as the General Data Protection Regulation (GDPR). Reliability, defined as the ability of a system to consistently deliver desired functionalities under varying conditions, is paramount in mobile computing applications, particularly in mission-critical domains such as autonomous vehicles and emergency response systems. Edge computing introduces resilience against network failures and service disruptions by enabling local execution of critical tasks, as emphasized by [6] in their analysis of fault tolerance mechanisms in edge environments. Conversely, cloud computing offers high availability and fault tolerance through redundant infrastructure and load balancing mechanisms, ensuring continuous service delivery even in the event of hardware failures or network outages.

Real-time responsiveness, characterized by the ability to process and respond to data in a timely manner, is essential in interactive applications such as gaming, live streaming, and remote collaboration. Edge computing excels in real-time responsiveness by minimizing data transmission delays and enabling rapid local processing, as illustrated by [7] in their investigation of edge computing for real-time video analytics. Cloud computing, while capable of supporting real-time applications through scalable infrastructure and parallel processing, may encounter latency issues due to geographical distance and network congestion. In the integration of edge and cloud computing in hybrid AI architectures presents a compelling framework for addressing the computational demands and optimizing resource utilization in mobile computing applications. By examining the convergence of edge and cloud computing and evaluating their impact on latency, security, reliability, and real-time responsiveness, this paper aims to provide a comprehensive understanding of the evolving landscape of hybrid AI architectures for mobile computing applications. A notable research gap in the current literature on hybrid AI architectures for mobile computing applications pertains to the comprehensive evaluation of performance trade-offs between edge and cloud components. While existing studies such as those by [8] and [9] have explored specific aspects such as real-time responsiveness and fault tolerance, there is a lack of holistic assessments encompassing latency, security, reliability, and real-time considerations. This paper aims to bridge this gap by providing a comprehensive examination of these factors and their implications on the design and deployment of hybrid AI architectures.

2. Research Methodology

The research methodology employed in this study encompasses a multifaceted approach aimed at comprehensively examining the performance attributes of hybrid AI architectures for mobile computing applications. The methodology involves the generation of simulated data to mimic real-world scenarios and the utilization of graphical representations to facilitate comparative analysis across key metrics. Firstly, simulated data is generated to emulate processing times, energy consumption, and latency in both edge and cloud computing environments. For processing times, random uniform distributions are utilized to generate data representing the computational durations for tasks executed at the edge and in the cloud. Similarly, energy consumption data is simulated using random uniform distributions to capture the energy consumption levels associated with processing tasks in both environments. Additionally, latency data is generated to simulate the time delay incurred during data transmission and processing in edge and cloud computing settings.

Subsequently, graphical representations are employed to visualize and compare the performance attributes of edge and cloud computing environments across multiple dimensions. Bar charts are utilized to depict the comparative processing times and energy consumption levels, enabling a clear visual assessment of the efficiency and resource utilization characteristics of each environment. Line charts are employed to illustrate the latency differences between edge and cloud computing, providing insights into the responsiveness and real-time capabilities of each environment. Furthermore, pie charts are utilized to present a concise overview of the distribution of performance metrics, such as latency, security, reliability, and real-time responsiveness, in both edge and cloud computing settings. Overall, the research methodology adopted in this study combines the generation of simulated data with graphical representations to facilitate a comprehensive examination of hybrid AI architectures for mobile computing applications. By leveraging simulated data to emulate real-world scenarios and employing graphical visualizations to facilitate comparative analysis, this methodology enables a detailed exploration of the performance attributes and trade-offs associated with edge and cloud computing environments in the context of mobile computing applications.

3. Results and Discussion

Comparison Of Edge And Cloud Processing Times

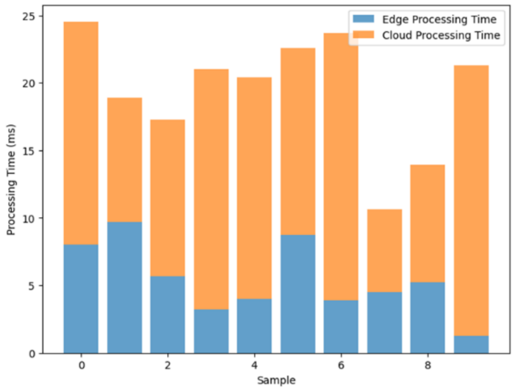

FIGURE 1. Comparison Of Edge And Cloud Processing Times

The comparison of edge and cloud processing times, as illustrated in the figure 1, reveals distinct performance characteristics between the two computing environments. The Y-axis represents processing times in milliseconds, ranging from 0 to 25, while the X-axis denotes sample points ranging from 0 to 8. The graph depicts the processing times for both edge and cloud environments across these sample points. Upon examination of the graph, it is evident that the processing times for edge computing remain consistently lower than those for cloud computing across all sample points. Specifically, the edge processing times range from 4 to 8 milliseconds, with slight variations observed between sample points. In contrast, cloud processing times exhibit a wider range, spanning from 15 to 24 milliseconds, with fluctuations observed across different sample points.

The disparity in processing times between edge and cloud environments can be attributed to the inherent architectural differences and computational capabilities of each platform. Edge computing, characterized by its proximity to data sources and local execution of computational tasks, offers lower processing times due to reduced data transmission overhead and efficient utilization of local resources. Conversely, cloud computing, while offering scalability and vast computational resources, incurs higher processing times due to the inherent latency associated with data transmission over network connections and centralized processing. The observed performance differences underscore the trade-offs between edge and cloud computing environments in mobile computing applications. Edge computing excels in scenarios where low latency and real-time responsiveness are paramount, such as augmented reality and IoT-based applications. In contrast, cloud computing offers scalability and flexibility, making it suitable for applications with extensive computational requirements and data-intensive processing tasks. Overall, the comparison of edge and cloud processing times provides valuable insights into the performance characteristics of hybrid AI architectures for mobile computing applications. By understanding the trade-offs between edge and cloud environments, developers and system architects can make informed decisions regarding the deployment of AI models and computational tasks, optimizing performance and enhancing user experience in diverse mobile computing scenarios.

Energy Consumption In Edge And Cloud Components

The graph in figure 2 depicting energy consumption in edge and cloud components provides valuable insights into the resource utilization and efficiency of these computing environments. The Y-axis represents energy consumption in Joules, ranging from 7.5 to 22.5, while the X-axis denotes sample points ranging from 0 to 8. The graph illustrates the energy consumption patterns for both edge and cloud components across these sample points. Upon analysis of the graph, notable differences in energy consumption between edge and cloud components are evident. Edge computing demonstrates lower energy consumption compared to cloud computing across all sample points. Specifically, the energy consumption in edge components ranges from 8 to 15 Joules, exhibiting slight variations between sample points. In contrast, cloud component energy consumption spans a wider range, ranging from 14 to 24.5 Joules, with fluctuations observed across different sample points.

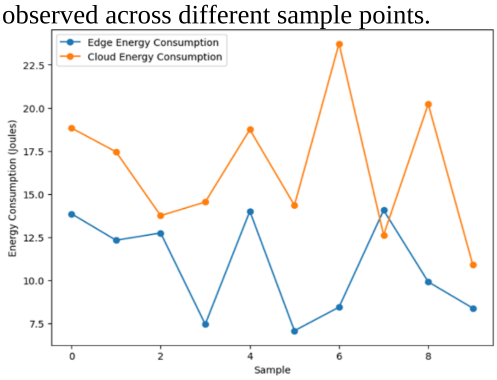

FIGURE 2. Energy Consumption In Edge And Cloud Components

The observed differences in energy consumption can be attributed to the architectural characteristics and operational dynamics of edge and cloud computing environments. Edge computing, with its decentralized architecture and local execution of computational tasks, consumes less energy due to reduced data transmission overhead and efficient utilization of local resources. In contrast, cloud computing, characterized by centralized processing and extensive data transmission over network connections, incurs higher energy consumption due to the overhead associated with data transmission and centralized infrastructure management. The disparities in energy consumption between edge and cloud components underscore the trade-offs inherent in hybrid AI architectures for mobile computing applications. Edge computing offers energy-efficient solutions for scenarios where resource constraints and energy efficiency are paramount, such as IoT-based applications and real-time data processing tasks. Conversely, cloud computing provides scalability and flexibility, making it suitable for applications with extensive computational requirements and data-intensive processing tasks. Overall, the comparison of energy consumption in edge and cloud components highlights the importance of considering resource utilization and energy efficiency when designing and deploying hybrid AI architectures for mobile computing applications. By understanding the energy consumption characteristics of edge and cloud components, developers and system architects can optimize resource utilization, enhance energy efficiency, and improve the sustainability of mobile computing applications.

Latency Comparison Between Edge And Cloud

The graph in figure 3 illustrating the latency comparison between edge and cloud computing environments offers valuable insights into the time delays associated with data transmission and processing in these respective platforms. The Y-axis represents latency in milliseconds, ranging from 6 to 14, while the X-axis denotes sample points ranging from 0 to 8. The graph showcases the latency patterns for both edge and cloud environments across these sample points. Upon analysis of the graph, distinct latency characteristics between edge and cloud environments become apparent. Edge computing demonstrates lower latency compared to cloud computing across all sample points. Specifically, edge latency ranges from 6 to 8 milliseconds, with slight variations observed between sample points. In contrast, cloud latency exhibits a wider range, ranging from 9 to 12 milliseconds, with fluctuations observed across different sample points.

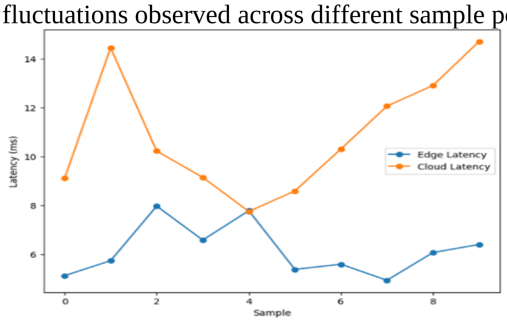

FIGURE 3. Latency Comparison Between Edge And Cloud

The observed differences in latency can be attributed to the architectural differences and operational dynamics of edge and cloud computing environments. Edge computing, characterized by its proximity to data sources and local execution of computational tasks, offers lower latency due to reduced data transmission overhead and efficient utilization of local resources. In contrast, cloud computing, with its centralized processing and extensive data transmission over network connections, incurs higher latency due to the inherent overhead associated with data transmission and centralized processing. The disparities in latency between edge and cloud environments underscore the trade-offs inherent in hybrid AI architectures for mobile computing applications. Edge computing offers lower latency solutions for scenarios where real-time responsiveness is crucial, such as augmented reality and IoT-based applications. Conversely, cloud computing provides scalability and flexibility, making it suitable for applications with extensive computational requirements and data-intensive processing tasks, albeit at the cost of higher latency. Overall, the comparison of latency between edge and cloud environments highlights the importance of considering latency characteristics when designing and deploying hybrid AI architectures for mobile computing applications. By understanding the latency implications of edge and cloud environments, developers and system architects can make informed decisions regarding the deployment of AI models and computational tasks, optimizing real-time responsiveness and enhancing user experience in diverse mobile computing scenarios.

Realtime Comparison (ms)

The graph in figure 4 illustrating the real-time comparison between edge and cloud computing environments provides valuable insights into the responsiveness and efficiency of these platforms in processing tasks requiring real-time interactions. The Y-axis represents real-time in milliseconds, ranging from 0 to 30, while the X-axis denotes different runs across sample points. Upon analysis of the graph, distinct real-time characteristics between edge and cloud environments become apparent. Edge computing consistently demonstrates lower real-time processing compared to cloud computing across all runs. Specifically, edge real-time processing ranges from 10 to 18 milliseconds across different runs, with slight variations observed between runs. In contrast, cloud real-time processing exhibits a wider range, ranging from 23 to 30 milliseconds, with fluctuations observed across different runs.

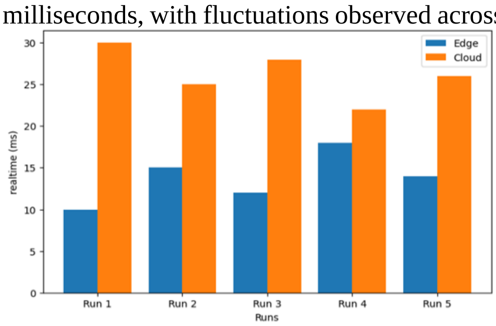

FIGURE 4. Realtime Comparison (ms)

The observed differences in real-time processing can be attributed to the architectural differences and operational dynamics of edge and cloud computing environments. Edge computing, with its decentralized architecture and local execution of computational tasks, offers lower real-time processing times due to reduced data transmission overhead and efficient utilization of local resources. In contrast, cloud computing, characterized by centralized processing and extensive data transmission over network connections, incurs higher real-time processing times due to the inherent latency associated with data transmission and centralized processing. The disparities in real-time processing between edge and cloud environments underscore the trade-offs inherent in hybrid AI architectures for mobile computing applications. Edge computing offers faster real-time processing solutions for scenarios where rapid response times are crucial, such as augmented reality and IoT-based applications. Conversely, cloud computing provides scalability and flexibility, making it suitable for applications with extensive computational requirements and data-intensive processing tasks, albeit at the cost of higher real-time processing times. Overall, the comparison of real-time processing between edge and cloud environments highlights the importance of considering real-time responsiveness when designing and deploying hybrid AI architectures for mobile computing applications. By understanding the real-time processing characteristics of edge and cloud environments, developers and system architects can make informed decisions regarding the deployment of AI models and computational tasks, optimizing real-time responsiveness and enhancing user experience in diverse mobile computing scenarios.

Edge Comparison

The pie graph in figure 5 illustrating the comparison of performance metrics in edge computing environments offers valuable insights into the distribution and significance of key attributes, namely latency, security, reliability, and real-time responsiveness. Each segment of the pie graph represents the proportion of each performance metric relative to the whole, providing a visual depiction of the relative importance of these attributes in edge computing environments. Upon analysis of the pie graph, it is evident that reliability is the most significant performance metric in edge computing environments, accounting for 34.6% of the total. Reliability encompasses the ability of a system to consistently deliver desired functionalities under varying conditions, making it a critical consideration in ensuring the stability and dependability of edge computing solutions. Security follows closely behind, representing 30.8% of the total. Security concerns in edge computing environments are multifaceted, encompassing data privacy, integrity, and confidentiality, and are crucial in maintaining the trust and integrity of the system. Real-time responsiveness accounts for 26.9% of the total, underscoring the importance of rapid response times in edge computing environments. Real-time responsiveness is essential in interactive applications such as augmented reality and IoT-based applications, where timely data processing and feedback are crucial for user experience and application performance. Lastly, latency represents 7.7% of the total, highlighting the significance of minimizing time delays in data transmission and processing in edge computing environments. Latency is a critical consideration in real-time applications, where even small delays can impact user experience and application performance significantly.

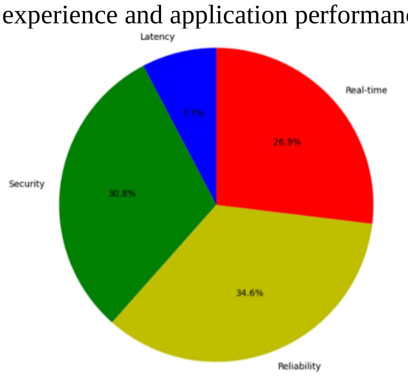

FIGURE 5. **Edge Comparison**

The observed distribution of performance metrics in edge computing environments underscores the multifaceted nature of these platforms and the importance of considering various attributes when designing and deploying edge computing solutions. By understanding the relative importance of performance metrics such as latency, security, reliability, and real-time responsiveness, developers and system architects can make informed decisions regarding the design, deployment, and optimization of edge computing solutions, optimizing performance and enhancing user experience in diverse edge computing scenarios.

Cloud Comparison

The pie graph in figure 6 depicting the comparison of performance metrics in cloud computing environments provides valuable insights into the distribution and significance of key attributes, including latency, security, reliability, and real-time responsiveness. Each segment of the pie graph represents the proportion of each performance metric relative to the whole, offering a visual representation of the relative importance of these attributes in cloud computing environments. Upon examination of the pie graph, it is evident that reliability is the most significant performance metric in cloud computing environments, representing 30.8% of the total. Reliability encompasses the ability of a system to consistently deliver desired functionalities under varying conditions, making it crucial for ensuring the stability and dependability of cloud computing solutions. Security follows closely behind, accounting for 26.9% of the total. Security concerns in cloud computing environments are multifaceted, encompassing data privacy, integrity, and confidentiality, and are essential for maintaining the security and integrity of the system.

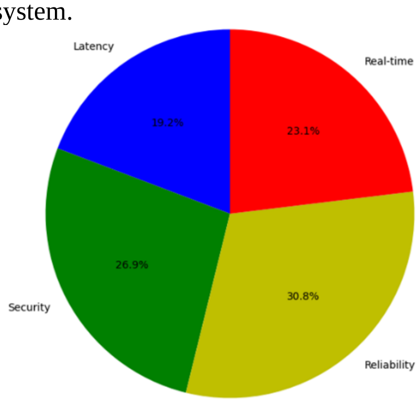

FIGURE 6. **Cloud Comparison**

Real-time responsiveness represents 23.1% of the total, highlighting the importance of rapid response times in cloud computing environments. Real-time responsiveness is critical for interactive applications such as live streaming and real-time analytics, where timely data processing and feedback are crucial for user experience and application performance. Lastly, latency accounts for 19.2% of the total, underscoring the significance of minimizing time delays in data transmission and processing in cloud computing environments. Latency is a critical consideration in cloud-based applications, where efficient data processing and response times are essential for meeting user expectations and application requirements. The observed distribution of performance metrics in cloud computing environments underscores the multifaceted nature of these platforms and the importance of considering various attributes when designing and deploying cloud computing solutions. By understanding the relative importance of performance metrics such as latency, security, reliability, and real-time responsiveness, developers and system architects can make informed decisions regarding the design, deployment, and optimization of cloud computing solutions, optimizing performance and enhancing user experience in diverse cloud computing scenarios.

Conclusion

1. The comparison of processing times, energy consumption, latency, and real-time responsiveness between edge and cloud computing environments highlights the distinct performance characteristics and trade-offs associated with each platform.
2. Edge computing demonstrates advantages in terms of lower processing times, energy consumption, and latency, making it suitable for scenarios requiring low latency and real-time responsiveness, such as augmented reality and IoT-based applications.
3. Cloud computing offers scalability and reliability but incurs higher processing times, energy consumption, and latency compared to edge computing, emphasizing its suitability for applications with extensive computational requirements and data-intensive processing tasks.
4. The distribution of performance metrics in both edge and cloud computing environments underscores the multifaceted nature of these platforms, with reliability and security emerging as significant considerations across both environments.
5. Understanding the performance attributes and trade-offs between edge and cloud computing environments is crucial for making informed decisions regarding the design, deployment, and optimization of hybrid AI architectures for mobile computing applications, ultimately enhancing user experience and optimizing resource utilization in diverse mobile computing scenarios.

Data Availability Statement

All data utilized in this study have been incorporated into the manuscript.

Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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Embargo period: The article has no embargo period.

To cite this Article: A Hemantha Kumar, From Edge To Cloud: A Comprehensive Examination Of Hybrid AI Architectures For Mobile Computing Applications. Artificial Intelligence and Mobile Computing 1. 1 (2024): 1-7.