INTISARI

Penerapan sistem rumah kaca cerdas berbasis Internet of Things (IoT) menuntut arsitektur komputasi yang mampu memberikan respons cepat, efisiensi energi, dan keandalan pada jaringan sensor berskala besar. Pendekatan berbasis cloud konvensional sering kali menimbulkan permasalahan berupa latency tinggi dan konsumsi energi yang besar akibat pemrosesan terpusat, sementara pemrosesan yang sepenuhnya dilakukan di sisi edge memiliki keterbatasan dalam analisis data yang kompleks dan pengambilan keputusan adaptif. Kondisi ini menunjukkan perlunya arsitektur komputasi terdistribusi yang mampu menyeimbangkan kebutuhan respon real-time, efisiensi sumber daya, dan akurasi pengambilan keputusan pada sistem rumah kaca cerdas.

Penelitian ini mengusulkan dan mengevaluasi arsitektur Edge–Cloud Fusion 3-Layer berbasis model hibrida Probabilistic Neural Network (PNN) dan Adaptive Neuro-Fuzzy Inference System (ANFIS). PNN diterapkan pada layer edge untuk mendukung deteksi kondisi lingkungan secara cepat dan ringan, sedangkan ANFIS digunakan pada layer cloud untuk melakukan analisis lanjutan dan pengambilan keputusan adaptif. Data lingkungan utama berupa suhu, kelembaban, dan konsentrasi CO_2 diperoleh dari sensor sebagai data primer, sementara data intensitas cahaya diperoleh dari sumber sekunder. Evaluasi kinerja dilakukan melalui simulasi jaringan menggunakan NS-3 pada variasi jumlah node sensor, dengan parameter pengujian meliputi latency, konsumsi energi, throughput, dan packet delivery ratio (PDR). Analisis statistik ANOVA dan MANOVA digunakan untuk menguji signifikansi perbedaan performa antar arsitektur.

Hasil penelitian menunjukkan bahwa arsitektur Edge–Cloud Fusion mampu beradaptasi secara stabil terhadap variasi jumlah node tanpa degradasi kinerja yang signifikan. Sistem menghasilkan latency dan end-to-end delay yang rendah, throughput yang stabil, serta PDR yang tinggi, sekaligus mengonsumsi energi lebih rendah dibandingkan arsitektur pembanding. Analisis multivariat menunjukkan bahwa perbedaan performa tersebut signifikan secara statistik ($p < 0{,}001$), dengan konfigurasi 100 node sebagai jumlah yang paling optimal. Temuan ini membuktikan bahwa arsitektur Edge–Cloud Fusion berbasis PNN–ANFIS efektif dalam menyeimbangkan kecepatan respon, efisiensi energi, dan keandalan sistem, sehingga berpotensi diterapkan secara berkelanjutan pada sistem rumah kaca cerdas dan aplikasi IoT berskala besar lainnya..

Kata Kunci: *Internet of Things*, *Edge–Cloud Fusion*, Rumah Kaca Cerdas, PNN, ANFIS, NS-3

ABSTRACT

The implementation of Internet of Things (IoT)–based smart greenhouse systems requires a computing architecture that is capable of delivering fast response, energy efficiency, and reliable operation over large-scale sensor networks. Conventional cloud-centric architectures often suffer from high latency and excessive energy consumption due to centralized data processing, while fully edge-based approaches are limited in their ability to perform complex data analysis and adaptive decision-making. These limitations highlight the need for a distributed computing architecture that can effectively balance real-time responsiveness, energy efficiency, and decision accuracy in smart greenhouse environments.

This study proposes and evaluates a three-layer Edge–Cloud Fusion architecture integrated with a hybrid artificial intelligence model combining Probabilistic Neural Network (PNN) and Adaptive Neuro-Fuzzy Inference System (ANFIS). PNN is deployed at the edge layer to enable fast and lightweight detection of environmental conditions, while ANFIS is implemented at the cloud layer to perform higher-level analysis and adaptive decision-making. Primary environmental data, including temperature, humidity, and CO_2 concentration, are collected from greenhouse sensors, while light intensity data are obtained from secondary sources. System performance is evaluated through network simulations using NS-3 under varying numbers of sensor nodes, with performance metrics including latency, energy consumption, throughput, and packet delivery ratio (PDR). Statistical analyses using ANOVA and MANOVA are employed to assess the significance of performance differences among architectures.

The experimental results demonstrate that the proposed Edge–Cloud Fusion architecture exhibits strong adaptability and stability across different network scales without significant performance degradation. The system achieves low latency and end-to-end delay, stable throughput, and high PDR, while consistently consuming less energy than the benchmark architectures. Multivariate analysis confirms that these performance improvements are statistically significant ($p < 0.001$), with the configuration of 100 sensor nodes identified as the optimal balance between responsiveness, energy efficiency, and transmission reliability. These findings indicate that the Edge–Cloud Fusion architecture based on the PNN–ANFIS hybrid model effectively addresses the limitations of conventional cloud-only and edge-only approaches, and provides a scalable and energy-efficient foundation for smart greenhouse systems and other large-scale IoT applications.

Keywords: *Internet of Things*, *Edge–Cloud Fusion*, Smart Greenhouse, PNN, ANFIS, NS-3