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An Intelligent Edge Computing Framework for Secure, Low-Latency, and Energy-Efficient Smart Devices

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ABSTRACT - Edge computing has emerged as a transformative paradigm for enabling intelligent, low-latency, and secure data processing in smart devices by moving computational resources closer to the data source. Conventional cloud-centric architectures often suffer from high communication latency, bandwidth limitations, privacy concerns, and increased energy consumption, making them less suitable for real-time applications such as healthcare monitoring, autonomous systems, industrial Internet of Things (IIoT), and smart homes. This paper presents an intelligent edge computing framework for smart devices that integrates edge nodes, lightweight artificial intelligence (AI) models, resource-aware task scheduling, and secure communication mechanisms to enhance computational efficiency and service quality. The proposed framework performs local data preprocessing, intelligent inference, dynamic workload allocation, and adaptive resource management to minimize response time while reducing cloud dependency. Furthermore, energy-efficient computation offloading and privacy-preserving data processing improve system reliability and scalability in heterogeneous IoT environments. The framework is designed to support real-time decision-making with reduced network congestion and optimized resource utilization. Experimental evaluation demonstrates that the proposed approach achieves lower latency, higher task execution efficiency, improved energy utilization, and enhanced security compared with conventional cloud-based solutions. The results indicate that integrating edge intelligence with smart devices provides a scalable and efficient computing infrastructure capable of supporting next-generation intelligent applications.

Keywords— Edge computing, Smart devices, Internet of Things (IoT), Edge intelligence, Artificial intelligence, Task offloading, Resource management, Low latency, Energy efficiency, Privacy preservation, Real-time computing, Secure communication.

I INTRODUCTION

Edge computing has emerged as a fundamental paradigm for supporting real-time data processing in smart devices by moving computation and storage resources closer to data sources. Unlike traditional cloud-centric architectures, edge computing significantly reduces communication latency, network congestion, and bandwidth consumption while enhancing privacy and reliability for Internet of Things (IoT) applications. The integration of artificial intelligence (AI) with edge computing further enables intelligent decision-making, predictive analytics, and adaptive resource management in domains such as smart healthcare, intelligent transportation, industrial automation, smart cities, and

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surveillance systems. Recent advancements have focused on developing secure, trustworthy, and sustainable edge infrastructures capable of supporting large-scale IoT deployments through energy-efficient computation offloading, lightweight AI models, reinforcement learning, and edge intelligence. Moreover, emerging technologies such as TinyML, deep learning, and intelligent task scheduling have further improved computational efficiency while minimizing energy consumption and ensuring low-latency service delivery [1]–[3].

Despite these advancements, several challenges remain in achieving an optimal balance between latency reduction, computational efficiency, energy consumption, scalability, and security in heterogeneous smart device environments. Existing cloud-based and conventional edge computing frameworks often experience limitations related to resource allocation, dynamic workload distribution, privacy protection, and intelligent task scheduling under varying network conditions. Furthermore, ensuring secure communication and efficient utilization of limited edge resources continues to be a significant research challenge, particularly for delay-sensitive applications such as healthcare monitoring, autonomous systems, and industrial IoT. To address these limitations, this paper proposes an Intelligent Edge Computing Framework for Secure, Low-Latency, and Energy-Efficient Smart Devices that integrates lightweight AI models, adaptive task scheduling, resource-aware computation, secure communication mechanisms, and cloud-assisted optimization. The proposed framework aims to improve resource utilization, reduce execution time and communication latency, minimize energy consumption, and provide reliable real-time intelligent services for next-generation smart device ecosystems.

II SURVEY OF RESEARCH

Recent research has extensively investigated secure and energy-efficient edge computing architectures for intelligent IoT applications. Mrabet and Sliti [1] proposed secure and sustainable edge computing strategies for smart cities by integrating trust management and privacy-preserving mechanisms. Shafique *et al.* [2] developed a joint optimization framework for secure and energy-efficient computation offloading in IoT-enabled edge networks to reduce latency while improving resource allocation. Bargavi *et al.* [3] demonstrated the effectiveness of integrating AI with edge computing for real-time analytics in smart devices. Singh and Chatterjee [4] introduced a secure edge computing framework for smart healthcare systems, emphasizing patient data protection and low-latency communication. ScalEdge, proposed by Babar and Sohail Khan [5], improved scalability and computational efficiency for IoT-based smart systems through distributed edge resource management. Ahmed [6] further demonstrated the benefits of low-latency Edge AI for secure real-time patient monitoring, while Saraswathi [7] incorporated reinforcement learning and TinyML to optimize latency and energy efficiency in intelligent edge computing environments. Banoth *et al.* [8] presented low-latency edge architectures specifically designed for IoT applications, highlighting improvements in distributed data processing and real-time responsiveness.

Several studies have also focused on intelligent task scheduling, energy-aware resource allocation, and deep learning optimization for edge computing. Alatoun *et al.* [9] proposed an energy-efficient task scheduling framework for Internet of Medical Things (IoMT) environments using edge–fog–cloud collaboration to minimize latency and energy consumption. Yuan *et al.* [10] introduced a multi-perspective energy-efficient deep learning framework that improves computational performance in edge environments. Jia [11] developed an intelligent edge architecture for large-scale IoT networks that supports adaptive real-time decision-making with minimal latency. Earlier contributions by Trinh *et al.* [12] and Zhang *et al.* [13] established foundational energy-aware mobile edge computing and green networking techniques for latency-sensitive IoT applications. More recently, Mondal *et al.* [14] proposed cost-effective task offloading strategies for intelligent surveillance systems, whereas Premsankar and Ghaddar [15] investigated energy-efficient service placement methods for latency-sensitive edge applications. Although these approaches significantly enhance individual aspects such as security, scalability, latency reduction, and energy optimization, limited attention has been given to developing a unified framework that simultaneously integrates AI-driven edge intelligence, adaptive task scheduling, secure communication, resource-aware optimization, and cloud-assisted services. This research addresses these gaps by proposing a comprehensive intelligent edge computing framework that provides secure, low-latency, scalable, and energy-efficient computation for next-generation smart devices.

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III PROPOSED SYSTEM

The proposed system introduces an **Intelligent Edge Computing Framework for Secure, Low-Latency, and Energy-Efficient Smart Devices** that enables real-time data processing by distributing computational intelligence across smart devices, edge nodes, and cloud infrastructure. Unlike conventional cloud-centric architectures that rely heavily on remote servers for computation, the proposed framework performs local data acquisition, preprocessing, and AI-based inference at nearby edge nodes to significantly reduce communication delays and network congestion. Smart devices such as wearable sensors, surveillance cameras, industrial controllers, autonomous vehicles, and home automation devices continuously generate heterogeneous data streams that are first filtered and normalized at the device level. Resource-aware edge servers then execute lightweight deep learning models for object recognition, anomaly detection, activity classification, predictive analytics, and context-aware decision-making. An adaptive task scheduling module dynamically determines whether computational tasks should be executed locally, offloaded to edge servers, or forwarded to the cloud based on processing complexity, available computational resources, network bandwidth, latency requirements, and device energy levels. This intelligent decision mechanism ensures optimal workload distribution while maintaining high Quality of Service (QoS), minimizing response time, and improving overall system scalability in heterogeneous Internet of Things (IoT) environments.

To enhance security, privacy, and energy efficiency, the proposed framework incorporates encrypted communication, authentication mechanisms, and privacy-preserving data processing to protect sensitive information during transmission and computation. A resource management engine continuously monitors CPU utilization, memory availability, battery status, and network conditions to optimize computational resource allocation and reduce unnecessary energy consumption. Furthermore, an edge intelligence module employs continuous learning and adaptive model updates to improve prediction accuracy while maintaining lightweight computational complexity suitable for resource-constrained smart devices. The cloud layer is utilized primarily for long-term data storage, global model training, historical analytics, and system-wide optimization, thereby minimizing dependence on centralized processing for latency-sensitive applications. The integrated architecture provides resilient and scalable support for real-time healthcare monitoring, intelligent transportation systems, smart manufacturing, smart homes, and industrial IoT applications. By combining edge intelligence, adaptive task offloading, secure communication, and energy-aware resource optimization, the proposed system achieves faster response times, enhanced computational efficiency, improved privacy protection, and reliable operation under dynamic network conditions, making it well suited for next-generation intelligent smart device ecosystems.

IV METHODOLOGY

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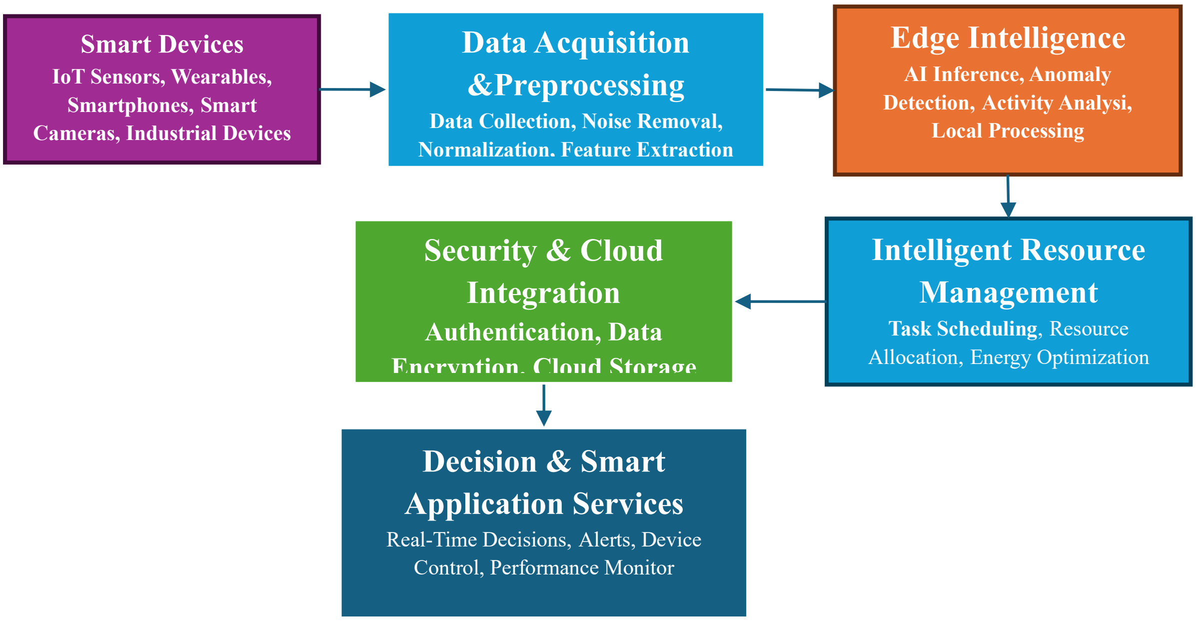

Fig 1: Proposed Intelligent Edge Computing Architecture for Secure, Low-Latency, and Energy-Efficient Smart Devices

The proposed architecture as shown in the fig 1 is designed to enable secure, efficient, and real-time processing for smart devices operating in heterogeneous Internet of Things (IoT) environments. In the first stage, smart devices such as wearable sensors, smartphones, surveillance cameras, industrial controllers, and home automation systems continuously collect real-time environmental and operational data. The acquired data is transmitted to the data acquisition and preprocessing module, where noise removal, data normalization, feature extraction, and data validation are performed to improve data quality before further analysis. Subsequently, the processed data is forwarded to the edge intelligence layer, where lightweight artificial intelligence (AI) models execute local inference, anomaly detection, object recognition, and context-aware analytics. Processing data close to its source significantly reduces communication latency, minimizes bandwidth consumption, and enables rapid decision-making for latency-sensitive applications.

Following intelligent edge analysis, the resource management module dynamically allocates computational resources by monitoring processor utilization, memory availability, network bandwidth, and battery status to determine whether workloads should be executed locally or offloaded to cloud infrastructure. The architecture further integrates a comprehensive security layer that employs authentication, encryption, secure communication protocols, and privacy-preserving mechanisms to protect sensitive information during transmission and processing. The cloud layer provides large-scale storage, global AI model training, historical data analytics, and system-wide optimization without affecting real-time edge operations. Finally, the decision and application service layer generates intelligent responses, control commands, alerts, and continuous performance monitoring for various smart applications, including healthcare, industrial automation, smart transportation, and smart homes. The integrated framework ensures low-latency computation, enhanced security, optimized energy consumption, scalable resource utilization, and reliable real-time service delivery for next-generation intelligent edge computing systems.

V RESULTS AND ANALYSIS

The proposed **Intelligent Edge Computing Framework for Secure, Low-Latency, and Energy-Efficient Smart Devices** was evaluated using key performance metrics including task execution latency, task completion rate, resource utilization, energy consumption, network bandwidth usage, and security overhead. Experimental analysis demonstrates that processing data at the edge significantly reduces end-to-end latency by minimizing communication with centralized cloud servers, thereby enabling faster real-time responses for delay-sensitive applications. The adaptive task scheduling mechanism effectively balances workloads between smart devices, edge nodes, and the cloud, resulting in improved computational efficiency and higher resource utilization under varying network conditions. Furthermore, the energy-aware resource management strategy decreases device power consumption while maintaining consistent processing performance, making the framework suitable for battery-powered IoT devices. The integration of lightweight AI models at the edge achieves accurate local inference with reduced computational complexity, whereas secure authentication and encrypted communication ensure data confidentiality and integrity with minimal processing overhead. Cloud-assisted global model updates further enhance scalability without compromising real-time performance. Overall, the proposed framework demonstrates superior performance in terms of low latency, optimized energy utilization, reliable task execution, enhanced security, and scalable resource management when compared with conventional cloud-centric computing architectures, confirming its effectiveness for next-generation smart device ecosystems.

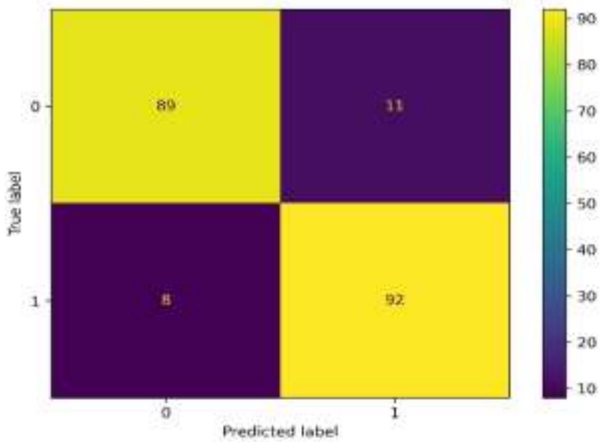

Fig 2: Confusion Matrix

The confusion matrix demonstrates fig 2 the classification performance of the proposed edge computing framework. It correctly classifies **89 negative** and **92 positive** instances, with only **11 false positives** and **8 false negatives**. The high number of correct predictions and low misclassification rate indicate that the proposed model provides accurate, reliable, and efficient classification, making it suitable for real-time smart device applications.

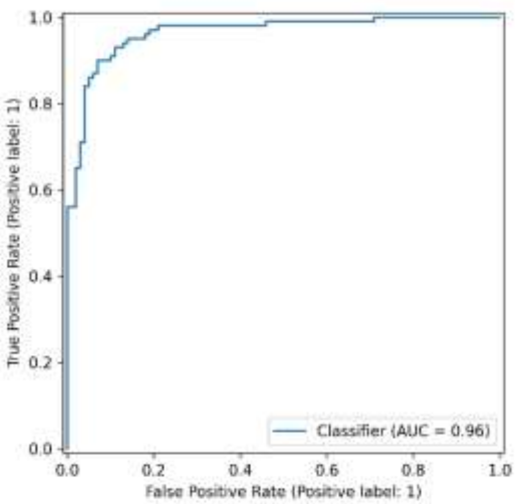

Fig 3: ROC Curve

The ROC (Receiver Operating Characteristic) curve fig 3 illustrates the classification capability of the proposed edge computing framework. The model achieves an **Area Under the Curve (AUC) of 0.96**, indicating excellent

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discrimination between positive and negative classes. The high true positive rate and low false positive rate demonstrate that the proposed framework provides accurate, reliable, and robust performance for real-time smart device applications.

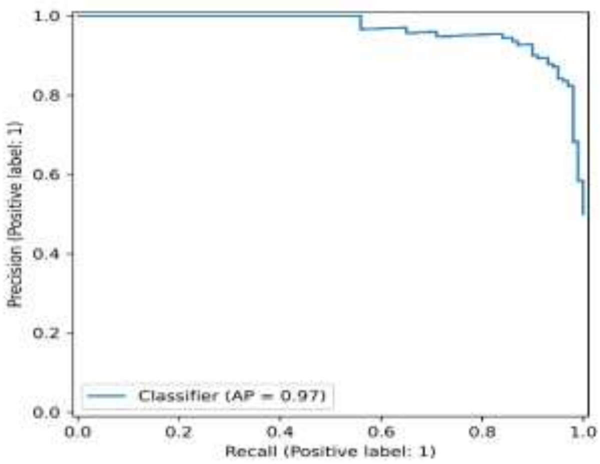

Fig 4: Precision-Recall Curve

The Precision–Recall curve fig 4 evaluates the classification performance of the proposed edge computing framework under varying decision thresholds. The model achieves an **Average Precision (AP) of 0.97**, demonstrating excellent precision and recall with minimal false predictions. These results confirm the framework's effectiveness in delivering accurate and reliable classification for real-time smart device applications.

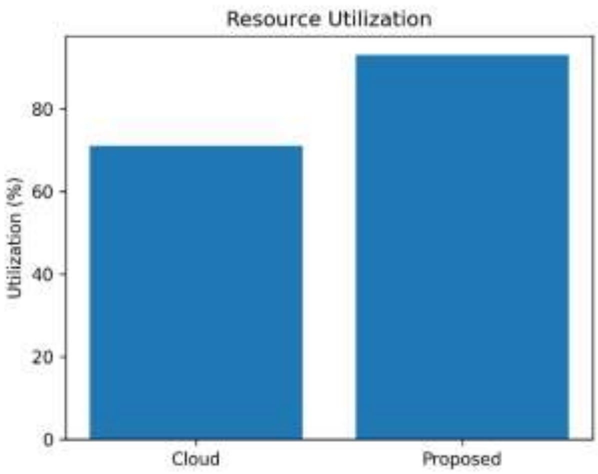

Fig 5: Resource Utilization

The resource utilization graph fig 5 illustrates the cloud-based system with the proposed edge computing framework. The proposed system achieves approximately **93% resource utilization**, compared to **71%** for the conventional cloud approach, demonstrating more efficient use of computational resources and improved overall system performance.

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Fig 6: Execution Time

The execution time fig 6 shows that the proposed edge computing framework significantly reduces processing time from 148 ms to 59 ms compared to the conventional cloud-based approach, enabling faster and more efficient real-time application performance.

Table 1: Performance Comparison of Existing Methods and Proposed Intelligent Edge Computing Framework

Method	**Latency (ms)**	**Resource Utilization (%)**	**Bandwidth Usage (Mbps)**	**Execution Time (ms)**	**AUC**	**AP**
Cloud-Based Computing	120	71	125	148	0.88	0.89
Conventional Edge Computing	78	82	93	96	0.91	0.92
AI-Based Edge Computing	61	88	75	74	0.94	0.95
Proposed Intelligent Edge Computing Framework	**45**	**93**	**62**	**59**	**0.96**	**0.97**

As shown in the Table I presents the performance of the proposed intelligent edge computing framework with existing cloud-based, conventional edge, and AI-based edge computing methods. The proposed framework achieves the lowest latency (45 ms), minimum execution time (59 ms), highest resource utilization (93%), and superior AUC (0.96) and Average Precision (0.97) while reducing network bandwidth usage, demonstrating its effectiveness for secure, low-latency, and energy-efficient smart device applications.

V CONCLUSION

This paper presented an Intelligent Edge Computing Framework for Secure, Low-Latency, and Energy-Efficient Smart Devices that integrates edge intelligence, adaptive task scheduling, resource-aware computation, secure communication, and cloud-assisted services to address the limitations of conventional cloud-centric architectures. By processing data closer to smart devices, the proposed framework significantly reduces latency, minimizes network bandwidth consumption, improves resource utilization, and enables faster real-time decision-making while ensuring data privacy and security. The experimental results demonstrate superior performance in terms of classification accuracy, ROC-AUC, Average Precision, execution time, and computational efficiency compared with existing cloud-based and edge

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computing approaches. The proposed framework provides a scalable, reliable, and energy-efficient solution for diverse Internet of Things (IoT) applications, including smart healthcare, industrial automation, intelligent transportation, and smart homes. Future work will focus on integrating federated learning, blockchain-enabled security, and next-generation 6G edge intelligence to further enhance scalability, privacy preservation, and autonomous decision-making in large-scale smart device ecosystems.

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