A Quantum Optimization Model for Dynamic Resource Allocation in Networks

Yu QingPing[1], You XiaoMing*[2] and Liu Sheng[3]

[1] **College of Electronic and Electrical Engineering, Shanghai University of Engineering Science, Shanghai, 200620, China**
sd2008yuqingping@163.com

[2] **College of Electronic and Electrical Engineering, Shanghai University of Engineering Science, Shanghai, 200620, China**
yxm6301@163.com

[3] **College of Electronic and Electrical Engineering, Shanghai University of Engineering Science, Shanghai, 200620, China**

Abstract

Dynamic resource allocation optimization model will be required to be perfect, and swarm intelligence processing model of dealing with dynamic resource allocation optimization problem is proposed in this paper. By establishing a mathematical model of quantum game theory a game theory based on the price mechanism is explored. Further, through finding the group behavior in swarm intelligence prototype and the inherent mechanisms of self-organization and cooperative behavior, we research the autonomy, equilibrium and stability of the model. Finally, we define the demand deviation function for an application of bandwidth assignment in broad networks and use a bigger demand satisfaction and smaller demand deviation optimization goal to verify the model performance. The results have shown that the model of game strategy based on the price mechanism is effective and feasible. It not only satisfies more benefits of both supply and demand, but also improves the utilization of resources.

Keywords: *Quantum model, swarm intelligence optimization model, dynamic resource allocation, game strategy.*

1. Introduction

Distributed problem solving in complex environments becomes increasingly complex, and systems with nonlinear, chaotic or uncertain dynamic behavior are making the requirements of model establishment higher and higher, so traditional theories and methods face serious challenges.

The basic question in distributed problem solving is how to optimize resource allocation [1], for example, with the expansion of network scale in the cloud computing model, network traffic is growing exponentially, and network resources are still far from being able to meet the user needs, therefore, the real-time dynamic optimization of network resources and network bandwidth allocation is an important way to improve the quality of service.

The complex, heterogeneous and diverse business needs of current network resources result in increased complexity of network resource management, thereby increasing the difficulty of dynamic network resource allocation mechanism and algorithm research. Compared with the previous resource allocation model, resource allocation model based on auction mechanism has obvious advantages. However, most current resource auction strategy with some limitations is a direct use of existing auction theory in economics [2-3], maximizing the economic benefits of buyers and sellers and neglecting the resource utilization, resource performance, customer satisfaction and other indicators. Literature [4] proposes an adaptive resource allocation mechanism on the cloud computing environment based two-way auction, improving user satisfaction and resource utilization of cloud computing systems, meanwhile the economic benefits have been accounted, but it still cannot reflect the changes of dynamic resource requirements of different applications [6-7]. The traditional heuristic method [5] is only for honest individuals between simple social interactions (cooperation and competition), when there is trap or fraud among individuals, it is impossible to properly express the individual stakeholders, so it is difficult to describe the real world. Simultaneously, dynamic changes of the network, intermittent network congestion, metabolism and random failures are difficult to express and describe, as a result, a new dynamic resource allocation optimization model will emerge urgently.

Quantum game theory is a branch of quantum information science [8], it expands the set of the original classic game strategy and introduces entanglement, so to seek the strategy to meet the conditions is becoming easier with expanding the strategy set; While the introduction of entanglement amends to some extent that the individual is rational, which is the basic classical assumption. In [6], we have proposed a mathematical model of the game quantum-field for network resource allocation and its convergence is proved. This article, continuing to draw on quantum field theory, proposes a swarm intelligent processing model to deal with dynamic resource allocation and explore the performance of the model.

The main contents are summarized as follows: 1)To investigate the theories and methods of swarm intelligence processing model, moreover, the autonomy, equilibrium and stability of swarm intelligence model is studied further via the game theory based on price mechanism; 2)Demand satisfaction and demand deviation is defined through the application examples of problems in the broadband network bandwidth allocation. By using optimization goal of a bigger demand satisfaction and a smaller demand deviation the model performance is verified.

This paper is organized as follows: Section 2 describes in detail the swarm intelligence processing model ; Section 3 focuses on the analysis of the swarm behavior mechanism based on evolutionary game theory, and mapped it into the evolutionary mechanism of swarm intelligence model, thereby exploring the autonomy, equilibrium state and stability of the model; Section 4 analyzes the dynamic network resource allocation optimization model based on the price mechanism and discusses its performance by the simulation. Section 5 to have a conclusion of the model proposed in this paper and present the open questions.

2. A swarm intelligence processing model

With the development of parallel computing, distributed computing and grid computing, cloud computing has become a hot topic, which usually deal with cooperation, competition and a few simple social behavior in the current theoretical research of distributed parallel processing. Therefore, cloud computing cannot handle changes of the dynamic environment [1] in the process of solving practical problems. In [6], we have proposed a mathematical model of game quantum-field for network resource allocation, it can effectively portray interactions between entities in the complex network, and be able to describe the game strategies and autonomous behaviors of the entities for their own benefits. In this paper, we continue to explore the dynamic resource allocation optimization model based on price mechanism game theory , and explore a reasonable allocation of network resources in real-time for different applications and different requirements on the network quality of service, providing novel model, theory and method for cloud computing theory.

Assuming in period τ , there is a task set $G(\tau)=\{G_1,G_2,...G_m\}$ and Agent set $A(\tau)=\{A_1,A_2,...A_n\}$. At time t, Agent A_i assigns resources $a_{ij}(t)$ to the task G_j , and at the same time task G_j pays to Agent A_i remuneration $p_{ij}(t)$ of unit resources. Because there are social coordination behaviors between Agent A_i and task G_j at time t and their intent strength is $\zeta_{ij}(t)$,we can design a resource assignment matrix $S(t)=[S_{ij}(t)]$, where $S_{ij}(t)=\{a_{ij}(t),p_{ij}(t),\zeta_{ij}(t)\}$; and at time t in period τ , we design a two-dimensional table $\Pi(t,\tau)$ to describe the social situation in MAS and use three correlation matrices $D(\tau),H(\tau),H^{'}(\tau)$ to represent the interdependence among tasks, the social interaction behavior among Agent and the resource allocation of Agent for tasks. Three correlation matrices $D(\tau),H(\tau),H^{'}(\tau)$ will change dynamically with period τ , and in the given period τ , the resource assignment matrix $S(t)$ will also change dynamically with time t.

Further, let f_i,f_j denote individual utility functions of particles P_i,P_j , J_p denote global utility function of gravitational field, E_g denote potential energy function of gravitational field, and $E_{ij}^{i}(f_i,f_j)$, $E_{ij}^{j}(f_i,f_j)$ be interaction potential energy functions between two particles. Assume that mixing energy function of individual P_i is Γ_i^j which can be described as $\Gamma_i^j(t)=\lambda_1 f_i+\lambda_2 J_p+\lambda_3 E_g+\lambda_4 E_{i,j},-1\le\lambda_1,\lambda_2,\lambda_3,\lambda_4\le 1$, where coefficients $\lambda_1,\lambda_2,\lambda_3,\lambda_4$ are determined by priority ,personality, autonomy, interaction strength and so on of individuals on different target. These coefficients corresponding to different individuals will be different, so as to indicate autonomous of individual. By analyzing and solving kinetic equation of the established model which should minimize mixing energy function Γ_i^j , and we discuss performance of the model.

3. Swarm intelligence optimization model and its performance

A evolutionary model of quantum behavior has been established through the study of quantum mechanical system and distributed parallel evolutionary model [6]. For thoose state parameters of speed, acceleration, momentum, kinetic and potential energy and so on in the evolutionary model, we design the evolutionary model with the self-activity(autonomy) same as neuron and map it into dynamic state. The degree of activity (dynamic state) is the piecewise linear function of the incentive degree affected, to ensurse the quantum dynamic state achieves a stable equilibrium point. In quantum field, particle based on corresponding rules (game strategy) changes their states of kinematics and dynamics until it reaches kinematics equilibrium, thereby researching the autonomy, equilibrium and stability of the model.

① The study of swarm dynamics mechanism in quantum field mainly includes the research of stable equilibrium point on autonomous behavior and dynamics state of particles. The composition of forces in quantum field includes the interaction between the particles, gravitation in gravitational field and autonomous driving force of particles. In addition to such state parameters of speed, acceleration, momentum, kinetic and potential energy and so on in the evolutionary model, we design the evolutionary model with the activity same as neuronal or chemical elements (autonomy) and map it into dynamic state. The degree of activity (dynamic state) is the piecewise linear function of the incentive degree affected, and the incentive degree is concerned with such factors as individual optimization goals, metabolic factors, priority, failure factors and so on, it is also an important factor to ensure that the dynamics state of particles can achieve a stable equilibrium state.

②Research on the swarm behavior mechanism based on quantum game theory includes equilibrium and stable strategy of evolutionary, using the methods of replication dynamic analysis discusses various replication dynamics equations and fixed point , thereby describing the change trends and predicting the swarm behavior of individuals by replication dynamic. In order to explore further the dynamical mechanism of quantum game theory, we describe the evolutionary mechanism of swarm behavior from the perspective of dynamics, and map it into evolutionary dynamics mechanism of swarm intelligence model.

③ Study on self-organizing behavior and cooperation mechanisms in swarm intelligence includes describing the game strategy and autonomous behavior of each particle under dynamic changes. We study the relational model of the degree of entanglement and evolutionary stable strategy, in order to explore the mechanism of promoting cooperation in quantum game theory, thereby illustrating the self-organizing behavior and swarm cooperation mechanisms in swarm intelligence.

Quantum entanglement property includes that the separation and entangled into each other, using Hadamard transform represents the processing of entanglement as follows:

$$|\varphi\rangle = U_{cn}U_H|0\rangle\otimes|0\rangle = U_{cn}(\frac{1}{\sqrt{2}}(|0\rangle+|1\rangle)|0\rangle) = \frac{1}{\sqrt{2}}(|00\rangle+|11\rangle)$$

and U_H is a Hadamard gate, U_{cn} is a NOT gate.

4. Dynamic Optimization of Resource Allocation and Its Application

There is a comprehensive analysis of allocation optimization problems of broadband network bandwidth resource, namely, wide distribution of multiple local networks need connecting via a semi-permanent virtual channel with a certain bandwidth. Virtual channel between two network nodes may contain multiple virtual paths, and a virtual path consists of multiple links cascaded together, there is competition, cooperation and interaction between some links and virtual path, finally, we establish the evolutionary model of quantum game. By establishing and solving various dynamic equations, game strategy of the model and its performance is validated.

Entity set $E=\{E_1,E_2,...,E_n\}$ and demand set $D=\{D_1,D_2,...,D_m\}$ is given, entity E_i owns vector resources $r_i=\{r_i(1),r_i(2),...,r_i(k)\}$ and set D_j owns vector resources $d_j=\{d_j(1),d_j(2),...,d_j(k)\}$ .It means an entity E_i allocates resources vector for demand D_j and the D_j is willing to provide compensation vector p_{ij} for entity . E_i

Game theory based on the price mechanism has been researched in the resource allocation problem in dynamic networks, there are two research models: oversupply market competition model of non-cooperative and tight market model of cooperation and competition.

For the oversupply market competition model of non-cooperative, when an entity E_i has sufficient resources, the entity E_i use non-cooperation scheme, each demand set D_j can be set according to the entity E_i of the current resource rent without worrying about the problem of excessive requests. According to the principle of the Nash equilibrium, each D_j only consider their own interests at this moment, eventually, each D_j reaches a Nash equilibrium ,which ensures each D_j obtain best interest.

For the tight market model of competition and cooperation, the resources of entity E_i are limited. Assuming that using non-cooperation scheme, when entity D_j requests the number of resources exceeding capacity of the entity E_i , and the utilization of resource reaches 1, E_i will still accept of the demand of D_j , which will cause serious network congestion. If E_i do not accept the demand of D_j , possibly the user will no longer trust the network provider. Therefore, this article uses the model of cooperative game to establish a compliance agreement with each other. By game strategy based on the price mechanism each participant demands for resources modestly and can reach a consensus on the collective interests of cooperation, to ensure the best interests of both supply and demand.

For the dynamic allocation of network bandwidth broadband, we assume B_q as the total bandwidth demand of the virtual channel P_q between two nodes, P_q = { $p_{q(1)}$, $p_{q(2)}$, ..., $p_{q(h)}$. b_j is bandwidth allocation of the virtual path p_j , C_i is the maximum bandwidth of the link of L_i .

The constraints of the problem are as follows:

$b_j = \min_i(a_{ij})$,for all virtual path p_j , $1 \le j \le m$;

$\sum_{j=1}^{m} b_j \le C_i$, for all links L_i $1 \le i \le n$;

$\sum_{j=q(1)}^{q(h)} b_j \ge B_q$, for all virtual channel P_q ;

The price strategy in the evolutionary model of the quantum behavior is based on the demand deviation function $\Delta p_{kj}(t) = Z_j(t) \cdot \theta$, price growth model is defined as $p(t+1) = p(t) + \Delta p(t)$. Demand deviation function is defined as $Z(t) = |a(t) - d(t)|$ (as shown in Figure 1), demand satisfaction is defined as $S(t) = (\sum_{k=1}^{n_j} a_{kj}(t)) / d_j(t)$, demand satisfaction and demand deviation has a direct relationship of optimal allocation of network resources. Demand deviation function is too large, the allocation scheme is imperfect, which is perfect only when the demand satisfaction is large and demand deviation is little. Therefore, by adjusting the allocation resources in each iteration to amend the demand deviation function, it should be achieved ultimately that a big demand satisfaction and a small demand deviation.

Figure 1 and figure 2 respectively explain the difference of the allocation resources in dynamic environment by using conventional quantum optimization model in [7] and optimization model of quantum game theory based on price mechanism in the paper. In Figure 1 curve shows the changes of the demand bandwidth, while the square represents the supply in a given period, and T represents for the calculation time required to obtain a balanced distribution. The two curves in figure 2 represent the changes in demand and supply bandwidth respectively, and the shaded area represents the demand deviation function, as the price strategy in this paper is based on the demand deviation function, so it would be adjusted in time. When the environment of resources changes frequently, the demand deviation should be smaller, because our model can adjust resources allocation according to the price mechanism based on the demand deviation in each iteration, as a result, the algorithm has superior performance.

5. Conclusion

This paper proposes a dynamic resource allocation optimization model based on swarm intelligence, theoretical analysis shows that the model can describe the game strategy and autonomous behavior of network resource allocation. Using game theory based on price mechanism the dynamic resource allocation problem is analyzed, the research model includes two categories: oversupply market competition model of non-cooperative and tight market model of cooperation and competition. The price mechanism in this paper is based on demand deviation function $\Delta p_{kj}(t)$ which can reflect changes of the resource demand and supply in time. Experiment results show that the price mechanism in this article can regulate the allocation of resources in network, by adjusting the resources allocation in each iteration to amend the demand deviation function, the higher demand satisfaction and resource utilization can be reached. The next work is to study the dynamic mechanism of distributed parallel processing model continuously and to analyze complex network behavior problems.

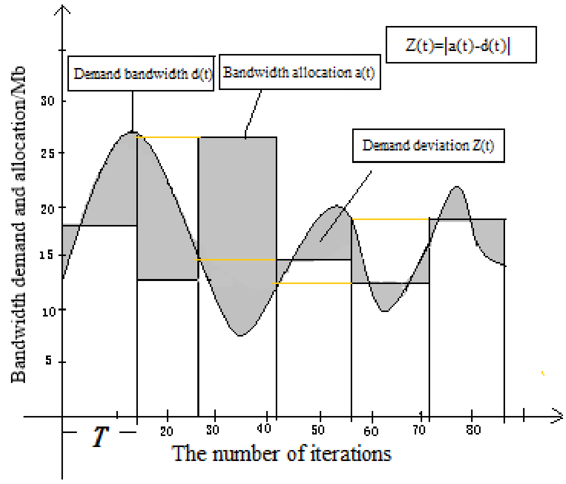

Fig.1 Demand deviation function of classical

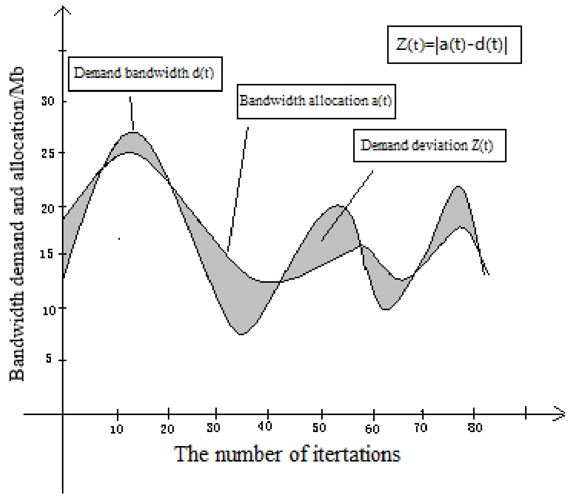

Fig.2 Demand deviation function of game theory optimization model based on price mechanism

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Yu QingPing(1989-----), The current research is the ant colony optimization algorithm, embedded systems.

You XiaoMing(1963-----), She is Corresponding author. Her research interests include quantum-inspired evolutionary computation, distributed parallel processing and evolutionary computing. She now works in Shanghai University of Engineering Science as a professor..

Liu Sheng, He now works in Shanghai University of Engineering Science as a professor.