documentclassarticle
usepackageamsmath
usepackagealgorithm
usepackagealgpseudocode
usepackagegraphicx

begindocument

titleQuantum-Inspired Swarm Intelligence for Dynamic Resource Allocation in Edge Computing Environments
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maketitle

sectionIntroduction Edge computing has emerged as a critical paradigm for supporting latency-sensitive applications and reducing bandwidth consumption in distributed systems. However, the dynamic nature of edge environments, characterized by fluctuating resource demands and heterogeneous computing nodes, presents significant challenges for efficient resource allocation. Traditional optimization approaches often struggle with the combinatorial complexity and real-time requirements of these systems.

This paper introduces a fundamentally new approach that bridges quantum computing principles with swarm intelligence to address these challenges. Our Quantum-Inspired Swarm Optimization (QISO) framework represents a departure from conventional methods by incorporating quantum mechanical concepts into the optimization process. The novelty of our work lies in three key aspects: (1) the application of quantum superposition to maintain multiple potential solutions simultaneously, (2) the use of quantum entanglement to model complex relationships between resources, and (3) the integration of quantum rotation gates for dynamic solution space exploration.

sectionMethodology

subsectionQuantum-Inspired Representation Traditional particle swarm optimization uses real-valued vectors to represent solutions. Our approach employs quantum bits (qubits) as the fundamental representation unit. A qubit can exist in a superposition of states, represented as:

beginequation |
psi
rangle =
alpha|0
rangle +
beta|1
rangle
endequation

where |
$alpha|^2 + |$
$beta|^2 = 1$. This allows each quantum-inspired particle to represent multiple potential resource allocation configurations simultaneously.

subsectionQuantum-Inspired Swarm Optimization Algorithm

The QISO algorithm extends classical PSO through several quantum-inspired mechanisms:

beginalgorithm
captionQuantum-Inspired Swarm Optimization
beginalgorithmic[1]
State Initialize quantum swarm with N particles
State Initialize quantum positions Q_i and velocities V_i
State Initialize personal best positions P_i
State Initialize global best position G
Whilenot converged
Foreach particle i
State Apply quantum rotation gate to update position
State Measure quantum state to obtain classical solution
State Evaluate fitness of measured solution
State Update personal best P_i if improved
State Update global best G if improved
State Apply quantum entanglement between neighboring particles
EndFor
State Update quantum velocities using quantum interference
EndWhile

endalgorithmic
endalgorithm

subsectionQuantum Rotation Gate Update

The position update mechanism uses quantum rotation gates to explore the solution space:

beginequation
beginbmatrix
alpha_i^t+1

beta_i^t+1
endbmatrix =
beginbmatrix
cos(
theta_i) & -
sin(
theta_i)

sin(
theta_i) &
cos(
theta_i)
endbmatrix
beginbmatrix
alpha_i^t

beta_i^t
endbmatrix
endequation

where
$theta_i$ is determined by the difference between current position and the global best position.

subsectionExperimental Setup We evaluated our approach using a simulated edge computing environment with 50-200 heterogeneous nodes and dynamic workload patterns. The simulation incorporated real-world traffic traces and resource utilization patterns from IoT deployments. Comparative analysis was performed against classical PSO, genetic algorithms, and reinforcement learning approaches.

sectionResults

Our experimental results demonstrate significant improvements in both convergence speed and solution quality. The QISO algorithm achieved:

beginitemize
item 37
item 42
item 28
item Enhanced adaptability to sudden workload changes
enditemize

beginfigure[h]
centering
includegraphics[width=0.8
textwidth]convergence_comparison.png
captionConvergence comparison between QISO and traditional methods
labelfig:convergence
endfigure

beginfigure[h]
centering
includegraphics[width=0.8
textwidth]resource_utilization.png
captionResource utilization efficiency across different algorithms
labelfig:utilization
endfigure

The quantum-inspired approach particularly excelled in scenarios with high dynamism and complex constraint relationships, where traditional methods often became trapped in local optima.

sectionConclusion

This paper has presented a novel quantum-inspired swarm intelligence framework for dynamic resource allocation in edge computing environments. Our approach represents a significant departure from conventional optimization techniques by incorporating quantum computing principles into swarm intelligence algorithms. The key contributions of this work include:

1. A quantum-inspired representation that enables simultaneous exploration of multiple solution possibilities 2. A quantum rotation gate mechanism for dynamic solution space navigation 3. An entanglement-based coordination mechanism for modeling complex resource relationships 4. Empirical demonstration of superior performance in dynamic edge computing scenarios

The QISO framework opens new possibilities for addressing complex optimization problems in distributed systems and demonstrates the potential of cross-pollination between quantum computing and computational intelligence. Future work will focus on extending these principles to other domains and exploring hardware implementations of quantum-inspired optimization.

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