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Cloud-based smart agriculture framework: Optimizing load balancing efficiency via integrated scheduling algorithm

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Abstract

The rise of smart agriculture has revolutionized farming through advanced technology, boosting efficiency, productivity, and sustainability. This study introduces a Cloud-Based Smart Agriculture Framework that optimizes load-balancing efficiency through integrated hybrid scheduling algorithms. The four-layer framework aims to transform agricultural practices by combining IoT, Edge, Cloud, and Network layers. The research explores the crucial roles of IoT and Cloud Computing in Agriculture, emphasizing their contributions to data acquisition, analysis, and management. Integrating GA+ IRR in the IoT layer enhances load balancing and system optimization, improving resource management and optimizing data processing in agricultural IoT devices.

Subject Classification: *68M20.*

Keywords: *Smart agriculture, Cloud computing, IoT, Edge, Load balancing.*

1. Introduction

Agriculture has evolved from traditional methods to smart agriculture, addressing challenges like unpredictable weather patterns and resource inefficiency. Integrating IoT and cloud computing has led to a paradigm shift in agriculture, known as precision agriculture. This approach

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Figure 1

Applications and Benefits of IoT in Agriculture [1]

combines technology with agricultural practices, leveraging data-driven insights and automation to optimize operations and meet global food demand [1]. This shift is a significant shift in the way agriculture is conducted.

IoT in Agriculture: Smart agriculture relies on deploying IoT devices, including sensors, drones, and actuators, which form an interconnected network that transforms farming into a data-rich and responsive ecosystem. Figure. 1 shows the Applications and Benefits of IoT in Agriculture.

Sensors in agricultural components monitor soil moisture, temperature, and nutrient content, while crop canopy sensors gather data on crop health, pest infestations, and growth patterns. Drones like DJI Phantom and SenseFly eBee provide a bird's-eye view of fields. At the same time, IoT-controlled actuators enable responsive actions for sprayers, electric actuators in tractors, and seed drills for precise planting, ensuring maintenance-free operation in demanding environments and economically viable crops.

Cloud Computing in Agriculture: With IoT, cloud computing is pivotal in reshaping agricultural practices. Cloud-based solutions provide a robust infrastructure for storing, processing, and analyzing vast agricultural data that IoT devices collect. Figure. 2 shows the Applications and Benefits of Cloud Computing in Agriculture.

With the help of cloud computing, farmers can store all their data in one place, allowing for better remote monitoring, crop evaluation, and real-time decision-making. It can quickly scale up or down in response to

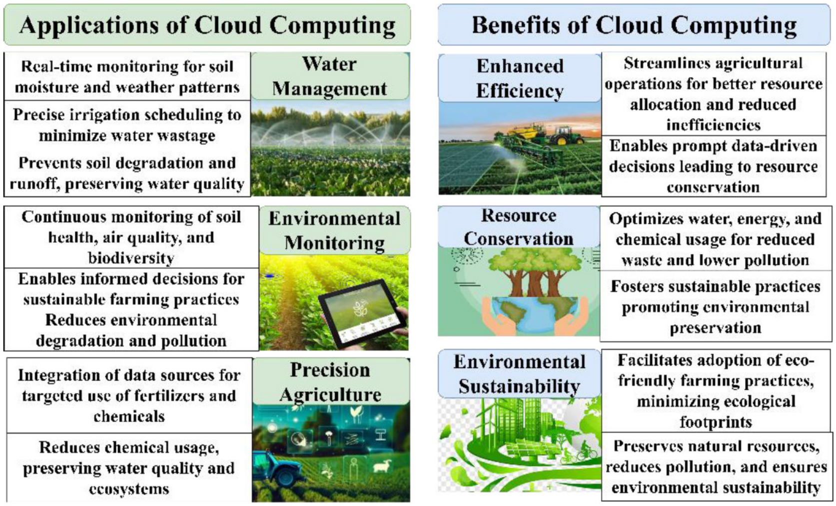

Figure 2

Applications and Benefits of Cloud Computing in Agriculture [2]

technological changes without sacrificing performance. Optimizing agricultural operations is made possible by predictive analytics, precision farming, and informed decision-making, which are made possible by the cloud's capacity to process and analyze agricultural data [2].

2. Proposed Framework

The Smart Agriculture Framework, incorporating a load-balancing algorithm within the IoT layer, is a sophisticated framework designed to revolutionize farming methodologies by enhancing resource allocation and data processing.

Multilayer Framework (IoT, Edge, Cloud, and Network Layers): This framework retains the four-layer framework, encompassing the IoT, Network, and Cloud layers. Within the IoT layer, incorporating the Genetic Algorithm with Improved Round Robin enhances the resource management capabilities of the devices and optimizes data processing. Figure 3 shows the Smart Agriculture Framework.

2.1 *IoT Layer*

(Data Collection, Sensing, Load Balancing, and Importance of Load Balancing in Smart Agriculture): The IoT layer is crucial for smart agriculture, enabling real-time data collection on vital parameters like soil

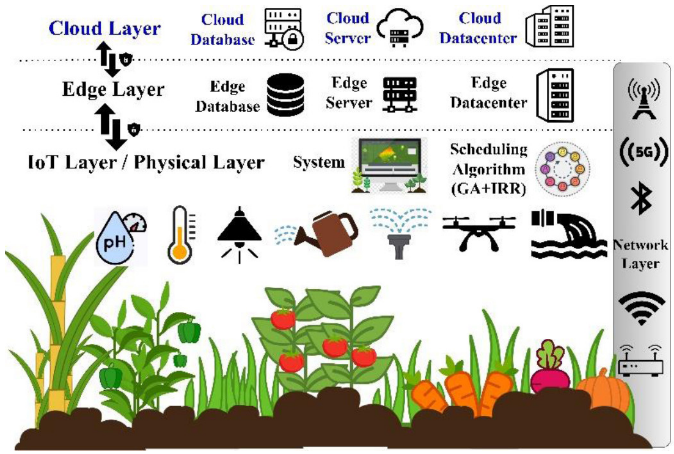

Figure 3

Smart Agriculture Framework [3]

moisture, temperature, humidity, and crop health, enabling informed decision-making. Let S represent the set of IoT devices deployed in the field, N be the number of devices, and D_i represent the data collected by device i at any given time. Thus, D_i is a function of time, t, and can be represented as $D_i(t)$. The collected data includes various sensor readings, denoted by $s_1, s_2, \ldots., s_m$, uch as soil moisture, temperature, etc.

$D_i(t) = \{s_1, s_2, \ldots., s_m\}$. Integrating advanced load-balancing techniques, such as the Genetic Algorithm with Improved Round Robin(GA+IRR), further amplifies its significance within the IoT layer. This algorithm dynamically allocates tasks and resources among IoT devices, ensuring equitable workload distribution and optimized data processing. The

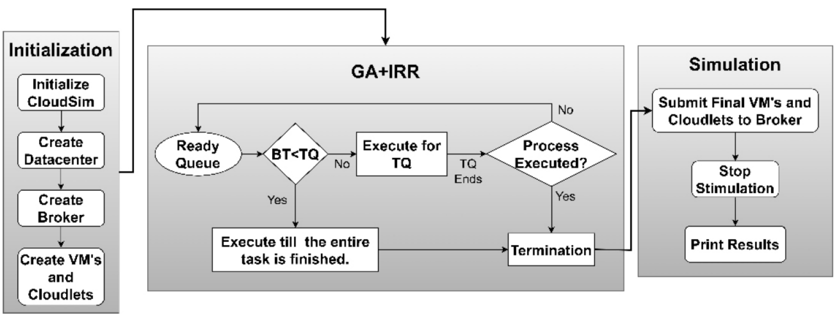

Figure 4

Flowchart of GA+IRR Algorithm

Genetic Algorithm with Improved Round Robin facilitates efficient utilization of computational resources, enhancing the IoT layer's capabilities for swift and effective data processing in smart agriculture scenarios. Figure 4 shows the flowchart of the GA+IRR algorithm.

Existing Load-Balancing Algorithms and Their Role: Load-balancing algorithms, including smart agriculture frameworks, are essential in computing systems. Traditional algorithms like Round Robin(RR), First-Come, First-Served (FCFS), and Shortest Job First (SJF) optimize resource allocation. Round Robin allocates CPU time to each process cyclically, ensuring fair allocation and preventing monopolization. FCFS operates non-preemptively, serving processes in order of arrival, but may lead to inefficient CPU utilization if long processes arrive first. SJF prioritizes processes based on expected execution time, executing the shortest tasks first to minimize waiting and turnaround time. However, it can cause longer processes to starve behind shorter ones, potentially causing them to starve. Overall, load-balancing algorithms are crucial in optimizing resource allocation in computing systems [4].

2.2 *Edge Layer*

(Localized Processing and Decision-Making): The Edge layer between IoT and Cloud is crucial for local data processing and decision-making, using edge computing for faster processing and real-time actionability. This shift offers advantages over traditional centralized models, especially in scenarios requiring rapid response and interactive experiences [5]. Edge computing is particularly useful in smart agriculture for autonomous

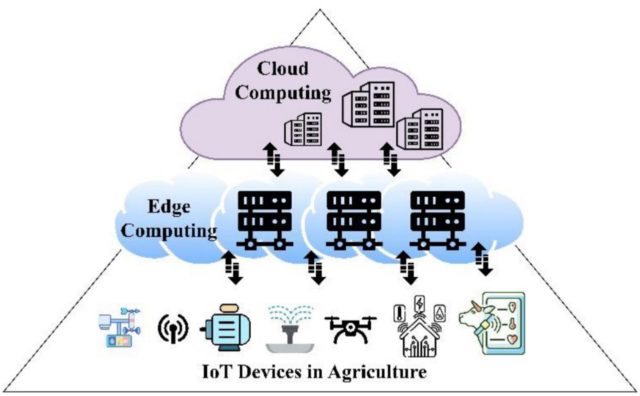

Figure 5

Edge Computing [6]

robots, smart equipment data analysis, and automated real-time decisions. Figure 5 shows the Edge Computing.

Optimization of Data Transmission: The efficiency of the Edge layer in reducing data transmission can be expressed as follows: Let D_{IoT} represent the total data generated by IoT devices in the agricultural field, and D_{Cloud} represent the data transmitted to the Cloud layer without intermediate processing.

The Edge layer's impact on data reduction can be quantified as: Data Reduction Efficiency = $\frac{D_{IoT} - D_{Edge}}{D_{IoT}} \times 100\%$

Where: D_{Edge} is the data transmitted to the Cloud layer after preliminary analytics by the Edge layer. This expression provides a quantitative measure of the Edge layer's effectiveness in reducing data transmission, emphasizing the percentage reduction achieved compared to the total data generated by IoT devices.

Optimizing Latency with Edge Computing: The Edge layer's impact on reducing latency can be expressed as Let L_{IoT} represent the latency experienced in direct data transmission from IoT devices to the Cloud layer, and L_{Edge} represent the reduced latency achieved by processing data locally in the Edge layer. The latency reduction can be expressed as: Latency reduction = $\frac{L_{IoT} - L_{Edge}}{L_{IoT}} \times 100\%$

Where: L_{Edge} is the reduced latency achieved by processing data locally in the Edge layer. This quantitatively assesses the efficiency gains in data transmission reduction and latency optimization achieved by incorporating the Edge layer in the smart agriculture framework.

2.3 *Cloud Layer*

(Centralized Data Storage, Processing, and Advanced Analytics): The Cloud layer is the central hub of the smart agriculture framework, facilitating data management and analytics. It comprises cloud servers, storage facilities, and databases for efficient data storage, processing, and analytics. Its strategic location ensures seamless connectivity with the Edge and Network layers, allowing centralized control and agricultural data analysis from the IoT layer [7]. The Cloud layer's functionality includes centralized data storage, enabling historical analysis and informed decision-making, and extensive data processing using powerful computing resources like AWS EC2 and Google Cloud. It also establishes high-bandwidth connections with the Edge and Network layers, enabling remote access and control.

2.4 *Network Layer*

(Interconnected Communication and Data Exchange): The Network layer in the smart agriculture framework is a crucial communication backbone, ensuring seamless connectivity and efficient data routing between different framework layers. It comprises routers, switches, and gateways and is pivotal in managing data traffic and ensuring reliable information transfer [8]. The layer's functionality includes efficient data routing, network traffic management, and connectivity. Routing Protocols and Network Switches are used to optimize routing for minimal latency and reliable communication. Network Monitoring Tools and Quality of Service Policies are used to prevent bottlenecks and optimize bandwidth utilization.

3. Performance Evaluation of Proposed Framework

The experiment uses Eclipse software and CloudSim libraries to simulate cloud-based environments. The execution time analysis calculates a process's burst time by adding timestamps for calculation and resources required [9]. Different scheduling algorithms are recorded across different CloudLets(CL). Configuration 1 comprises a VM with RAM = 5,120, bandwidth (BW) = 1,000, and a Host with RAM = 102,400 and BW = 100,000. Table 1 and Figure 6 shows the burst time of cloudlets. Configuration 2 comprises a VM with RAM = 92160, bandwidth (BW) = 50,000, and a Host with RAM = 1,02,400 and BW = 1,00,000. Table 2 and Figure 7 shows the burst time of cloudlets.

Table 1

Burst Time of Cloudlets

Scheduling Algorithms	40 Cl	50 CL	60 CL	70 CL
GA+IRR	53.01	71.18	91.59	111.36
SJF	55.33	73.62	93.94	116.09
RR	86.97	97.61	113.72	142.44
FCFS	72.52	104.12	122.59	138.15

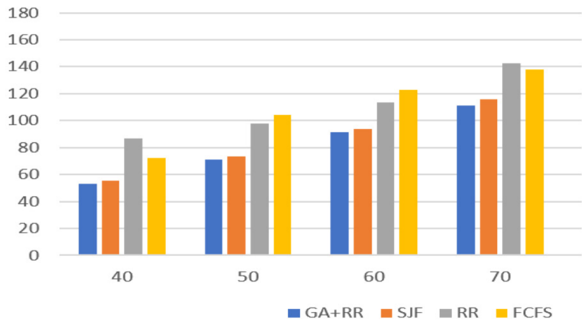

Figure 6

Burst Time of Cloudlets

Table 2

Burst Time of Cloudlets

Scheduling Algorithms	40 CL	50 CL	60 CL	70 CL
GA+IRR	54.83	73.56	94.16	114.03
SJF	55.75	74.6	95.34	118.14
RR	77.10	100.75	128.13	140.33
FCFS	79.94	97.58	121.92	134.23

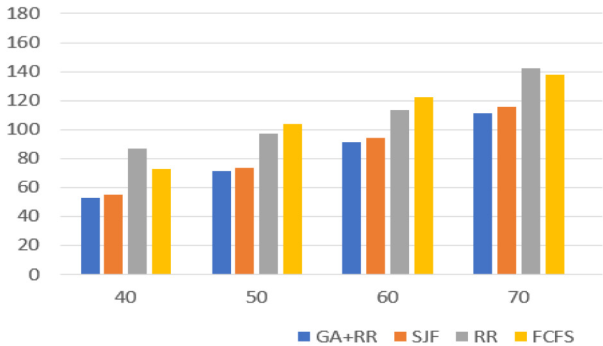

Figure 7

Burst Time of Cloudlets

4. Result and Conclusion

The Cloud-Based Smart Agriculture Framework, a four-layer framework, has revolutionized traditional farming practices by integrating

IoT, Edge, Network, and Cloud layers. It focuses on load-balancing optimization, with GA+ Improved RR algorithms outperforming RR, FCFS, and SJF in execution times under the cloud environment. This results in a more equitable distribution of computational workloads across agricultural IoT devices, enhancing system efficiency and performance. The framework's resource management capabilities are strengthened, leading to optimal resource utilization, reduced wastage, and improved sustainability. The optimization of data processing within IoT devices enables real-time sensor data analysis, providing farmers with timely insights for informed decision-making. This framework is a valuable tool for modern agriculture.

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