

# Energy-Efficient Resource Scheduling Algorithms for Virtualized Cloud Computing Data Centers: Postprint

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## Abstract

To address the issues of long processing time, high energy consumption, and low data transmission accuracy in current cloud computing data center resource scheduling processes, this paper proposes a VR immersive-based energy-efficient scheduling algorithm for virtualized cloud computing data center resources. A resource sampling model for cloud computing data centers is constructed, which integrates Virtual Reality (VR) interactive devices to output, transform, and schedule data center resources, extracts association rule feature quantities of center resources, employs an embedded fuzzy clustering fusion analysis method to three-dimensionally reconstruct center resources, establishes an information fusion center for virtualized cloud computing data center resources, and utilizes a decision correlation analysis method combined with differential fusion feature quantities to achieve data center resource scheduling, thereby realizing real-time energy-efficient scheduling of virtualized cloud computing data center resources. Simulation results demonstrate that the proposed method exhibits high data transmission accuracy, short time overhead, and low energy consumption for virtualized cloud computing data center resource energy-efficient scheduling, and possesses significant application value in center resource scheduling.

## Full Text

### Research on Energy-Efficient Resource Scheduling Algorithms for Virtualized Cloud Computing Data Centers

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## Abstract

To address the problems of time-consuming processes, high energy consumption, and low data transmission accuracy in current cloud computing data center resource scheduling, this paper proposes a VR immersive-based energy-efficient scheduling algorithm for virtualized cloud computing data center resources. The algorithm constructs a resource sampling model for cloud computing data centers, integrates VR (Virtual Reality) interactive devices to output, transform, and schedule center resources, extracts association rule feature quantities of center resources, employs embedded fuzzy clustering fusion analysis methods to three-dimensionally reconstruct center resources, and establishes an information fusion center for virtualized cloud computing data center resources. Using decision correlation analysis methods combined with differentiated fusion feature quantities, the algorithm achieves data center resource scheduling and realizes real-time energy-efficient scheduling for virtualized cloud computing data center resources. Simulation results demonstrate that the proposed method achieves higher data transmission accuracy, shorter time overhead, and lower energy consumption in virtualized cloud computing data center resource scheduling, offering significant application value in center resource scheduling.

**Keywords:** virtualization; cloud computing; data center resources; VR immersion

## 0 Introduction

Cloud computing data originates from diverse sensors, controllers, and computing terminals without a fixed architectural plan, making data center resource scheduling a critical challenge for cloud computing services. VR technology utilizes computers and advanced sensor technologies to simulate a three-dimensional virtual space, providing users with immersive experiences and creating a novel human-computer interaction paradigm [?]. Currently, VR technology is widely applied across numerous research domains, including medicine and mechanical engineering [?]. To enhance center resource scheduling capabilities, resource scheduling must be performed within a virtualized visual simulation model, establishing a three-dimensional data reconstruction model for energy-efficient scheduling of virtualized cloud computing data center resources. Consequently, research on energy-efficient scheduling algorithms for virtualized cloud computing data center resources has attracted considerable attention.

Several scholars have investigated energy-efficient scheduling for virtualized cloud computing data center resources. Reference [?] proposed a task scheduling algorithm based on the Multi-Scale Quantum Harmonic Oscillator Algorithm (MQHOA), which employs Gaussian sampling characteristics to treat scheduling solutions as sampling positions for finding partial optimal solutions and determines whether the algorithm can maintain a stable energy state. If stable, the energy value decreases and replaces the worst scheduling solution. During scale reduction, the algorithm transitions from global to

partial search, repeating this feedback process multiple times until termination yields the optimal solution. While this algorithm converges rapidly and reduces total task completion time, its scheduling energy consumption remains high.

Reference [?] introduced a virtual machine scheduling algorithm for balanced resource utilization in cloud data centers, employing an adaptive particle swarm optimization algorithm to construct a virtual machine scheduling model that frames the scheduling problem as a multi-dimensional vector, where each dimension represents a resource category, thereby completing cloud data center resource virtual machine scheduling. This method balances resource utilization and reduces data transmission energy consumption but suffers from low data transmission accuracy and poor scheduling real-time performance.

Reference [?] proposed energy-aware resource allocation for cloud computing data centers, utilizing different energy-aware resource allocation selection algorithms for virtual machines in cloud computing data and designing energy-conscious resource allocation techniques for cloud environments. This approach reduces operational costs for hardware, software, and maintenance but faces negative environmental impacts due to increased power consumption from large-scale data centers.

Reference [?] presented a bi-objective decision support system for task scheduling in cloud computing based on genetic algorithms, using genetic methods to model task planning problems in cloud computing and designing a core decision support system based on the time required to execute a set of tasks. This method reduces processing costs and scheduling time but exhibits low data transmission accuracy.

Reference [?] proposed a fault-tolerance-aware scheduling method for agents in cloud computing data centers, which records event locations through clustering, sets ranges for CPU, memory, and bandwidth, and employs fault tracking methods to check violations by comparing request data with cluster data, thereby completing scheduling requests. This method reduces execution time and improves performance but suffers from low accuracy in cluster data transmission.

Reference [?] introduced joint energy scheduling for geo-distributed mixed-use buildings, employing coordination methods between data center and non-data center loads in buildings and scheduling workloads by coupling edge data centers arranged in buildings to schedule the entire system across the time horizon. This method maximizes system cost reduction from load reduction and addresses the problem of time-consuming resource scheduling processes.

Reference [?] proposed a Dynamic Load Balancing Scheduling (DLBS) method for cloud computing data, constructing an OpenFlow network model based on DLBS problems and developing an effective heuristic scheduling algorithm to balance data flows in each time slot. This method achieves high data transmission accuracy in balanced scheduling but suffers from long scheduling times and poor real-time performance.

To address these issues, this paper proposes a VR immersive-based energy-efficient scheduling algorithm for virtualized cloud computing data center resources. The algorithm constructs a model for center resource scheduling data, establishes an information fusion center for virtualized cloud computing data center resources, employs multi-scale feature decomposition methods for feature decomposition and statistical analysis of virtualized cloud computing data center resources, combines statistical feature quantities to achieve data center resource scheduling, and guides center resource scheduling based on scheduling results to enhance real-time scheduling capabilities for carrying center resources. Simulation and analysis demonstrate that the proposed method achieves high data transmission accuracy, short resource scheduling process time, and good energy efficiency in virtualized cloud computing data center resource scheduling.

## 1.1 Cloud Computing Center Resource Data Sampling Model

To achieve energy-efficient scheduling of virtualized cloud computing data center resources, a cloud computing center resource data sampling model must first be constructed. Selecting the minimum embedding dimension and optimal time delay, the cloud computing center resource data features are reconstructed to establish a phase space reconstruction model for cloud computing center resource data. Using a link random allocation model for entity dataset analysis of virtualized cloud computing data center resources and combining real-time transmission scheduling methods [?], cloud computing center resource data is scheduled in real-time, yielding the virtual resource information flow model for center resource scheduling as:

$$x_0(t) = \sum_{n=1}^N [q(t) + \Delta t] \cdot h_n(t) \cdot \omega + \Delta t + x_0(t) \cdot \Delta t$$

where  $x_0(t)$  represents center resource reconstruction data,  $t_0$  and  $\Delta t$  represent reconstruction initial time and total time consumption respectively,  $h_n(\omega)$  is the multivariate quantitative value function of virtualized cloud computing data center resource flow, and  $\omega$  is the adaptive weighting coefficient.

Using real-time collection methods to schedule virtualized cloud computing data center resources, the collected cloud computing data center resource information flow serves as the initial sample sequence. VR virtual reality interactive devices input the center resource scheduling virtual resource information flow model into the host system for operation, with built-in sensors matching center resource information flow in the VR virtual reality interactive device and inputting the center resource multivariate quantitative value function to convert it into center resource information flow reconstruction data. Combining real-time resource information analysis methods, cloud computing data center resource information flow reconstruction is performed to obtain the finite dataset of virtual cloud computing data center resource information flow as:

$$Y = \frac{1}{K} \sum_{i=1}^N (\Gamma_i + x_i) \cdot T_h$$

Using spatial motion capture methods, the distribution of resource information flow transmission characteristic quantities in cloud computing data centers is obtained as  $C_f$ . In high-dimensional evolution models, the high-dimensional mapping vector of cloud computing data center resource information flow is  $Y_k$ . Employing VR immersive virtual reality technology, the data center resource information transmission time is  $t$ , with its peak parameter model being:

$$Q_{Rate} = \frac{s(t) - e(t)}{l(t)} = \sum_{n=1}^N [a(t) \cdot l(t) \cdot s(t) \cdot e(t)] \cdot \pi \cdot \tau$$

where  $X_f$  is the orthogonal characteristic vector of real-time information distribution for virtualized cloud computing data center resources,  $\tau$  is the sampling time delay for virtualized cloud computing data center resources, thereby constructing the virtualized cloud computing data center resource sampling model as:

$$W(k) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} X(v) \cdot R_y(k) \cdot \theta(k) \cdot \varphi(k) dv$$

where  $f_0$  is the normalized initial frequency and  $C$  is the normalized correlation coefficient of real-time traffic for virtualized cloud computing data center resources. Using nonlinear feature decomposition methods for information collection and feature reorganization of virtualized cloud computing data center resources, real-time information collection of virtualized cloud computing data center resources is performed. Based on the above analysis, the center resource scheduling cloud computing center resource data sampling model has been constructed, and cloud computing center resource output conversion scheduling is performed according to sampling results.

## 1.2 Cloud Computing Center Resource Output Conversion Scheduling

Combining VR virtual reality interactive devices for output conversion scheduling of virtualized cloud computing data center resources, association rule characteristic quantities of cloud computing data center resources are extracted. Using time-frequency joint feature analysis methods, the output conversion scheduling model for virtualized cloud computing data center resources is constructed, yielding the output characteristic quantity description as:

$$R(k) = \sum_{n=1}^N [y_n(k) \cdot \theta(k)] \cdot \varphi(k)$$

where  $H$  is the global matching function,  $y_n(k)$  is the center resource scheduling resource output information flow on the  $n$ -th transmission channel,  $f$  is the frequency characteristic quantity, and  $t$  is the scheduling time.

The output response of virtualized cloud computing data center resources can be described as:

$$E(t) = H \cdot A(t) + W \cdot a(t) + B(t)$$

where  $\tau_n$  is the time delay on the  $n$ -th transmission channel and  $f_c$  is the modulation frequency. Using spectrum adaptive scheduling methods for spectral feature extraction of virtualized cloud computing data center resources, the feature extraction result is:

$$p(t) = \sum_{n=1}^N a(t) \cdot c_n(t) \cdot \pi \cdot \tau$$

where  $W(t)$  is the short-time window function for virtualized cloud computing data center resource transmission. Through spectral feature results, output conversion scheduling of virtualized cloud computing data center resources is performed to enhance energy-efficient scheduling capabilities [?, ?].

## 2.1 Three-Dimensional Reconstruction of Cloud Computing Data Center Resources

Building upon the completion of output conversion scheduling for virtualized cloud computing data center resources, the center resource energy-efficient scheduling algorithm is further optimized. Using embedded fuzzy clustering fusion analysis methods for three-dimensional reconstruction of cloud computing data center resources, the iterative formula for matched filtering scheduling of cloud computing data center resources is:

$$x_{p+1}(v_t) = v_t \cdot Y_u \cdot \beta + p(t) + v_0(t)$$

where  $x_{p+1}(v_t)$  is the resource information obtained after filtering iteration,  $v_t$  is the matching resource information, and  $p(t)$  is the filtered resource information. Combining real-time feature sequence distributed scheduling methods, cloud computing data center resource scheduling and output scheduling are performed. Using spectrum adaptive scheduling methods for spectral analysis of data center resources [?, ?, ?], the output spectral characteristic quantity of

virtualized cloud computing data center resources is obtained as  $D_i$ . Then, employing fuzzy association rule scheduling methods, virtualized cloud computing data center resource optimization scheduling is performed, yielding the resource transmission optimization scheduling set as:

$$J_{std} = \sum_{i=1}^m \sum_{k=1}^K d_{ik}^2$$

where  $a$  is the oscillation amplitude of virtualized cloud computing data center resource information and  $c_f$  is the fuzzy association rule coefficient. Using empirical mode decomposition methods, the VR reconstruction output of virtualized cloud computing data center resources is:

$$x_i(v_t) = \sum_{n=1}^N [s_n(t) \cdot p(t)] \cdot \Delta s + v_i$$

where  $x_i(v_t)$  represents the cross-correlation function of output virtualized cloud computing data center resources,  $n_i(t)$  is the non-Gaussian colored noise term,  $c_n$  is the mode decomposition coefficient, and  $v_i$  is the white noise term of virtualized cloud computing data center resources. Based on VR reconstruction processing, data center resource spectral characteristic quantities are obtained for real-time monitoring of virtualized cloud computing data center resources [?, ?]. Using  $D_i$  to represent the association rule term of virtualized cloud computing data center resources, optimization scheduling and mining of virtualized cloud computing data center resources are performed based on the above analysis, yielding the priority clustering model for virtualized cloud computing data center resource sharing scheduling as:

$$V_{DD}^+ = V_{DD} + D_i^+ - D_i^-$$

where  $D_i^+$  represents the positive association term and  $D_i^-$  is the negative association term. In summary, an adaptive fusion clustering processing model for virtualized cloud computing data center resources is constructed to perform energy-efficient scheduling of virtualized cloud computing data center resources [?, ?, ?].

## 2.2 Cloud Computing Data Center Resource Energy-Efficient Scheduling Algorithm

Through the above analysis, decision correlation analysis methods are employed, combined with differentiated fusion feature quantities, to implement the cloud computing data center resource energy-efficient scheduling algorithm as follows:

**Input:** Based on the priority clustering model for virtualized cloud computing data center resource sharing scheduling, using VR immersive expression

methods, input the fuzzy index set of virtualized cloud computing data center resources.

**Output:** Virtualized cloud computing data center resources.

- a) Employ decision correlation analysis methods to construct an intelligent sharing fusion model for virtualized cloud computing data center resource information.
- b) Using multivariate regression analysis methods, obtain the intelligent sharing calculation formula for virtualized cloud computing data center resources as:

$$U_i(z_t) = \exp \left[ - \left( \frac{z_t - V_i}{\sigma_i} \right)^2 \right]$$

where  $\lambda_i$  is the statistical analysis eigenvalue of correlation, yielding the similarity of virtualized cloud computing data center resource sharing as:

$$S_{i,j}(p_t) = \frac{p(t) \cdot s_i(t) - p(t) \cdot \Delta s_{i,j}(p_t)}{p(t) \cdot s_i(t)}$$

- c) Data Transmission Bit Error Rate (BER): In virtualized cloud computing data center resource scheduling data transmission, BER is the metric for measuring data transmission accuracy, calculated as:

$$BER = \frac{C_Q}{Z_Q} \times 100\%$$

where  $C_Q$  represents the amount of erroneous data in virtualized cloud computing data center resource scheduling data transmission and  $Z_Q$  represents the total amount of data in virtualized cloud computing center resource scheduling.

- d) Signal-to-Noise Ratio (SNR): The ratio of useful signal power to noise power, calculated as:

$$SNR = \frac{P_{signal}}{P_{noise}} = \left( \frac{A_{signal}}{A_{noise}} \right)^2$$

where  $\rho$  is the correlation coefficient of virtualized cloud computing data center resources,  $F_K$  is the fuzzy correlation feature distribution set of virtualized cloud computing data center resource sharing,  $A_{signal}$  represents signal amplitude,  $A_{noise}$  represents noise amplitude,  $P_{signal}$  represents signal power, and  $P_{noise}$  represents noise power.

- e) Perform fuzzy correlation feature analysis of virtualized cloud computing data center resource sharing within the range [0,1] to obtain the differentiated fusion quantity of virtualized cloud computing data center resource sharing:

$$W_E = F_E + K_E$$

where  $m$  is the finite dataset of virtualized cloud computing data center resource distribution and  $F_W$  is the similarity distribution mapping.

- f) Consequently, the decision-dependent variable of virtualized cloud computing data center resources is obtained as:

$$z = f(x_1, x_2, \dots, x_m) + \epsilon$$

where  $b$  is the data intercept of virtualized cloud computing center resources.

If the deterministic relationship is not satisfied, set  $z \leftarrow z + \Delta z$  and return to step (1) until the functional relationship is satisfied.

- g) End.

In summary, real-time energy-efficient scheduling of virtualized cloud computing data center resources is achieved.

### 3 Experimental Analysis

To verify the application performance of the proposed method in virtualized cloud computing data center resource energy-efficient scheduling, simulation experiments were conducted. The experiments utilized the CloudSim cloud simulation platform combined with Visual C++ simulation tools, applying the scheduling model to center resource scheduling and practical operation simulation, and integrating VR virtual reality technology for virtualized cloud computing data center resource energy-efficient scheduling.

#### 3.1 Experimental Environment and Dataset

The experiments employed data from the Redis dataset (<https://github.com/microsoft/archive/redis/releases>). In the CloudSim platform, the simulation configured 500 computer cloud computing center resource data totaling 200GB, 6000 bytes. The sampling time length for virtualized cloud computing data center resources was 120s, with a frequency of 120 KHz and a carrier frequency of 24 KHz. A 250 Hz frequency component was set for carrier modulation between sampling points 400-600, yielding the virtualized cloud computing data center resource information sampling results shown in [Figure 1: see original paper].

#### Experimental Metrics:

- c) Total Resource Scheduling Power: Primarily refers to the sum of energy consumption from increased data load length after resource scheduling and energy consumption during data no-load operation. Smaller total power indicates lower algorithm energy consumption, calculated as:

$$P_{total} = P_{load} + P_{idle}$$

where  $P_{load}$  represents energy consumption from increased data load length after resource scheduling and  $P_{idle}$  represents energy consumption during data no-load operation.

- d) Resource Scheduling Time: Using resource scheduling time consumption as a metric, the proposed method is compared with references [?], [?], and [?] to verify performance.

### 3.3 Experimental Results

Based on the resource data obtained from the virtualized cloud computing data center resource information sampling results, data transmission bit error rate was used as the test metric to evaluate the data transmission accuracy of the proposed method for cloud computing data center resource scheduling. Using reference [?], reference [?], reference [?] methods, and the proposed method for virtualized cloud computing data center resource energy-efficient scheduling, the comparison results of bit error rates after scheduling are shown in [Figure 2: see original paper].

According to [Figure 2: see original paper], the data transmission bit error rate after scheduling using reference [?] method averages  $10^{-2.5}$ , reference [?] method averages  $10^{-2.2}$ , reference [?] method averages  $10^{-2.4}$ , while the proposed VR immersive virtual reality technology-based cloud computing data center resource energy-efficient scheduling achieves a bit error rate of  $10^{-4.5}$ , significantly lower than comparison methods. This demonstrates that the proposed method achieves higher data transmission accuracy.

**Signal-to-Noise Ratio (SNR):** The ratio of useful signal power to noise power, calculated using equation (23) input into simulation software. Under identical unit time, the SNR of resource scheduling data for reference [?], reference [?], reference [?] methods, and the proposed method were obtained, with results shown in [Figure 3: see original paper].

According to [Figure 3: see original paper], at a data load length of 2000 bytes, the proposed method achieves a resource scheduling data SNR of 43 dB, compared to 14 dB for reference [?], 26 dB for reference [?], and 23 dB for reference [?]. At 4000 bytes, the proposed method achieves 46 dB, compared to 19 dB, 30 dB, and 26 dB respectively. At 6000 bytes, the proposed method achieves 48 dB, compared to 21 dB, 33 dB, and 30 dB respectively. Evidently, the proposed method achieves the highest SNR with minimal noise interference.

To further verify the energy efficiency of the scheduling method, the network efficiency of three methods was tested, with results shown in [Figure 4: see original paper].

According to [Figure 4: see original paper], the total power for virtualized cloud computing data center resource scheduling is 6900 KW using reference [?] method, 7100 KW using reference [?] method, 6000 KW using reference [?] method, and only 2300 KW using the proposed method. This demonstrates that the proposed method achieves the lowest total power, indicating lower energy consumption and enabling energy-efficient scheduling of center resources. The algorithm can be applied in center resource scheduling to improve resource scheduling capabilities.

Analysis of scheduling time consumption is shown in [Figure 5: see original paper]. At a data load length of 2000 bytes, the proposed method consumes 14 seconds, compared to 27 seconds for reference [?], 20 seconds for reference [?], and 24 seconds for reference [?]. At 4000 bytes, the proposed method consumes 15 seconds, compared to 40 seconds, 31 seconds, and 35 seconds respectively. At 6000 bytes, the proposed method consumes 18 seconds, compared to 48 seconds, 42 seconds, and 45 seconds respectively. Traditional methods suffer from noise interference that prevents accurate identification of association rules between data. When algorithm execution instructions encounter obstacles, the algorithm automatically returns to the data collection module to recalculate association rules between data, repeatedly computing until proceeding to the next step, which significantly increases scheduling time. The proposed method combines VR virtual reality interactive device output, conversion, and scheduling of center resources to accurately complete extraction of center resource association rule feature quantities. Consequently, the proposed method achieves the shortest scheduling time, fulfilling the objective of energy-efficient scheduling for virtualized cloud computing data center resources.

## 4 Conclusion

To address the issues of time-consuming processes, high energy consumption, and low data transmission accuracy in cloud computing data center resource scheduling, this paper proposes a VR immersive virtual reality technology-based design for virtualized cloud computing data center resource energy-efficient scheduling. By constructing a cloud computing data center resource sampling model, combining VR virtual reality interactive devices for output conversion scheduling of virtualized cloud computing data center resources, employing embedded fuzzy clustering fusion analysis methods for three-dimensional reconstruction of center resources, and utilizing decision correlation analysis methods combined with differentiated fusion feature quantities to achieve data center resource scheduling, the algorithm realizes real-time energy-efficient scheduling of virtualized cloud computing data center resources. Simulation experiments demonstrate that the proposed method achieves high data transmission accuracy, short resource scheduling process time, and good energy efficiency in vir-

tualized cloud computing data center resource scheduling, offering significant application value in center resource scheduling. However, this research has limitations regarding algorithm performance, as it is only applicable in simulated environments. The effectiveness of the algorithm in real-world environments requires further investigation.

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