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Unified AI–IoT– Cloud–Energy Framework for Smart, Secure, and Sustainable Environments

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Abstract

Rapid advancements in artificial intelligence, Internet of Things, cloud computing, and renewable energy technologies have enabled the development of integrated frameworks capable of transforming conventional infrastructures into intelligent, secure, and sustainable environments. The unified AI-IoT-Cloud-Energy framework presented in this chapter provides a comprehensive architecture that harmonizes real-time sensing, predictive analytics, cloud-based orchestration, and adaptive energy management. The framework supports low-latency decision-making, efficient resource utilization, and operational resilience across diverse applications, including smart cities, intelligent buildings, industrial IoT ecosystems, and renewable energy grids. Edge and federated AI techniques are employed to enhance decentralized decision-making, reduce communication overhead, and preserve data privacy. Integration with cloud and fog computing ensures scalable computation, synchronized orchestration, and seamless interoperability across heterogeneous devices and systems. Security and reliability are reinforced through AI-driven monitoring, intrusion detection, and encrypted communication protocols, safeguarding critical infrastructures against cyber threats. Energy sustainability is achieved by incorporating renewable energy sources, load forecasting, and adaptive consumption strategies, optimizing energy allocation while minimizing environmental impact. The proposed framework offers a cohesive blueprint for next-generation smart environments, enabling autonomous, resilient, and energy-efficient operations. This chapter provides detailed insights into architectural design, functional components, implementation strategies, and potential applications, addressing key challenges in scalability, interoperability, and sustainability.

Keywords: Artificial Intelligence, Internet of Things, Cloud Computing, Energy Management, Smart Environments, Edge AI.

Introduction

The rapid evolution of modern technologies has fundamentally reshaped the development and management of smart environments, encompassing urban infrastructure, industrial facilities, and intelligent buildings [1]. Traditional systems, which often operate in isolation, are increasingly inadequate to handle the dynamic complexity, large-scale connectivity, and sustainability requirements of contemporary infrastructures [2]. The integration of Artificial Intelligence (AI), Internet of Things (IoT), cloud computing, and energy management systems provides the

necessary foundation for creating intelligent, responsive, and sustainable environments [3]. IoT devices generate real-time data from a wide range of sources, including environmental sensors, energy meters, and operational machinery. AI algorithms process this data to extract meaningful patterns, perform predictive analytics, and enable adaptive decision-making, while cloud platforms provide scalable computation and centralized orchestration [4]. Energy systems, particularly renewable sources, are intelligently managed to optimize consumption, balance loads, and minimize environmental impact. This combination of sensing, computation, intelligence, and energy control forms a unified framework that addresses operational efficiency, reliability, and sustainability simultaneously. By establishing a cohesive architecture, the framework ensures seamless interaction between heterogeneous devices, distributed energy resources, and advanced analytics, creating a resilient infrastructure capable of adapting to rapidly changing environmental and operational conditions [5].

IoT serves as the primary enabler for data collection and operational monitoring in unified smart environments [6]. Sensors and actuators deployed across physical infrastructure provide continuous streams of heterogeneous data, capturing energy usage, environmental parameters, and system health metrics [7]. The vast volume of data generated by these devices necessitates sophisticated analytics and processing techniques. AI-based machine learning and deep learning models analyze the collected data to identify anomalies, forecast future system states, and optimize operational parameters [8]. Edge computing extends intelligence closer to the data source, enabling low-latency decision-making, reducing network congestion, and conserving energy. Federated learning techniques allow distributed devices to collaboratively train AI models without sharing raw data, ensuring privacy preservation while maintaining collective intelligence [9]. Cloud computing complements edge intelligence by providing centralized data aggregation, high-performance computation, and orchestration across geographically distributed nodes. This integrated approach facilitates real-time monitoring, predictive maintenance, and adaptive control, thereby enhancing operational efficiency, system reliability, and environmental sustainability in smart environments [10].