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A Multi-factor SLA Negotiation Model Based on Evolutionary Game in Cloud Environment

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Abstract

Service providers and service consumers in the cloud environment are two important subjects to regulate the cloud computing market and the interests of the game between these two have a certain dynamic. Therefore, in this paper, a framework of SLA negotiation based on evolutionary game theory is proposed in the cloud environment, and the purposes are not only that the parties can negotiate successfully, but also that it clearly demonstrates dynamic evolutionary game process of the participant groups and the internal of the groups. The experimental results show that there are two long-term stable strategies of service providers and service consumers: Firstly, if the service providers take high-quality strategy, then service consumers adopt the high-price strategy; secondly, if service providers take low-quality strategy, then service consumers adopt the low-price strategy. And the analysis by the evolutionary game model and the evolutionary game path shows that the cooperation of the service providers and the service consumers in the consultation are mainly affected by the direct incomes, the distribution percentage, the preferential subsidies, the violation penalties, the violation revenues, the payment costs and other factors .

Keywords*: Cloud Computing, SLA Negotiation, Evolutionary Game, Multiple Factors*

1. Introduction

Cloud computing is another radical change after the big transformation of the mainframe computer to client-server in the 1980s. Because cloud computing enables the sharing of computing resources all over the world, in recent years, the large-scale computing and data storage cloud computing are becoming more and more popular. Cloud computing infrastructure breaks the inherent physical barriers in traditional isolation system, automates resource group management as a single entity, and provides users with the computing power and data storage devices, from users accessing a single laptop to distribution of hundreds of thousands of compute nodes around the world. Cloud computing is a natural evolution of data and computing centers of automated system management, load balancing and virtualization technology [1]. Cloud computing is the development and integration product of distributed computing, parallel computing, utility computing, network storage, virtualization, load balancing, high available and other traditional computer and network technologies. Cloud computing is the increase, use and delivery model of the related services based on the Internet, which usually involves providing dynamically scalable and often virtualized resources through the Internet [2].

With the rise of cloud computing, Quality of Service (QoS) issues of cloud computing are becoming more and more attentive, what is more, the Service Level Agreement (SLA) [3] is an important solution to ensure QoS in cloud computing. SLA is a mutually approved agreement which is defined by the service providers and the users in a certain cost in order to guarantee the performance and reliability of services. In the cloud computing environment, service providers and service consumers in the SLA negotiation usually are based on the traditional game theory [4] to consider and negotiate. Because the

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traditional game theory often assumes that participants are completely rational, and participants are in the conditions of complete information, but participants in the real economic life, it is more difficult to achieve the condition of complete rational and complete information of participants. Therefore, in this paper, the proposed SLA negotiation of service providers and service consumers in the cloud computing environment is based on evolutionary game theory [5]. Evolutionary game theory no longer models into a super rational game party for the person, believes that human beings are usually by trial and error method to reach game equilibrium, and has a common biological evolution, the eclectic equilibrium is a function of equilibrium process of equilibrium, so history, institutional factors and some details of the equilibrium process will influence choice of multiple equilibriums on the game. This paper adopts evolutionary game methods of the replicator dynamics [6] and the Jacobi matrix to research the SLA negotiation process in cloud computing between service providers and service consumers groups. The study in theory and application in economics of evolutionary game theory becomes one of the most popular research fields in foreign academia. Evolutionary game theory is economics and a new field especially in game theory and it is foreseeable in quite a long period in the future that evolutionary game theory will still be one of the most developing potential frontiers in economic research.

The structure of this paper is as follows. The second part introduces the related research work. The third part of this paper introduces the architecture of SLA negotiation in the basis of evolutionary game theory in the cloud computing environment. The fourth part of this paper puts forward the basic model of SLA negotiation in the basis of evolutionary game theory for SLA negotiation between service providers and service consumers groups in the cloud computing environment, and then conducts a dynamic evolutionary analysis for behaviors of service providers and service consumers. The fifth part analyzes the simulation for the dynamic evolutionary model. The sixth part is the summary of this paper.

2. Related Work

At present, the standardization work of SLA in cloud computing has conducted an extensive research. Among them, the SLA negotiation of service providers and service consumers in cloud computing is the subject of some researches in the past few years. And at the level of negotiation or cooperation competition issues, mainly in the basis of game theory and evolutionary game theory method, here we will mainly introduce some main research work:

Chao X. and Zongfang Z. [7] use evolutionary game theory to study the credit behavior of enterprises. First of all, organization consists of two companies is analyzed to ensure continuous and stable development conditions. In addition, organizations of some enterprises are researched, and the results of the research show that realization of a reasonable access and exit mechanism can effectively manage and control the credit risk. Estalaki S. M. et al. [8] propose a new evolutionary game theory method to determine the monitoring points along the river, when the monitoring points are limited, the environmental protection departments should levy sewage discharge to meet punishment function of the water quality standard. In the proposed method, the concept of non-symmetric matrix evolutionary game stable strategy more truly is used to simulate the interaction between polluters. It describes a method for the participants' system model, and the method is very suitable for business strategy simulation [9]. This method is based on the game theory and machine learning, applied to a group of competitive behavior of participants. The method of game theory and evolutionary simulation is based on the combination of three technologies: Monte Carlo sampling, searching for the equilibrium point from the game theory and locally search the meta-heuristic algorithm for machine learning. Arshad, Sara and Nasrollah Moghadam [10] propose an efficient job scheduling strategy by using multi-agent system and in the basis of information exchange protocol SLA, and at the same time put forward a new algorithm in the basis of optimal use of available resources, namely the negotiation time and grid resources; also use the previous negotiation session information, this not only improves the probability of successful negotiation, but also reduces the negotiation time.

Gomes et al. [11] propose a common SLA negotiation protocol and a language specification for virtualization environment. The proposed protocol allows users to negotiate resources and characteristics used in the virtualization environment. In the future there still needs to extend the protocol to support the SLA renegotiation and terminal to terminal SLA negotiation. The main purpose of research of Krześlak M. and Świerniak A. [12] is the use of evolutionary game theory to simulate radiation caused by bystander effect. The game is carried out on a lattice; therefore two kinds of spatial evolutionary games are presented and compared. Moreover, different polymorphic equilibrium points which depend on the model parameters and cell reproductions are discussed. Wu J. et al. [13] aim to analyze the competitive game behavior for graduates' scholarship in China by using evolutionary game theory approach [14]. It first analyzes the process of knowledge sharing between the logistics enterprises. And then the evolutionary game theory model is proposed, and some factors that influence the knowledge sharing are given. Finally, some meaningful suggestions are presented [15]. The evolutionary game model of a two echelon closed loop supply chain is developed; the model aims to study the evolutionary stable strategy of manufacturers and retailers. By analyzing the evolutionary path of the game, it can be found that there are two possible evolutionary results to affect the profits of the manufacturers.

Farhana H. Zulkernine and Patrick Martin [16] propose a novel trust negotiation agent framework, which executes bilateral negotiation of SLA adaptability and intelligence between service provider and service consumer in the basis of high level business needs. The defined mathematical model maps the business level requirements to the layer parameters of decision function, and hides the complexity of the parties of the system. Yuhua Xu et al. [17] use stochastic learning scheme of game theory in the opportunistic spectrum access (OSA) system, in which the availability statistics of the channel and the number of the secondary users are apriori unknown problems of the investigative distributed channel selection. The constitutive channel selection problem as a game is proved to be an exact potential game.

3. Architecture

The proposed architecture in this paper is based on evolutionary game theory, in which the ecological chain for network information is in the Internet information environment. And by the continuous game to form a chain dependent relation of information flow, the ecological chain for network information is based on the architecture of the original traditional game theory to improve and form.

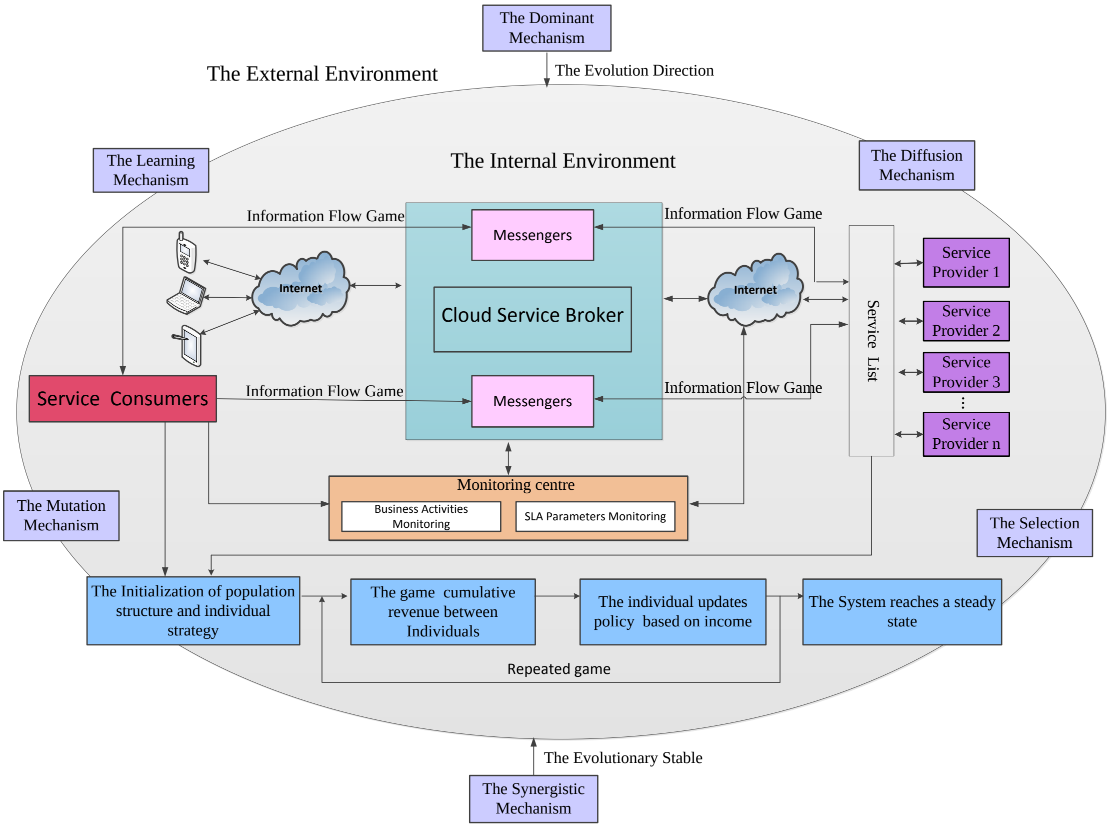

Figure 1. The SLA Negotiation Architecture Based on Evolutionary Game in Cloud Environment

The general process of the architecture based on the evolutionary game can be described as follows. The individual with neighbor game accumulates earnings, and then according to the comparative results of revenue, it updates strategy. By repeating to achieve the above processes, the level of negotiation participants in the whole system will eventually maintain at a relatively stable state. In the evolutionary game theory, the game revenue of individual corresponds to the fitness of the process of biological evolution. Therefore, individuals of high income have higher fitness, namely the strategies of the high-income individuals have better ability to communicate. This study usually adopts to compare the income of individuals, then according to the comparative results, to update strategies. In Figure 1, the main components of the architecture are the service consumers, cloud service broker, the monitoring center, the main evolutionary mechanisms and service providers. In the following section, these main components will be introduced.

(1) Cloud service broker (CSB)

Since service consumers usually do not have the capability to negotiate, manage and monitor QoS, so they appoint tasks to cloud service broker, such as choosing the appropriate service provider and SLA negotiation. Cloud service broker acts as the third party intermediary between service consumers and service providers, and is mainly responsible for processing the SLA requests by service consumers to submit, sending these requests to the service list of the service providers, then conducting corresponding search, selecting corresponding service, and negotiating with service providers group, in which these requests express mainly service consumers who use benefits of some types of service, and the registered service providers are willing to provide some types of service.

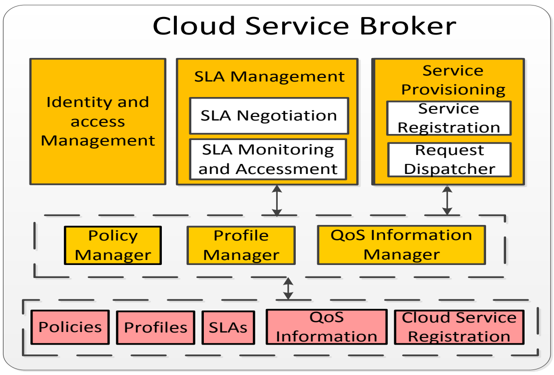

Figure 2. Cloud Service Broker in Cloud Computing

(2) The main evolutionary mechanisms

The proposed evolutionary mechanisms in this paper can promote intercommunication, the inherent operating logic of interaction and the rules and principles of interaction relationship among the main bodies of the information in the evolutionary process of the network information ecological chain. Some of the main evolutionary mechanisms will be introduced as follows.

Dominant mechanism refers to the evolution of the ecological chain for network information, which can dominate and influence functional mechanism of the evolutionary direction and the evolutionary process of network information chain. As for learning mechanism in the game of main body of information, if the decision participants adopt a dominant strategy, and main body of information will continue to adopt this strategy, or main body of information uses the probability of this strategy is large, while other main bodies of information will learn and imitate this strategy. As for mutation mechanism, mutation refers to that, the process of the game, a main body of information or some main bodies of information in the subjective sense or random behavior adopt a certain unconventional strategy, which results in the win or out phenomenon with other main bodies of information in game. As for selection mechanism, selection refers to the main body of information in the process of game by certain standards to select who can take strategies. As for diffusion mechanism, diffusion refers to "infectious" of a certain kind of behavior or a certain kind of strategy of the main body of participant in the group that is whether diffusion can copy, imitate and then spread for other game participants in the group. In the evolutionary process of the network ecological chain, the various main evolutionary mechanisms interact with each other in a particular environment, and jointly promote development of the ecological chain for network information from disorder to order. Mechanisms which play the major role in the different types of the network information ecological chain are different; also mechanisms which play the major role in different stages of development of the network information ecological chain are different. Each mechanism interacts with each other and mutually promotes the evolution of the network information ecological chain.

(3) The monitoring center

The monitoring center is responsible for monitoring the service providers and the service consumers' activities, QoS and SLA protocol parameters and so on.

(4) The service providers

Service providers can provide some service types that realize and use simple or composite services. In order to detect the existing quality of service provided by service providers, service providers need to use monitoring technology, which allows to collect the measurement data in the selected observation points. Through the summary of the collected data, service providers can detect index value of each QoS. If the current provision of QoS has a significant decrease, and then service providers will add additional resources to meet SLA commitment. The SLA manager of service providers is responsible for the management of SLA templates, and negotiates with cloud service broker or directly with service consumers the delivery service and the level of QoS, the duration of SLA, implementation of SLA and makes adjustment.

4. Construction of Evolutionary Game Model and Dynamic Evolution

4.1. Construction of Evolutionary Game Model between Service Providers and Service Consumers

In this paper, there are two groups of participants in the game: service consumers and service providers. Assuming in cloud computing services, there are a number of service consumers M_1 and service providers M_2 to carry out the strategy for the game, where service consumers have two different ways to provide price to service providers which are high price and low price, namely strategy set of consumer services is (high price, low price); strategy set of service providers is (high quality, low quality).

Suppose that there are only two types. If q is the probability of high price of service consumers, and then the probability of low price is $1-q$; if the probability of high quality of service providers is p, and then the probability of low quality is $1-p$. The game matrix is shown in Table 1.

Table 1. Game Payoff Matrix of Service Consumers and Service Providers

		service consumers	
		High price(q)	Low price($1-q$)
service providers	High quality(p)	$\pi_s+N_s+E-C_s,\pi_c+N_c+E-C_c$	$\pi_s+f+E-C_s,\pi_c+H_c-f$
	Low quality($1-p$)	$\pi_s+H_s-f,\pi_c+f+E-C_c$	π_s,π_c

In Table 1, π_s and π_c respectively refers to general income of service providers and service consumers who respectively take the low quality and the low price, N_s and N_c respectively refers to direct income of service providers and service consumers who respectively take high quality and high price. Service providers and service consumers in the signed agreement, if any party violates the agreement, then the party will be punished accordingly, and f is the punishment of a party who violates the agreement, C_s and C_c respectively refers to the payment cost of service providers and service consumers who respectively promise to provide high quality and high price in the agreement, H_s and H_c respectively represents the income of service providers and service consumers who violate the agreement, and the benefit must be more than the loss, E represents the various preferential policies which are provided by market monitoring mechanism in order to create a good market environment and encourage partners that are service providers and service consumers, and the default party cannot obtain such concessions.

So service providers select expected return U_{11}, U_{12} of two kinds of games of high quality and low quality and the average revenue $\bar{U}_1$ of the whole service providers group respectively is

$$U_{11}=q(\pi_s+N_s+E-C_s)+(1-q)(\pi_s+f+E-C_s) \quad (1)$$

$$U_{12}=q(\pi_s+H_s-f)+(1-q)\pi_s \quad (2)$$

$$\bar{U}_1=pU_{11}+(1-p)U_{12} \quad (3)$$

Service consumers select expected return U_{21}, U_{22} of two kinds of game of high-price, low-price and the average revenue $\bar{U}_2$ of the whole service consumers group respectively is

$$U_{21} = p(\pi_c + N_c + E - C_c) + (1-p)(\pi_c + f + E - C_c) \tag{4}$$

$$U_{22} = p(\pi_c + H_c - f) + (1-p)\pi_c \tag{5}$$

$$\bar{U}_2 = qU_{21} + (1-q)U_{22} \tag{6}$$

Analysis of evolutionary stable strategies of service providers is performed by the formulas (1) and (3) that can obtain the replicated dynamic equation $f(p)$ of high-quality allocation strategy adopted by the service providers:

$$\begin{aligned} f(p) = \frac{dp}{dt} &= p(U_{11} - \bar{U}_1) = p(1-p)(U_{11} - U_{12}) \\ &= p(1-p)\left(qN_S + f + E - C_s - qH_s\right) \end{aligned} \tag{7}$$

If the derivations of $f(p)$ can meet points of $f^{'}(p) < 0$, then the corresponding strategies are the evolutionary stable strategies. So the first-order derivation of $f(p)$ on p is

$$f^{'}(p) = (1-2p)\left(qN_S + f + E - C_s - qH_s\right) \tag{8}$$

In formulas (7), $\frac{dp}{dt}$ shows dynamics of service providers group of evolutionary game, namely the selection probability of high quality varies with the time. If $\frac{dp}{dt} = 0$, then $p^* = 0$, $p^* = 1$, $q^* = \frac{C_s - f - E}{N_s - H_s}$ can be calculated, at this time, all p are in steady state, but it could not ensure whether these p belong to the evolutionary stable strategies, only when $f^{'}(p) < 0$, these equilibrium points are the evolutionary stable strategies. When $q = q^* = \frac{C_s - f - E}{N_s - H_s}$, $\frac{dp}{dt} = 0$, that is the ratio of p does not change with the time, and all points in [0,1] are evolutionary stable strategies. q^* is the probability of service consumers who select "high price" strategy in the mixed strategy equilibrium state. If $q > q^*$, then $f^{'}(0) > 0$, $f^{'}(1) < 0$. At this time $p^* = 1$ is the evolutionary stable strategy, namely the service providers select the strategy of high quality. Otherwise, $p^* = 0$ is the evolutionary stable strategy, namely the service providers select the strategy of low quality. The specific change trend can be seen in Figure 3.

Seen from Figure 3, when the service consumers select the ratio of high price which is higher than the critical point ($q^* = \frac{C_s - f - E}{N_s - H_s}$), and then service providers select the probability of high quality which will gradually increase to 1. When the service consumers select the ratio of high price which is less than this value, service providers select the probability of low quality which will gradually increase to 1.

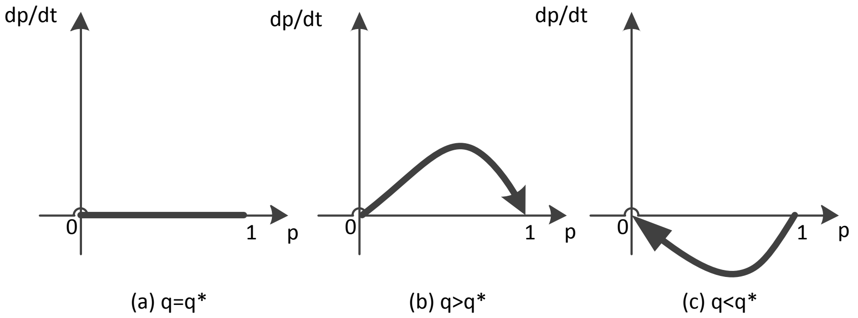

Figure 3. The Replicator Dynamics Diagram of Service Providers Group

Analysis of evolutionary stable strategies of service consumers: by the formulas (4) and (6), the replicator dynamic equation $f(q)$ of high price allocation strategy can be adopted by the service consumers.

$$f(q) = \frac{dq}{dt} = q(U_{21} - \bar{U}_2) = q(1-\text{q})(U_{21} - U_{22}) \\ = q(1-q)\left(pN_c + f + E - C_c - pH_c\right) \tag{9}$$

The derivations of $f(q)$ can meet points of $f'(q) < 0$, and then the corresponding strategies are the evolutionary stable strategies. So the first-order derivation of $f(q)$ on q is

$$f'(q) = (1-2q)\left(pN_c + f + E - C_c - pH_c\right) \tag{10}$$

In formula (9), $\frac{dq}{dt}$ shows dynamics of service consumers group of evolutionary game, namely the selection probability of high price varies with the time. According to $\frac{dq}{dt} = 0$, $q^* = 0$, $q^* = 1$, $p^* = \frac{C_c - f - E}{N_c - H_c}$ can be calculated, and at this time, all q are in steady state, but it could not ensure whether these p belong to the evolutionary stable strategies, only when $f'(p) < 0$, these equilibrium points are the evolutionary stable strategies. When $p = p^*$, no matter what value q is, and all points in [0, 1] are evolutionary stable strategies. At this time, p^* is the probability of service providers who select "high quality" strategy in the mixed strategy equilibrium state. If $p > p^*$, then $f'(0) > 0, f'(1) < 0$. At this time $q^* = 1$ is the evolutionary stable strategy, namely the service consumers select the strategy of high price. Otherwise, $q^* = 0$ is the evolutionary stable strategy, namely the service consumers selecting the strategy of low price. The specific change trend can be seen in Figure 4.

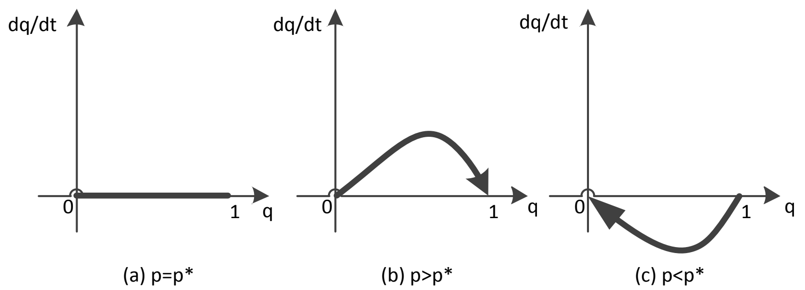

Figure 4. The Replicator Dynamics Diagram of Service Consumers Group

Seen from Figure 4, when the service providers select the ratio of high quality which is higher than the critical point ($p^* = \frac{C_c - f - E}{N_c - H_c}$), then service providers select the probability of high price which will gradually increase to 1. Otherwise it will tend to 0.

4.2. The Dynamic Evolution of Service Providers and Service Consumers' Behavior

Jacobi matrix reflects the optimal linear approximation of a differential equation and the given points, and by analyzing the Jacobi matrix of the system, it can be judged whether the stable point of the system is evolutionary stable strategy. The Jacobi matrix of the system by equations (8) and (10) can be obtained.

$$J = \begin{bmatrix} \frac{\partial f(p)}{\partial p} & \frac{\partial f(p)}{\partial q} \\ \frac{\partial f(q)}{\partial p} & \frac{\partial f(q)}{\partial q} \end{bmatrix} = \begin{bmatrix} (1-2p)\left(qN_s + f + E - C_s - qH_s\right) & \mathrm{p}(1-\mathrm{p})(N_s - H_s) \\ q(1-q)(N_c - H_c) & (1-2q)\left(pN_c + f + E - C_c - pH_c\right) \end{bmatrix} \tag{11}$$

By analyzing the equations (8) and (10), in this paper the game rigorous phase diagram is made, as shown below, and it can be seen that there are five partial equilibrium points in the evolutionary game. The five partial equilibrium points are $(p^*, q^*) = (0,0)$, $(0,1)$, $(1,0)$, $(1,1)$, $(\frac{C_c - f - E}{N_c - H_c}, \frac{C_s - f - E}{N_s - H_s})$.The five partial equilibrium points into J , and then the results are obtained by using local analysis of the Jacobi matrix, as shown in Table 2.

By analyzing the local stability of the system, $(0,0)$ and $(1,1)$ are stable points and evolutionary stable strategies of the system, namely ESS. $(0,1)$ and $(1,0)$ are unstable points of the system, and $(\frac{C_c - f - E}{N_c - H_c}, \frac{C_s - f - E}{N_s - H_s})$ is the saddle point of the system.

The replicator dynamics of service providers and service consumers' behavior are combined to analyze the stability as follows. Figure 5 shows the path diagram for evolutionary game of the system, and it describes the dynamic evolutionary process of the game of service providers and service consumers. The connected lines by the unstable points $(0,1)$ and $(1,0)$ and saddle point E are the dividing lines of system evolution to different states, so the whole area is divided into four areas. $(0,0)$ and $(1,1)$ are ESS of this game, in the absence of strong external interference, area I and area II in the diagram are evolutionary stable areas, area Ⅲ and area Ⅳ are unstable states.

In the area II, stable strategy will converge to $(1,1)$, namely service providers provide the high-quality service, and service consumers will choose high-price strategy, which makes the trading between service providers and service consumers into the healthy development track in cloud computing; in area, stable strategy will converge to $(0,0)$, namely service providers providing the low-quality service, and service consumers will choose low-price strategy, at this time, the trading between service providers and service consumers in cloud computing is more difficult to develop in the natural state.

Table 2. Local Stable Analysis of the System

Equilibrium point	Determinant of J (sign)	Trace of J (sign)	Result
$p=0,q=0$	$(f+E-C_s)(f+E-C_c)$ (+)	$(2f+2E-C_s-C_c)$ (-)	Stable point
$p=0,q=1$	$-(N_s+f+E-C_s-H_s)*(f+E-C_c)$ (+)	$(N_s-C_s-H_s+C_c)$ (+)	Unstable point
$p=1,q=0$	$-(f+E-C_s)*(N_c+f+E-C_c-H_c)$ (+)	$(N_c-C_c-H_c+C_s)$ (+)	Unstable point
$p=1,q=1$	$(N_s+f+E-C_s-H_s)*(N_c+f+E-C_c-H_c)$ (+)	$(-N_s-2f-2E+C_s+H_s-N_c+C_c+H_c)$ (-)	Stable point
$p=\frac{C_c-f-E}{N_c-H_c}$, $q=\frac{C_s-f-E}{N_s-H_s}$	$\frac{(C_c-f-E)(N_c-H_c-C_c+f+E)}{(N_c-H_c)}*\frac{(C_s-f-E)(N_s-H_s-C_s+f+E)}{(N_s-H_s)}$	0	Saddle point

In Figure 5, there are five equilibrium points, in which point E is a saddle point, point B and point C are the starting points of the source of the instability, and point A and point D are evolutionary stable states.

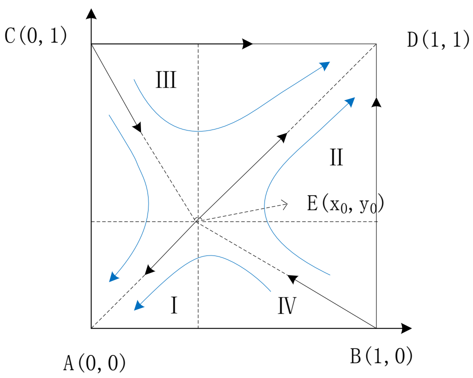

Figure 5. Evolutionary Game Path Diagram

5. Simulation and Analysis of Dynamic Evolutionary Model

Assume that values of the parameters in the game payoff matrix as follows (unit: myriad yuan). In the payoff matrix, the direct income of service providers and service consumers who respectively take high quality and high price that respectively is $N_s=1350$, $N_c=1300$, the punishment of a party who violates the agreement is $f=300$, the payment cost of service providers and service consumers who respectively promise to provide the high quality and the high price in the agreement that respectively is $C_s=900$, $C_c=850$, the benefit of service providers and service consumers who violate the agreement respectively is $H_s=450$ and $H_c=400$, preferential subsidies $E=100$.

In the process of the game, the changes of some parameters' initial values of the participants' payoff functions in game matrix will lead to convergence of evolutionary system to different equilibrium points. Analysis of specific parameters is as follows:

5.1. Cost Parameters C_s and C_c of Service Providers and Service Consumers

Figure 6 analyzes the effect of increase of cost parameters C_s and C_c of service providers and service consumers on coordinate of the saddle point, and the effect on evolutionary paths of service providers and service consumers. When the cost C_s of service providers increases from 900 to 1400 and the step is 10, the cost C_c of service consumers increases from 850 to 1300, and the step is 10, so coordinate of the saddle point changes from E(0.5,0.5) to E'(1.0,1.0). Thus the area CDE of evolution towards the direction of (high quality, high price) turns into 0(*i.e.* CDE' area is 0), and this area reduces CDE, so that the system converges to the equilibrium point; the area CEA of evolution towards the direction of (low quality, low price) turns into CE'A, therefore area this increases CE'E, so that the probability of the system which converges to the equilibrium point D reduces, and the probability of the system which converges to the equilibrium point A increases. As a consequence, service providers and service consumers evolve to the direction of (low quality, low price).

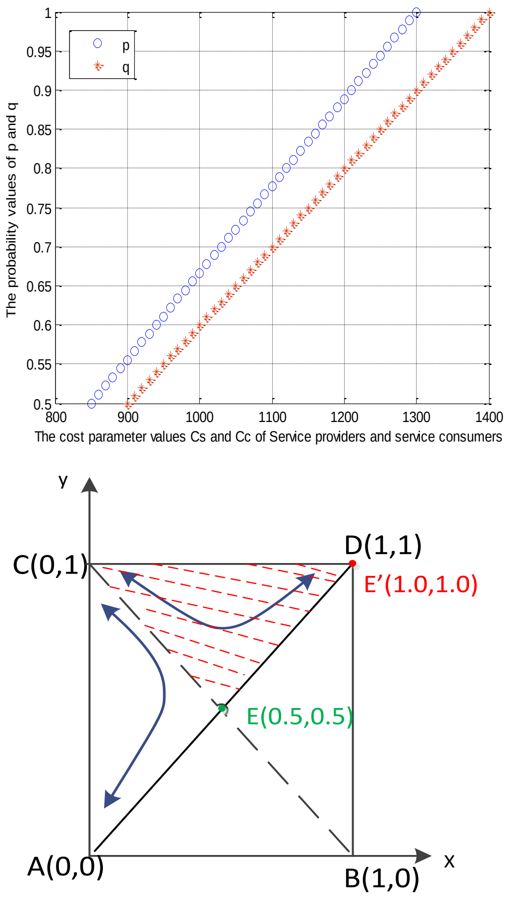

Figure 6. The Effect of Increase of Parameters C_s and C_c on Evolutionary Paths of Service Consumers and Service Providers

5.2. Default Income Parameters H_s and H_c of Service Providers and Service Consumers

Figure 7 analyzes the effect of increase of default income parameters H_s and H_c of service providers and service consumers on coordinate of the saddle point. When the default income parameter H_s of service providers increases from 350 to 750 and the step is 7, the default income parameter H_c of service consumers increase from 400 to 800, so coordinate of the saddle point changes from E(0.5,0.5) to E'(0.8982,0.8319). Thus the area CDE of evolution towards the direction of (high quality, high price) turns into CDE', and this area reduces; the area CEA of evolution towards the direction of (low quality, low price) turns into CE'A, therefore this area increases CE'AE, so that the probability of the system which converges to the equilibrium point A increases, and the probability of the system which converges to the equilibrium point D reduces. As a consequence, service providers and service consumers evolve to the direction of (low quality, low price).

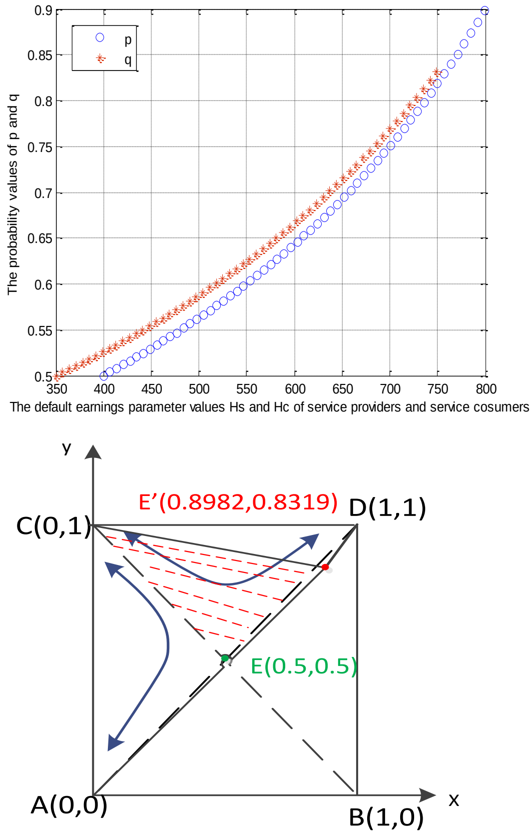

Figure 7. The Effect of Increase of Parameters H_s and H_c on Evolutionary Paths of Service Consumers and Service Providers

5.3. The Punishment Parameter f of a Party Who Violates the Agreement

Figure 8 analyzes the effect of increase of punishment f on coordinate of the saddle point, where service providers and service consumers in the signed agreement, if any party violates the agreement, then the party will be punished accordingly, with the punishment parameter f increaseing from 300 to 750, and the step is 10, so coordinate of the saddle point changes from E(0.5,0.5) to E'(0,0.05). Thus the area CDE of evolution towards the direction of (high quality, high price) turns into CDE', and this area increases; the area CEA of evolution towards the direction of (low quality, low price) turns into 0 (*i.e.* CE'A area is 0), therefore this area reduces CEA, so that the probability of the system which converges to the equilibrium point D increases, and the probability of the system which converges to the equilibrium point A reduces. As a consequence, service providers and service consumers evolve to the direction of (high quality, high price).

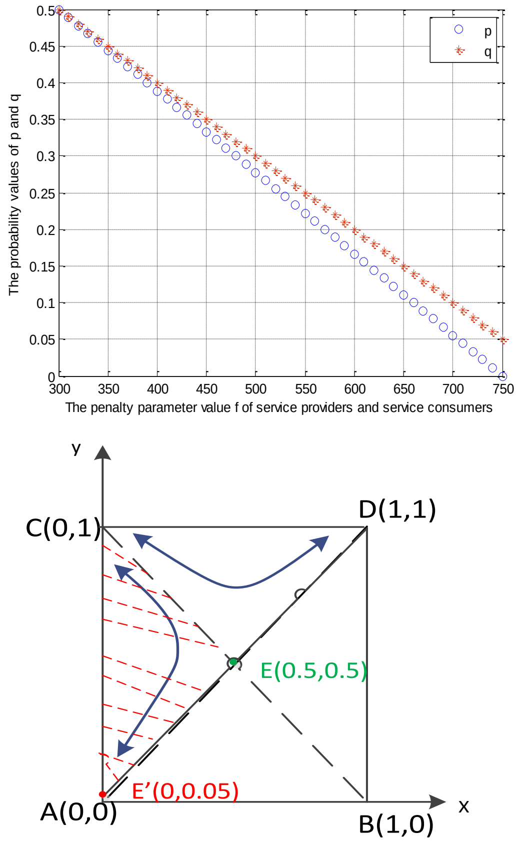

Figure 8. The Effect of Increase of Parameter f on Evolutionary Paths of Service Consumers and Service Providers

5.4. Direct Income Parameter N_c of Service Consumers Take High Price

Figure 9 analyzes the effect of increase of direct income parameter N_c of service consumers on coordinate of the saddle point. When the direct income N_c of service consumers increases from 1300 to 1500 and the step is 5, then coordinate of the saddle point changes from E(0.5,0.5) to E'(0.4091,0.5). Thus the area CDE of evolution towards the direction of (high quality, high price) keeps unchanged; the area CEA of evolution towards the direction of (low quality, low price) turns into CAE', therefore this area reduces CE'AE, so that the probability of the system which converges to the equilibrium point D keeps unchanged, and the probability of the system which converges to the equilibrium point A reduces. As a consequence, service providers and service consumers evolve to the direction of (high quality, high price).

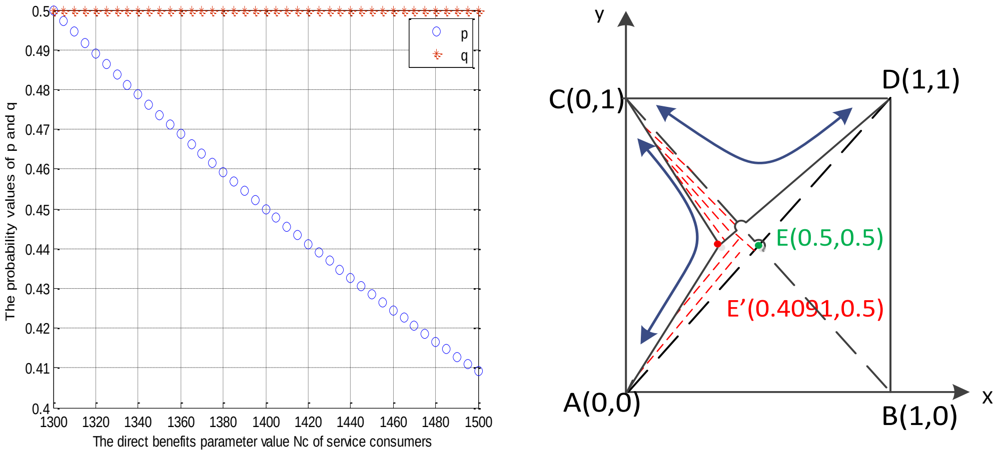

Figure 9. The Effect of Increase of Parameter N_c on Evolutionary Paths of Service Consumers and Service Providers

6. Conclusions

In the past few years, SLA negotiation between service providers and service consumers in the cloud computing environment is mainly confined to the method of game theory, due to the traditional game theory often assuming that participants are completely rational, and participants are in the conditions of complete information, but participants in the real economic life, it is more difficult to achieve the condition of complete rational and complete information of participants. Therefore, this paper proposes a framework in which the negotiation between service providers and service consumer groups is based on evolutionary game theory, and the proposed framework increases dynamic evolutionary modules of within population and between populations in the architecture of the existing traditional game theory, so that these can better reflect the evolutionary game between service providers and service consumers within population and between populations. Evolutionary game theory is a combined theory of game theory analysis and the dynamic evolutionary process analysis. In the methodology, evolutionary game theory is different from the game theory that focuses on the static equilibrium and comparative static equilibrium, which emphasizes a kind of dynamic equilibrium.

Through the analysis of the evolutionary game model of SLA negotiation between service providers and service consumers in cloud computing, there are two long-term stable strategies of service providers and service consumers: Firstly, if the service providers take the high-quality strategy, and then service consumers adopt the high-price strategy; secondly, if service providers take low-quality strategy, and then service consumers adopt the low-price strategy. And the simulation results show that the cooperation of the service providers and the service consumers in the consultation are mainly affected by the direct incomes, the distribution percentage, the preferential subsidies, the violation penalties, the violation revenues, the payment costs and other factors.

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