Journal of Computers Vol. 32 No. 3, 2021, pp. 188-209
doi:10.3966/199115992021063203014

Profit Maximization for Service Organizer Based on IABC Algorithm

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Received 15 March 2020; Revised 21 April 2021; Accepted 22 April 2021

Abstract. In the interaction of service resources among multiple participants, the maximization of profit is always the most concerned fundamental expectation of these participants. However, their expectations can hardly be satisfied simultaneously for the reason of the contradictions and conflicts that existed in their interest demands. In this paper, the interaction between the service organizer and the service provider is discussed in detail. From the perspective of the value of service groups, the value composition and synergy of all participants in science and technology service activities are studied, the service activity process is sorted out, the behavioral characteristics of service entities are analyzed, and the interaction process of interests between service intermediaries and service providers is organized into a mixed-integer linear programming model with constraints. It is determined that the value embodiment in the process of service activities is portrayed by introducing the relevant model of game theory. A game approach is used to describe the mathematical relationships between different service entities in terms of cooperation or non-cooperation. An improved artificial bee colony algorithm is used to solve the problem and promote the multi-party value collaborative optimization of science and technology service activities.

Keywords: profit maximization, game theory, transfer probability, improved artificial bee colony algorithm, perturbation

1 Introduction

Service can often be thought of as the interaction between service consumers, service organizers, and service providers, which can be collectively referred to as the service participants [1]. Service consumers put forward a series of demands and expectations according to their interests. Based on such demands and expectations, service organizers interact with service providers to formulate appropriate service strategies and provide them to service consumers [2]. For a given service system, the interaction of services among service participants will construct a collaborative manufacturing service chain based on service level agreement (SLA) [3]. A typical application of the system is intelligent manufacturing [4], which plays an important role in the development of the manufacturing industry in the automated, intelligent design and network directions. Significantly, the interaction of service resources will certainly bring the transfer of service value, which makes it important to understand the economics in the service system [5].

All service participants, including service consumers, service organizers, and service providers, are always most concerned with service value, which is the integration of quality, function, structure, and content of the service system. Especially for service consumers, their focus gradually changes from the function and content of the service system to better satisfaction towards the services and the maximization of profits [6]. Given this, the following two questions are proposed for research: (i) Satisfaction is a qualitative concept, which cannot be directly used for quantitative analysis. Therefore, it is essential to explore a mapping relationship between satisfaction and service value, to better describe

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the impact of satisfaction on the profit of different service participants from a quantitative perspective. (ii) How to determine the parameters that affect profit, and how to realize the maximization of profit by changing the relevant parameters?

Generally, service consumers and service providers have conflicting interests. From the perspective of the servisce consumers, they are usually preferring to choose the services with better quality within an acceptable budget for the reason that better quality of service (QoS) equals higher consumer satisfaction in this case. However, since the better QoS means the higher cost of service consumers, once the cost of service consumers exceeds their budget, their satisfaction will fall. From the perspective of service providers, better QoS can bring them higher revenue, but they also have to pay higher rental and maintenance costs. Therefore, the profits of service consumers and service providers can hardly be maximized at the same time. In this paper, we consider service organizers as an agent of service consumers and expect to maximize the profit of service consumer on the premise of seeking the compromise between 。 service consumer and service provider.

The main contributions of this paper are summarized below:

The profit maximization problem for service organizers has been taken into consideration on the premise of minimizing the loss of each service provider as far as possible. This problem is organized into a mixed-integer linear programming model with constraints, in which the objective is optimized with an improved artificial bee colony algorithm.

A game-based profit calculation method is proposed to depict price competition between a service organizer and service provider, in which the satisfaction of service consumers is quantified as part of the profits. Price fluctuations can stimulate service organizers and service providers to the game, to obtain more profits based on the game strategy updating mechanism.

The occurrence of perturbation in the execution procedure of service has been discussed as a special case to simulate a realistic scenario. In this case, the profit of service organizers and service providers will both be affected, which can stimulate service organizers and service providers to game to increase their profits.

Numerical simulations have been performed for the profit maximization of service organizers in a general service value chain with the undisturbed service provider and disturbed service provider separately. Simulation results show the effectiveness and advantage of the proposed algorithm.

The rest of this paper is organized as follows: In Section 2, the related works are reviewed. The system model and the related background knowledge are described in Section 3. In Section 4, a game-based profit calculation method is proposed to describe the price competition between service organizers and service providers. Section 5 formulate an improved artificial bee colony algorithm to achieve the maximization of the profit of service organizers, and a special case with the perturbation occurring in the execution process of service is discussed in detail. Numerical simulation results are presented in Section 6. At last, the proposed algorithm is concluded in Section 7.

2 Related Work

According to the supply-demand relationship of services among all service participants, the pursuit of profits has always been a major concern for these participants. Recently, such a scientific problem has attracted extensive attention from a large number of scholars. Next, we will discuss the existing work in three separate areas: (i) the value added by service providers; (ii) the value added by service organizers; (iii) the simulation of the gaming process.

（A）the value added by service providers

Mihailescu [7] proposes an auction-based mechanism based on the budgetary and deadline constraints of service consumers to determine the optimal price of service providers. However, only the case with one provider has been considered in the algorithm. Tram [8] studies an optimal price strategy for multiple service providers in the cloud market to maximizes the final revenue and improves the competitive advantage. The competition and cooperation behavior among the service providers is taken into consideration separately. For the former one, a discrete choice model has been adopted to calculate the probability of the service provider to be selected, then a Markov decision process has been adopted to update the price strategy of each provider. For the latter one, a cooperation decision algorithm has been proposed based on the learning curve model and the price strategy obtained from the former part. Xu [9] studies both the problem of optimal pricing and capacity right-sizing for the case with a single IaaS provider, while the case with multiple providers is missed. On the contrary, Tang [10] concentrates on the research of joint pricing and capacity planning in the IaaS cloud market both for two cases, one is a monopoly IaaS provider and the other is the multiple IaaS providers. Then a three-stage Stackelberg game strategy is formulated based on the research and an iterative algorithm is proposed to reach the Nash equilibrium. Considering the dynamic interaction between the requests of service consumer and cloud service provider, Cong [11] develops a user-perceived value-based dynamic pricing model to optimize the profit of the cloud service provider without violating the service-level agreement of service consumer. Moreover, Duan [12] describes an interaction between the global provider and local monopolistic provider as a two-stage dynamic game and determines the revenues of the providers based on the combination of different preferences. However, although these methods achieve profit maximization of service provider from different aspects, the effect of this process on the other two types of participants in the market is not taken into consideration: service consumers and service organizers.

(B) the value added by service organizers;

Wadhwa [13] points out that cloud service organizer plays an important role on the management of the costs, capacity, and resources in the interactions of service consumers and providers at agreed service levels. On this basis, Li [14] proposes a pricing-repurchasing strategy based on multiple cloud service organizer frameworks, which aims to design an optimal pricing and user subletting strategy for the service organizer to maximize its total revenue. Wang [15] proposes a cloud service organizer framework, which provides an idea for the service consumers to minimize their cost by selecting different pricing options according to their requirements. A dynamic strategy is introduced for the service organizer to make-instance reservations to minimize its service cost. Moreover, a special scenario involving multiple service organizers is described in Guan [16], a cooperative problem is discussed to minimize the total average price of all service organizers under the constraints that each organizer should not pay a price higher than the competitive price. Lin [17] proposes a Becloud-tree for the cloud service organizer to classify and store various types of service resources as well as manage updated service information based on the requirements of consumers. However, according to the complex relationships among all service participants, such as service provider and service organizer, the expectation of maximizing their profits will result in price competition, which has not been fully studied.

(C) the simulation of the gaming process.

As an extension of the previous algorithms, Zhang [18] propose a two-stage strategy to schedule task in cloud dynamically, so that the task execution cost and the cost to be paid by consumer are minimized. Yuan [19-20] designs a profit-sensitive spatial scheduling approach to maximize the total profit and throughput with different constraints. Zhang [21] designs polynomial-time auctions to achieve social welfare maximization and/or profit maximization of provider with good competitive ratios. Jin [22] considers the contradictory relationship among the profits of resource providers and consumers as well as the maintenance overhead of virtual machines, derives an optimal price in the acceptable range for providers and consumers simultaneously, and determines a best-fit billing cycle to maximizing social welfare. Wu [23] leverage Lyapunov optimization to develop a distributed online approach that can maximize the time-average profit with only local information. Cao [24] treats a multiserver system as an M/M/m queueing model and studies the problem of optimal multiserver configuration for profit maximization in a cloud computing environment so that the profit of consumer and provider can achieve a balanced point. Mei [25] is focused on the configuration of cloud service organizer and the pricing of virtual machines reserved from service providers, to maximize the revenue of service organizer on the premise of saving costs for service consumers. Zhang [26] proposes a hybrid pricing framework for the mobile network operator, which is adapted to coordinate the tethering decisions of network users with network management objectives. According to such a scheme, mobile network operators and users both can double their profits, and such improvement will increase with the heterogeneity of the network. However, all these methods did not consider the cooperation and competition relationship between consumer and provider or with internal providers. On this basis, Liu [27] formulate a price competition model to describe the competition between a service organizer and service provider or within internal service provider, and then build a game-based service price decision (GSPD) model to depict the process of price decisions.

3 System Model and Problem Statement

3.1 System Model

The concrete model of a service system consists of three parts. (1) Service consumer. These participants are willing to seek solutions from the service providers according to their demands and expectations, and return corresponding costs to them; (2) Service provider. These participants provide multiple candidate services for service consumers and obtain corresponding revenues from them. For each service provider, part of candidate services comes from itself, while the rest is leased from other service providers. (3) Service organizer. Considering some problems that existed in the supply-demand relationship between service consumer and service provider, such as service resources dispersion, difficulty to share and the application of low degree, etc. cloud service platform play a role as a service organizer to effectively integrate multiple service consumers and service providers so that service provider can obtain amounts of consumer resources, and service consumer can also obtain multi-functional and personalized composite services. In this paper, we consider the scenario that service consumers publish their demands and expectations to service organizer, which act as an agent to fulfill the interactions between service consumer and service provider.

Consider the preferences of service organizer and service provider, for the former, they always expect to obtain as much revenue as possible on the premise of reducing costs, and for the latter, they can be separated into two groups. One group is willing to improve their competitiveness by cooperating, to increase the probability of being chosen by service organizers, and increase their revenues. However, when service provider chooses to cooperate, their costs will also increase. For this reason, the other group is more likely to choose non-cooperation behavior to reduce their costs. In this paper, we assume that each demand or expectation of service consumer should be accomplished by composite services rather than single candidate service to improve the accomplished quality, meanwhile, each service provider can accomplish a specific demand or expectation of service consumer individually, which means service organizer can obtain composite services from either a single service provider or multiple service providers.

To better illustrating the proposed method, we present a simplified logical structure for the relationship between service organizers and service providers as shown in Fig. 1. $T_i\left(i=1,2,\cdots,n\right)$ denotes for the i-th task, which is decomposed by the demands and expectations published by service consumers. All tasks are arranged in a sequential structure, which means each task can be executed when all of its former tasks have already been finished. Besides, the execution process of each task is independent of the others, namely, the outcome of the current task will not affect any other tasks. $E_i\left(i=1,2,\cdots,s\right)$ denotes for the i-th service provider which possesses m_i candidate services with different specific functions. S_{ij} denotes for the j-th service provided by the i-th service provider. For example, $m_2=3$ denotes that the number of candidate services provided by service providers E_2 is 3, and S_{43} is the third service provided by service providers E_4.

As can be seen from Fig. 1, service providers E_1, E_2, E_3, E_4, E_5 are divided into two groups, where E_1, E_2 are linked to the task T_2, and E_3, E_4, E_5 are linked to the task T_3. Service organizers adopt different strategies for each task. For example, the task T_2 is accomplished by the candidate services provided E_1 alone, in which the strategy adopted by service organizers is called centralized strategy. Nevertheless, the task T_3 is accomplished by the candidate services provided E_3, E_4, E_5 together, in which the strategy adopted by service organizers is called distributed strategy. The selected candidate service is depicted as a solid box, while the unselected candidate service is depicted as a dotted box.

Similar to the strategy classification approach of service organizers, the strategy adopted by each service provider can also be divided into two categories, namely, cooperative strategy and non-cooperative strategy. For the former, service providers is willing to rent the candidate services from other service providers to increase their competitiveness and revenue. For the latter, service providers take an opposite attitude to reduce its cost.

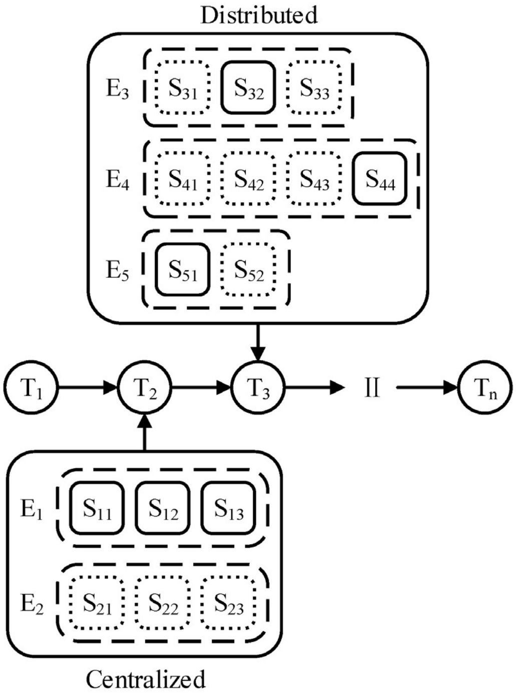


Fig. 1. Structure diagram of the supply-demand relationship between service organizer and service provider

3.2 Problem Statement

To provide composite services for service consumers with a certain QoS, service organizers need to obtain such services from service providers. When the supply-demand relationship of services is established, service organizers and service providers will obtain the corresponding profits, which are the difference between their revenues and costs. Regardless of the strategies chosen by service organizers and service providers, they always expect to increase their profits. Therefore, the profit calculation method for service organizers and service providers should first be given.

Generally, no matter what strategy service organizers and service providers adopt, the tasks published by service consumers can always be accomplished, which will bring basic revenue α to service organizers. However, the different strategies will determine the difference in QoS, which will further determine the difference in potential value for service consumers. In other words, the higher the potential value, the higher the satisfaction of service consumers, which is associated with the potential revenue β in the total revenue of service organizers. To obtain composite services from service providers, the corresponding cost γ must be paid by service organizers. Moreover, when service organizers adopt distributed strategy, they should pay the additional costs ϑ , which include communication costs, negotiation costs, and other costs to interact with more than one service provider. Therefore, the profit of service organizers so can be obtained as follow.

$$so = \begin{cases} \alpha + \beta - \gamma & centralized \\ \alpha + \beta - \gamma - \vartheta & distributed \end{cases} \tag{1}$$

For service providers, their revenue consists of two parts. First, when they provide composite services to service organizers, the costs γ paid by service organizers will become part of their revenue, which is defined as the basic revenue. Second, the satisfaction of service consumers will be reflected not only in the revenue of service organizers but also in the revenue of service providers, which is defined as their potential revenue δ. In other words, the higher the satisfaction of service consumers, the greater the chance that the provider of the chosen services will continue to be selected in the future. Moreover, when service provider adopts cooperative strategy, they should pay the additional costs λ to rent some useful candidate services from other service providers. Therefore, the profit of service providers sp can be obtained as follow.

$$sp = \begin{cases} \gamma + \delta - \lambda & cooperative \\ \gamma + \delta & non\text{-}cooperative \end{cases} \tag{2}$$

As can be seen from Eqs. (1) and (2), without considering the influence of other parameters, a decrease in γ will result in an increase in so and a decrease in sp, and vice versa, which represents an opposite relationship between the profits of service organizer and service provider. β and δ, which are affected by the satisfaction of service consumers, can change so and sp in the same direction. Also, $\alpha, \lambda, \vartheta$ are constant for each task. However, when analyzing the profits of service organizers and service providers, the influence of all the above parameters should be considered comprehensively. Therefore, competition and cooperation are both existed in the relationship between service organizers and service providers.

Consider the tasks shown in Fig. 1, service organizer is generally facing multiple service providers for each task, which will lead to competition and cooperation between service providers as well. However, such a relationship between service organizers and service providers as well as the relationship between service providers has never been studied on the premise of considering the profits of service organizers and each service provider. Therefore, to maximize the profit of service organizer on the premise of minimizing the loss of each service provider, the following two questions are proposed for research: how to describe the comprehensive influence of parameters on the relationship between service organizer and service provider as well as the relationship between service providers? How to change the appropriate parameters to maximize the profit of service organizers? The former question will be discussed in the next section, and the latter question will be discussed in section 5.

4 Game Based Profit Calculation

4.1 Game Matrix Based on Consumer Satisfaction

According to the profit calculation method discussed in the previous section, service organizers and each service provider possess their profits. Consider the competition and cooperation that existed in the relationship between service organizers and each service provider, game theory is adopted to describe such a relationship based on their profits.

Consider the framework of the three-player game, which includes a service organizer and two service providers, i.e. provider A and provider B. Each player can adopt two strategies, for example, service organizers can adopt either a centralized or distributed strategy, and each service provider can adopt either a cooperative or non-cooperative strategy. By combining all of these strategies, a game matrix will be established as shown in Table 1.

Table 1. Game matrix

		The strategies adopted by provider A and B			
		coop coop	coop non-coop	non-coop coop	non-coop non-coop
service organizer	centralized	gs1	gs2	gs3	gs4
	distributed	gs5	gs6	gs7	gs8

Each item in the game matrix is a combination of the strategies adopted by service organizers and each service provider respectively, which can be named as a game strategy $gs_i\left(i = 1, 2, \cdots, 8\right)$. For each game strategy, all of the players can obtain corresponding profits, which are described in Eqs. (3).

$$gs_i : \left\{SO, \left(SP_A, SP_B\right)\right\} \quad \forall i \in \left\{1, 2, \cdots, 8\right\} \tag{3}$$

Where, SO, SP_A, SP_B represent the profits of service organizer, provider A, and provider B respectively. When service organizer adopts a centralized strategy, service provider A and B both have a certain probability of being selected to provide services. In this case, SO, SP_A, SP_B can be described as mathematical expectations in Eqs. (4) and (5).

$$SO = p_A so_A + p_B so_B \tag{4}$$

$$\begin{bmatrix} SP_A \\ SP_B \end{bmatrix} = \begin{bmatrix} sp_A & sp'_A \\ sp'_B & sp_B \end{bmatrix} \begin{bmatrix} p_A \\ p_B \end{bmatrix} \tag{5}$$

Where, p_A, p_B represent the service provider A's and B's probability of being selected, and their sum is equal to 1, which means that service organizer can only obtain the services from either provider A or provider B. so_A, so_B are the profit of service organizer when the selected services are provided by service provider A and B respectively. sp_A, sp_B are the profits of service providers A and B when they are selected and sp'_A, sp'_B are the profits of service providers A and B when they are not selected. Combined with Eqs. (1), (2), (4), and (5), the profits of service organizers and each service provider can be described as Eqs. (6-8) when service organizers adopt a centralized strategy. Notice that, compare to Eqs. (1) and (2), β and δ in Eqs. (6-8) are rewritten as the reference value, and $\varepsilon, \varepsilon'$ are introduced as the weight to better distinguish the differences in the satisfaction of service consumer. For example, the service provider who adopt a cooperative strategy can obtain more potential revenue than those who adopt the non-cooperative strategy, namely, $\varepsilon > \varepsilon'$.

$$gs_1 : \left\{ \begin{aligned} &\tfrac{1}{2}(\alpha + \varepsilon\beta - \gamma) + \tfrac{1}{2}(\alpha + \varepsilon\beta - \gamma), \\ &\left(\tfrac{1}{2}(\gamma + \varepsilon\delta - \lambda) + \tfrac{1}{2}(-\lambda), \tfrac{1}{2}(-\lambda) + \tfrac{1}{2}(\gamma + \varepsilon\delta - \lambda)\right) \end{aligned} \right\} \tag{6}$$

$$gs_{2,3} : \left\{ \begin{aligned} &\tfrac{3}{4}(\alpha + \varepsilon\beta - \gamma) + \tfrac{1}{4}(\alpha + \varepsilon'\beta - \gamma), \\ &\left(\tfrac{3}{4}(\gamma + \varepsilon\delta - \lambda) + \tfrac{1}{4}(-\lambda), \tfrac{3}{4} \times 0 + \tfrac{1}{4}(\gamma + \varepsilon'\delta)\right) \end{aligned} \right\} \tag{7}$$

$$gs_4 : \left\{ \begin{aligned} &\tfrac{1}{2}(\alpha + \varepsilon'\beta - \gamma) + \tfrac{1}{2}(\alpha + \varepsilon'\beta - \gamma), \\ &\left(\tfrac{1}{2}(\gamma + \varepsilon'\delta) + \tfrac{1}{2} \times 0, \tfrac{1}{2} \times 0 + \tfrac{1}{2}(\gamma + \varepsilon'\delta)\right) \end{aligned} \right\} \tag{8}$$

And when service organizers adopt distributed strategy, both service providers A and B can be selected to provide services. In this case, SO, SP_A, SP_B can be described as follows.

$$gs_5 : \left\{ \alpha + \varepsilon''\beta - \gamma - \vartheta, \left(\tfrac{1}{2}\gamma + \tfrac{1}{4}\varepsilon''\delta - \lambda, \tfrac{1}{2}\gamma + \tfrac{1}{4}\varepsilon''\delta - \lambda\right) \right\} \tag{9}$$

$$gs_{6,7} : \left\{ \alpha + \varepsilon''\beta - \gamma - \vartheta, \left(\tfrac{1}{2}\gamma + \tfrac{1}{4}\varepsilon''\delta - \lambda, \tfrac{1}{2}\gamma + \tfrac{1}{2}\varepsilon'\delta\right) \right\} \tag{10}$$

$$gs_8 : \left\{ \alpha + \varepsilon''\beta - \gamma - \vartheta, \left(\tfrac{1}{2}\gamma + \tfrac{1}{2}\varepsilon'\delta, \tfrac{1}{2}\gamma + \tfrac{1}{2}\varepsilon'\delta\right) \right\} \tag{11}$$

Similar to $\varepsilon, \varepsilon'$ discussed in Eqs. (6-8), ε'' in Eqs. (9-11) is also introduced as the weight to describe the satisfaction of service consumer. For example, service organizer who adopts distributed strategy can obtain more potential revenue than those who adopt the centralized strategy, namely, $\varepsilon'' > \varepsilon > \varepsilon'$. Notice that, since service organizers select the services equally from each service provider, the revenues obtained by each service provider should also be equally distributed according to the number of service providers.

4.2 Game Matrix Based on Price Competition

Consider more general cases, the game matrix discussed in the previous subsection can be extended by increasing the number of service providers from 2 to m. In this case, a framework of the multiplayer game can be constructed, and then, each game strategy in the game matrix and the corresponding profit can be rewritten as Eqs. (12).

$$gs_i : \left\{SO, \left(SP_1, \cdots, SP_m\right)\right\} \quad \forall i \in \left\{1, 2, \cdots, 2^{m+1}\right\} \tag{12}$$

According to the profit calculation method discussed in Eqs. (6-11), each gs_i in Eqs. (12) can be described in Eqs. (13-18), where Eqs. (13-15) and Eqs. (16-18) are the profits of service organizer and each service provider when service organizer adopts centralized and distributed strategy respectively. For the sake of simplicity, when service organizers adopt the centralized strategy, all cases involving k service providers with cooperative strategies and $m-k$ service providers with non-cooperative strategies are regarded as one case, which is also applicable to the case where service organizer adopt distributed strategy. Therefore, the number of game strategies in-game matrix will be reduced from 2^{m+1} to $2m+2$, which can effectively reduce the complexity of the proposed method.

In the profit calculation method, the effects of all the parameters on the profits of service organizers and each service provider have been discussed except for γ, which is the most important factor in determining the price competition between service organizer and service provider. Similar to β and δ discussed in Eqs. (6-8), γ in Eqs. (13-18) is also rewritten as the reference value, and a price factor x is introduced as the weight to simulate the effect of price fluctuation on the profits. When game strategy remains unchanged, the profits of service organizers and each service provider will always change in the opposite direction no matter x increases or decreases. However, through updating the game strategy while adjusting the price factor, which can be implemented by the 1-step memory mechanism [28], the profit of service organizers can be increased on the premise of minimizing the loss of each service provider.

$$\left\{\sum_{i=1}^{m} \tfrac{1}{m}\left(\alpha + \varepsilon\beta - x\gamma\right), \left(\tfrac{1}{m}\left(x\gamma + \varepsilon\delta - \lambda\right) + \tfrac{m-1}{m}\left(-\lambda\right), \cdots, \tfrac{1}{m}\left(x\gamma + \varepsilon\delta - \lambda\right) + \tfrac{m-1}{m}\left(-\lambda\right)\right)\right\} \tag{13}$$

$$\left\{\sum_{i=1}^{k} \tfrac{2^m-m+k}{2^m k}\left(\alpha+\varepsilon\beta-x\gamma\right)+\sum_{i=1}^{m-k}\tfrac{1}{2^m}\left(\alpha+\varepsilon'\beta-x\gamma\right), \left(\underbrace{\tfrac{2^m-m+k}{2^m k}\left(x\gamma+\varepsilon\delta-\lambda\right)+\left(1-\tfrac{2^m-m+k}{2^m k}\right)\left(-\lambda\right)}_{for\ k\ cooperated\ providers}, \cdots, \underbrace{\tfrac{1}{2^m}\left(x\gamma+\varepsilon'\delta\right)+\left(1-\tfrac{1}{2^m}\right)\times 0}_{for\ m-k\ non\text{-}cooperated\ providers}\right)\right\} \tag{14}$$

$$\left\{\sum_{i=1}^{m} \tfrac{1}{m}\left(\alpha + \varepsilon'\beta - x\gamma\right), \left(\tfrac{1}{m}\left(x\gamma + \varepsilon'\delta\right) + \tfrac{m-1}{m}\times 0, \cdots, \tfrac{1}{m}\left(x\gamma + \varepsilon'\delta\right) + \tfrac{m-1}{m}\times 0\right)\right\} \tag{15}$$

$$\left\{\alpha + \varepsilon''\beta - x\gamma - \left(m-1\right)\vartheta, \left(\tfrac{x}{m}\gamma + \tfrac{1}{2m}\varepsilon''\delta - \lambda, \cdots, \tfrac{x}{m}\gamma + \tfrac{1}{2m}\varepsilon''\delta - \lambda\right)\right\} \tag{16}$$

$$\left\{\alpha + \varepsilon''\beta - x\gamma - \left(m-1\right)\vartheta, \left(\underbrace{\tfrac{x}{m}\gamma + \tfrac{1}{2m}\varepsilon''\delta - \lambda}_{for\ k\ cooperated\ providers}, \cdots, \underbrace{\tfrac{x}{m}\gamma + \tfrac{1}{m}\varepsilon'\delta}_{for\ m-k\ non\text{-}cooperated\ providers}\right)\right\} \tag{17}$$

$$\left\{\alpha + \varepsilon''\beta - x\gamma - \left(m-1\right)\vartheta, \left(\tfrac{x}{m}\gamma + \tfrac{1}{m}\varepsilon'\delta, \cdots, \tfrac{x}{m}\gamma + \tfrac{1}{m}\varepsilon'\delta\right)\right\} \tag{18}$$

5 Profit Maximization by IABC Algorithm

In this section, our main purpose is to find the optimal price factor x and combine the game strategy updating mechanism, to achieve the maximization of profit of service organizer on the premise of minimizing the loss of each service provider. On this basis, an improved artificial bee colony (IABC) algorithm is proposed.

5.1 IABC Algorithm

Algorithm 1 shows the procedure of IABC, which can be divided into the following five phases: initialization phase, employed bee phase, game strategy updating phase, onlooker bee phase, and scout bee phase. The spe cific description of each phase is given below.

Algorithm 1. maximize profit by IABC algorithm

```
Input: price factor $x$
Output: Total profit of service organizer from all tasks
begin
    count ← 0
    Initialize SN solutions by Eqs. (19)
    while (count < Max number of iterations) do
        // Employed Bee Phase
        for each $X_v \in$ SN solutions do
            $X_u \leftarrow$ randomly select a solution different from $X_v$
            $X_v' \leftarrow$ generate a neighborhood solution of $X_v$ by Eqs. (20)
        end for
        // Game Strategy Updating Phase
        for each $i \in n$ tasks do
            for each $gs \in 2m+2$ game strategies do
                Substitute $x'_{v,i}$ into $gs$
                $\bar{R}_i^t, \hat{R}_i^t \leftarrow$ calculate the difference by Eqs. (21) and (22)
                $\bar{\phi}_i^{\,t}, \hat{\phi}_i^t \leftarrow$ calculate transfer probability by Eqs. (23)
            end for
            if ($\hat{\phi}_i^t > \max\left(\bar{\phi}_i^{\,t}\right)$ and $\bar{R}_i^t, \hat{R}_i^t > 0$) then
                $SO_i^{t+1} \leftarrow \overline{\overline{SO}}_i^{\,t}$, $SP_{ij}^{t+1} \leftarrow \overline{\overline{SP}}_{ij}^{\,t}$, $c_r^{t+1} \leftarrow c_r^t$
            else if ($\hat{\phi}_i^t < \max\left(\bar{\phi}_i^{\,t}\right)$ and $\bar{R}_i^t, \hat{R}_i^t > 0$) then
                $SO_i^{t+1} \leftarrow \overline{SO}_i^{\,t}$, $SP_{ij}^{t+1} \leftarrow \overline{SP}_{ij}^{\,t}$, $c_r^{t+1} \leftarrow \bar{c}_r^t$
            else if ($\max\left(\bar{R}_i^t, \hat{R}_i^t\right) < 0$) then
                $SO_i^{t+1} \leftarrow SO_i^t$, $SP_{ij}^{t+1} \leftarrow SP_{ij}^t$, $c_r^{t+1} \leftarrow c_r^t$
            end if
        end for
        // Onlooker Bee Phase
        Calculate the probability of each solution $X_v$ by Eqs. (28)
        for each $X_v \in$ SN solutions do
            $X_u \leftarrow$ select a solution by roulette wheel selection method
            $X_v' \leftarrow$ generate a neighborhood solution of $X_v$ by Eqs. (20)
            $X_v \leftarrow$ select the better one of $X_v'$ and $X_v$
        end for
        // Scout Bee Phase
        if ( $X_v$ has not been updated during prescribed iterations) then
            $X_v \leftarrow$ generate a new solution as an alternative by Eqs. (19)
        end
        Update the best solution from SN solutions
        Calculate total profit by the best solution, which is named as P
```

```
count ← count + 1
end while
return P
```

Initialization phase. Generate SN solutions randomly from a given interval, each of which can be represented by $X_v = \left[x_{v,1}, x_{v,2}, \cdots, x_{v,n}\right], \forall v \in \{1, 2, \cdots, SN\}$. For each vector element $x_{v,i}$ in X_v, it represents a price factor for each task T_i, which can be described as Eqs. (19).

$$x_{v,i} = x_{v,i\_LB} + rand(0,1)\left(x_{v,i\_UB} - x_{v,i\_LB}\right) \quad \textbf{(19)}$$

Where $i \in \{1, 2, \cdots, n\}$ represents the index of the task T_i, $rand(0,1)$ is a function that produces random real numbers that vary from 0 to 1, x_{v,i_UB} and x_{v,i_LB} represent the upper and lower bound of $x_{v,i}$ respectively. Notice that, we consider x_{v,i_UB} greater than 1 to represent the highest price acceptable to service organizers, and x_{v,i_LB} less than 1 to represent the lowest price acceptable to service providers.

Employed bee phase. For the current solution X_v, randomly select a solution X_u from SN solutions, and combine the elements $x_{v,i}$ and $x_{u,i}$ of two solutions X_v, and X_u in turn, a neighborhood solution X_v' can be obtained. For each vector element $x_{v,i}'$ in X_v', it can be described as Eqs. (20).

$$x_{v,i}' = x_{v,i} + rand(-1,1)\left(x_{v,i} - x_{u,i}\right) \quad \textbf{(20)}$$

Where, v and u in the subscript, both represent the indexes of the solution, $v \neq u$. Only one of the two solutions X_v and X_v' will be preserved in the next phase, and the other one will be discarded.

Game strategy updating phase. Based on the premise that game strategy does not change, no matter which of X_v and X_v' is preserved, the profit of service organizers on each task will change correspondingly, while the profit of each service provider on each task will change in the opposite directions. Combined with the 1-step memory mechanism, it is reasonable to update game strategy, and then determine the optimal profits of service organizers and each service provider by substituting price factor X_v and X_v' into Eqs. (13-18). To realize the game strategy updating process, transfer probability is introduced in this paper. The higher the transfer probability, the more likely the corresponding game strategy is to be adopted.

For a specific task T_i, consider that the profits of service organizer and each service provider before game strategy changes are calculated by substituting X_v into Eqs. (13-18) in the *t*-th iteration of the IABC algorithm, and the number of service providers who adopt cooperative and non-cooperative strategy is k_1 and $m - k_1$ respectively, where m is the total number of service providers. Based on the premise that the total number of service providers will not change during the updating process of game strategy, we further consider that the profits after game strategy changes are calculated by substituting X_v' into Eqs. (13-18), and the number of service providers who adopt cooperative and non-cooperative strategy is changed into k_2 and $m - k_2$ respectively. Then the difference between the total profits of service organizers and each service provider can be described as Eqs. (21).

$$\overline{R}_i^t = \overline{c}_1^t \overline{SO}_i^t + \overline{c}_2^t \sum_{j=1}^{k_2} \overline{SP}_{ij}^t + \overline{c}_3^t \sum_{j=k_2+1}^{m} \overline{SP}_{ij}^t - \left[c_1^t SO_i^t + c_2^t \sum_{j=1}^{k_1} SP_{ij}^t + c_3^t \sum_{j=k_1+1}^{m} SP_{ij}^t\right] \quad \textbf{(21)}$$

Where, SO_i^t, SP_{ij}^t and $\overline{SO}_i^t, \overline{SP}_{ij}^t$ represent the profits of service organizer and each service provider before and after game strategy changes in the *t*-th iteration of IABC algorithm respectively. $c_1^t, \overline{c}_1^t$ are the stimulation factors of service organizers, the higher the stimulation factors, the more important the service organizer is to pursue the increase of profit. $c_2^t, \overline{c}_2^t$ and $c_3^t, \overline{c}_3^t$ are the penalty factors of service providers who adopt cooperative and non-cooperative strategies respectively, the higher the penalty factors, the more important the service provider is to reduce the loss.

Especially, consider that the number of service providers who adopt cooperative and non-cooperative strategy does not change during the game strategy updating process, namely, $k_1 = k_2$, the difference between the total profits of service organizers and each service provider can be rewritten as Eqs. (22).

$$\hat{R}_i^t = c_1^t\left[\overline{\overline{SO}}_i^t - SO_i^t\right] + c_2^t\sum_{j=1}^{k_1}\left[\overline{\overline{SP}}_{ij}^t - SP_{ij}^t\right] + c_3^t\sum_{j=k_1+1}^{m}\left[\overline{\overline{SP}}_{ij}^t - SP_{ij}^t\right] \quad \textbf{(22)}$$

Where, $\overline{\overline{SO}}_i^t$ and $\overline{\overline{SP}}_{ij}^t$ represent the profit of service organizer and each service provider calculated by substituting X_v' into Eqs. (13-18) in the $k_1 = k_2$ case. Combined with Eqs. (21) and (22), the transfer probability ϕ_i^t can be described as follow.

$$\phi_i^t = \begin{cases} \bar{\phi}_i^t = \dfrac{\bar{R}_i^t}{\hat{R}_i^t + \sum\limits_{2m+1}\bar{R}_i^t}, & if\ k_1 \neq k_2 \\ \hat{\phi}_i^t = \dfrac{\hat{R}_i^t}{\hat{R}_i^t + \sum\limits_{2m+1}\bar{R}_i^t}, & if\ k_1 = k_2 \end{cases} \quad \textbf{(23)}$$

Where $2m+1$ represent the number of options during the game strategy updating process except for $k_1 = k_2$ the case. Among all of the transfer probabilities shown in Eqs. (23), the largest one can be selected to represent that service organizers can obtain the optimal profit on the premise of minimizing the loss of each service provider by adopting the corresponding game strategy in the *t*-th iteration of IABC algorithm. Moreover, besides game strategy, the profits of service organizers and each service provider will also be updated in the next iteration, which is described in Eqs. (24-26).

$$SO_i^{t+1} = \begin{cases} \overline{\overline{SO}}_i^t, & if\ \hat{\phi}_i^t > \max\left(\bar{\phi}_i^t\right) and\ \bar{R}_i^t, \hat{R}_i^t > 0 \\ \overline{SO}_i^t, & if\ \hat{\phi}_i^t < \max\left(\bar{\phi}_i^t\right) and\ \bar{R}_i^t, \hat{R}_i^t > 0 \\ SO_i^t, & if\ \max\left(\bar{R}_i^t, \hat{R}_i^t\right) < 0 \end{cases} \quad \textbf{(24)}$$

$$SP_{ij}^{t+1} = \begin{cases} \overline{\overline{SP}}_{ij}^t, & if\ \hat{\phi}_i^t > \max\left(\bar{\phi}_i^t\right) and\ \bar{R}_i^t, \hat{R}_i^t > 0 \\ \overline{SP}_{ij}^t, & if\ \hat{\phi}_i^t < \max\left(\bar{\phi}_i^t\right) and\ \bar{R}_i^t, \hat{R}_i^t > 0 \\ SP_{ij}^t, & if\ \max\left(\bar{R}_i^t, \hat{R}_i^t\right) < 0 \end{cases} \quad \textbf{(25)}$$

$$c_r^{t+1} = \begin{cases} c_r^t, & if\ \hat{\phi}_i^t > \max\left(\bar{\phi}_i^t\right) and\ \bar{R}_i^t, \hat{R}_i^t > 0 \\ \bar{c}_r^t, & if\ \hat{\phi}_i^t < \max\left(\bar{\phi}_i^t\right) and\ \bar{R}_i^t, \hat{R}_i^t > 0, r \in \{1, 2, 3\} \\ c_r^t, & if\ \max\left(\bar{R}_i^t, \hat{R}_i^t\right) < 0 \end{cases} \quad \textbf{(26)}$$

Where, $SO_i^{t+1}, SP_{ij}^{t+1}, c_r^{t+1}$ represent the profits of service organizer and each service provider, stimulation and penalty factors in the (*t*+1)-th iteration respectively. Notice that, $\max\left(\bar{R}_i^t, \hat{R}_i^t\right)$ in Eqs. (24-26) represent that the profits of service organizers and each service provider have not been better during the game strategy updating process. Therefore, X_v will be preserved during the game, and X_v' will be discarded.

Besides, the game strategy updating process can be further extended to all other tasks. Similarly, the transfer probability for these tasks can also be obtained. By combining all of the transfer probabilities, the following matrix will be obtained. Then, by following the same synthesis as discussed above, the profits of service organizers and each service provider will be calculated, so that the total profits of service organizers from all of the tasks will be optimized on the premise of minimizing the loss of each service provider.

$$\Phi^t = \left[\phi_1^t, \phi_2^t, \cdots, \phi_n^t\right] \in \Re^{(2m+2)\times n} \tag{27}$$

Onlooker bee phase. Each solution X_v in SN solutions has a probability p_v to perform neighborhood search, such probability can be represented as Eqs. (28).

$$p_v = fit_v / \sum_{v=1}^{SN} fit_v \tag{28}$$

Where, fit_v is the fitness function of the v-th solution, which can be represented as Eqs. (29).

$$fit_v = \sum_{i=1}^{n} SO_i^t\left(x_{v,1}, x_{v,2}, \cdots, x_{v,n}\right) \tag{29}$$

For each probability p_v greater than a certain threshold, a new solution will be created by the current solution X_v according to Eqs. (20). Calculate the fitness both for the new solution and the current solution, the better one will be preserved, while the worse one will be discarded.

Scout bee phase. Considering some solutions that have not been updated during multiple iterations, which means such solutions fall into local optimality. Therefore, they should be replaced by some new solutions, which can be created by Eqs. (19).

To summarize, according to the execution process of IABC algorithm, the profit maximization problem for service organizers is organized into a mixed-integer linear programming model, which is described in Eqs. (30). Notice that, compare to Eqs. (29), the fitness function represented in Eqs. (30) has been modified to convert the profit maximization problem into a minimization problem. Moreover, Δ_1, Δ_2 are the difference between stimulation factor and penalty factor to distinguish the importance between service organizer for increasing profit and service providers for decreasing losses, and d is a positive number, which is used to demonstrate that the partial reduction in the profits of service organizer and each service provider is acceptable to ensure the global optimization, namely, to maximize the profit of service organizer on the premise of minimizing the loss of each service provider.

$$\begin{aligned}
&\min \quad \exp\left[-\sum_{i=1}^{n} SO_i^t\left(x_{v,1}, x_{v,2}, \cdots, x_{v,n}, \Delta_1, \Delta_2\right)\right] \\
&s.t.\begin{cases}
SO_i^{t+1} - SO_i^t > -d \\
SP_{ij}^{t+1} - SP_{ij}^t > -d \\
c_1^{t+1} SO_i^{t+1} + c_2^{t+1} \sum\limits_{j=1}^{k_2} SP_{ij}^{t+1} + c_3^{t+1} \sum\limits_{j=k_2+1}^{m} SP_{ij}^{t+1} - \left[c_1^t SO_i^t + c_2^t \sum\limits_{j=1}^{k_1} SP_{ij}^t + c_3^t \sum\limits_{j=k_1+1}^{m} SP_{ij}^t\right] > 0 \\
c_1^t + k_1 c_2^t + \left(m - k_1\right) c_3^t = 1 \\
c_1^{t+1} + k_2 c_2^{t+1} + \left(m - k_2\right) c_3^{t+1} = 1 \\
\left|c_1^t - c_3^t\right| \le \Delta_1; \left|c_2^t - c_3^t\right| \le \Delta_2 \\
\left|c_1^{t+1} - c_3^{t+1}\right| \le \Delta_1; \left|c_2^{t+1} - c_3^{t+1}\right| \le \Delta_2 \\
0.75 \le x_i \le 1.2; \\
0 \le \Delta_1 \le 1; 0 \le \Delta_2 \le 1 \\
i = 1, 2, \cdots n; \; j = 1, 2, \cdots, m
\end{cases}
\end{aligned} \tag{30}$$

5.2 Perturbation

To simulate a realistic scenario of the supply-demand relationship among service organizers and each service provider, we consider that the QoS of service providers may be affected by the perturbation under a certain probability. In this case, the profits of service organizers and each service provider will also be affected to some extent. Generally, it is reasonable to assume that the larger the perturbation, the smaller the probability of occurrence, and vice versa. Therefore, the relationship between the degree and probability of the perturbation can be described as a negative exponential function as follow.

$$\Pr\left(X=o_{ij}\right)=\rho e^{-\rho K o_{ij}},\quad o_{ij}\in\left[0,1\right] \tag{31}$$

Where, o_{ij} and $\Pr$ are the degree and probability of the perturbation occurred in the service provided by service providers E_j in the task T_i, ρ is the rate parameter, $\rho>0$, and K is the expansion factor of o_{ij}. Without loss of generality, the case that k service providers adopt cooperative strategies and $m–k$ service providers adopt non-cooperative strategies are considered when service organizer adopt centralized and distributed strategy respectively. Therefore, Eqs. (14) and (17) will be further discussed in this section.

For the case that service organizers adopt a centralized strategy when the perturbation occurs in service providers who adopt the cooperative strategy, the profits of service organizers and each service provider in Eqs. (14) can be rewritten as follow.

$$\begin{aligned}
SO_{ce} &= g\left(\tfrac{2^m-m+k}{2^m k}\right)\left[g(\alpha)+g(\varepsilon)\beta-x\gamma\right]+\sum_{i=1}^{k-1} p_{SP_{ce}^{co}}\left[\alpha+\varepsilon\beta-x\gamma\right]+\sum_{i=1}^{m-k}\tfrac{1}{2^m}\left(\alpha+\varepsilon'\beta-x\gamma\right)\\
SP_{ce}^{co} &= p_{SP_{ce}^{co}}\left(x\gamma+\varepsilon\delta-\lambda\right)+\left(1-p_{SP_{ce}^{co}}\right)(-\lambda)\\
\overline{SP}_{ce}^{co} &= g\left(\tfrac{2^m-m+k}{2^m k}\right)\left[x\gamma+g(\varepsilon)\delta-\lambda\right]+\left[1-g\left(\tfrac{2^m-m+k}{2^m k}\right)\right](-\lambda)\\
SP_{ce}^{nc} &= \tfrac{1}{2^m}\left(x\gamma+\varepsilon'\delta\right)+\left(1-\tfrac{1}{2^m}\right)\times 0
\end{aligned} \tag{32}$$

Where $SO_{ce}, SP_{ce}^{co}, SP_{ce}^{nc}$ is the profit of service organizers who adopt the centralized strategy and the profits of service providers who adopt cooperative and non-cooperative strategy respectively, $\overline{SP}_{ce}^{co}$ is the profit of service providers who adopt the cooperative strategy with perturbation, and $p_{SP_{ce}^{co}}$ is the probability that undisturbed service providers who adopt cooperative strategy is selected, which can be represented as Eqs. (33).

$$p_{SP_{ce}^{co}}=\tfrac{1}{k-1}\left[1-g\left(\tfrac{2^m-m+k}{2^m k}\right)-\tfrac{m-k}{2^m}\right] \tag{33}$$

According to Eqs. (32) and (33), a service provider who adopt the cooperative strategy with perturbation will suffer a decreased probability to be selected, which will promote the probability of the undisturbed service provider who adopt the cooperative strategy to be selected.

When the perturbation occurs in service providers who adopt the non-cooperative strategy, the profits of service organizers and each service provider in Eqs. (14) can be rewritten as follow.

$$\begin{aligned}
SO_{ce} &= \sum_{i=1}^{k}\tfrac{2^m-m+k}{2^m k}\left(\alpha+\varepsilon\beta-x\gamma\right)+\sum_{i=1}^{m-k-1} p_{SP_{ce}^{nc}}\left(\alpha+\varepsilon'\beta-x\gamma\right)+g\left(\tfrac{1}{2^m}\right)\left[g(\alpha)+g(\varepsilon')\beta-x\gamma\right]\\
SP_{ce}^{co} &= \tfrac{2^m-m+k}{2^m k}\left(x\gamma+\varepsilon\delta-\lambda\right)+\left(1-\tfrac{2^m-m+k}{2^m k}\right)(-\lambda)\\
SP_{ce}^{nc} &= p_{SP_{ce}^{nc}}\left(x\gamma+\varepsilon'\delta\right)+\left(1-p_{SP_{ce}^{nc}}\right)\times 0\\
\overline{SP}_{ce}^{nc} &= g\left(\tfrac{1}{2^m}\right)\left[x\gamma+g(\varepsilon')\delta\right]+\left[1-g\left(\tfrac{1}{2^m}\right)\right]\times 0
\end{aligned} \tag{34}$$

Where, $\overline{SP}_{ce}^{nc}$ is the profit of service providers who adopt the non-cooperative strategy with perturbation, and $p_{SP_{ce}^{nc}}$ is the probability that undisturbed service providers who adopt the non-cooperative strategy are selected, which can be represented as Eqs. (35).

$$p_{SP_{ce}^{nc}} = \tfrac{1}{k-1}\left[1 - g\left(\tfrac{2^m - m + k}{2^m k}\right) - \tfrac{m-k}{2^m}\right] \tag{35}$$

For the case that service organizers adopt distributed strategy when the perturbation occurs in service providers who adopt the cooperative strategy, the profits of service organizer and each service provider in Eqs. (17) can be rewritten as follow.

$$\begin{aligned} SO_{di} &= \tfrac{1}{m}\left[g(\alpha) + g(\varepsilon'')\beta\right] + \tfrac{m-1}{m}(\alpha + \varepsilon''\beta) - x\gamma - (m-1)\vartheta \\ SP_{di}^{co} &= \tfrac{x}{m}\gamma + \tfrac{1}{2m}\varepsilon''\delta - \lambda \\ \overline{SP}_{di}^{co} &= \tfrac{x}{m}\gamma + \tfrac{1}{2m}g(\varepsilon'')\delta - \lambda \\ SP_{di}^{nc} &= \tfrac{x}{m}\gamma + \tfrac{1}{2m}\varepsilon'\delta \end{aligned} \tag{36}$$

Where $SO_{di}, SP_{di}^{co}, SP_{di}^{nc}$ is the profit of service organizers who adopt distributed strategy and the profit of service providers who adopt the cooperative and non-cooperative strategy respectively, $\overline{SP}_{di}^{co}$ is the profit of service providers who adopt the cooperative strategy with perturbation.

When the perturbation occurs in service providers who adopt the non-cooperative strategy, the profits of service organizers and each service provider in Eqs. (17) can be rewritten as follow.

$$\begin{aligned} SO_{di} &= \tfrac{1}{m}\left[g(\alpha) + g(\varepsilon'')\beta\right] + \tfrac{m-1}{m}(\alpha + \varepsilon''\beta) - x\gamma - (m-1)\vartheta \\ SP_{di}^{co} &= \tfrac{x}{m}\gamma + \tfrac{1}{2m}\varepsilon''\delta - \lambda \\ SP_{di}^{nc} &= \tfrac{x}{m}\gamma + \tfrac{1}{2m}\varepsilon'\delta \\ \overline{SP}_{di}^{nc} &= \tfrac{x}{m}\gamma + \tfrac{1}{2m}g(\varepsilon')\delta \end{aligned} \tag{37}$$

Where $\overline{SP}_{di}^{nc}$ is the profit of service providers who adopt the non-cooperative strategy with perturbation. Notice that, the function $g(\cdot)$ in Eqs. (32), (34), (36) and (37) represents the effect of the perturbation on the profits of service organizers and service providers, which can be described as Eqs. (38).

$$g(z) = \begin{cases} \left(1 - \tfrac{\xi}{5}o_{ij}\right)z & if\ o_{ij} > o_{th} \\ z & else \end{cases} \quad \forall z \in \{\alpha, \varepsilon, \varepsilon', \varepsilon''\} \tag{37}$$

Where, o_{th} is the threshold of the perturbation, which represents the maximum tolerance of service organizer when the perturbation in QoS of service provider fluctuates within a certain range. ξ is an integer from 5 to 0, and $\tfrac{\xi}{5}o_{ij}$ represents that the effect of perturbation will gradually decrease to 0 after 5 iterations.

The effect of perturbation occurred on the profits of service organizers and each service provider is described in Algorithm 2.

Algorithm 2. Effect of perturbation

```
Input: Occurred probability of perturbation Pr.
Output: Profit of service organizer and service provider SO, SP
begin
count ← 0, $U$ ← {1, 2, …, $SN$}, $V$ ← {1, 2, …, $n$}
while (count < Max number of iterations) do
    for each $i \in U$ && $j \in V$ do
        Calculate $o_{ij}$ according to Eqs. (31)
        if ($o_{ij} > o_{th}$) then
            count_current = count
            for ($\xi < 5$) do
```

```
    Update $\alpha$ according to Eqs. (38)
    Update $\varepsilon, \varepsilon'$ and $\varepsilon''$ according to Eqs. (38)
    Calculate SO, SP according to Eqs. (32), (34), (36), (37)
    count ← count + 1
    $\xi$ ← count – count_current
end for
end if
end for
count ← count + 1
end while
return SO, SP
```

5.3 Complexity Analysis

In the first phase, i.e. initializing the artificial bee colony, the IABC algorithm has the time complexity of $O(SN)$, where SN is the size of the artificial bee colony. During each round of iteration in the while loop, two times of neighborhood search (during employed bee phase and onlooker bee phase respectively) and one random selection (during scout bee phase) is performed in the IABC algorithm, besides, $2m+2$ times of game strategy updating process are also performed (during game strategy updating phase). Therefore, as the process of the IABC algorithm continues until the maximum number of iterations is reached, the total time complexity of the IABC algorithm is, where MCN is the maximum number of iterations.

6 Experimental Analysis

In this section, we implement the proposed algorithm in MATLAB based on the source code of the ABC algorithm provided by S. Mostapha [29]. Combined with the equality and inequality constraints discussed in Eqs. (30), a penalty function-based constraint optimization method [30] is introduced. The population size and maximal iterations are set to 300. The experiment is conducted on Intel Core CPU i5-4200M with 2.60 GHz and 12.00GB RAM running under Windows 10.

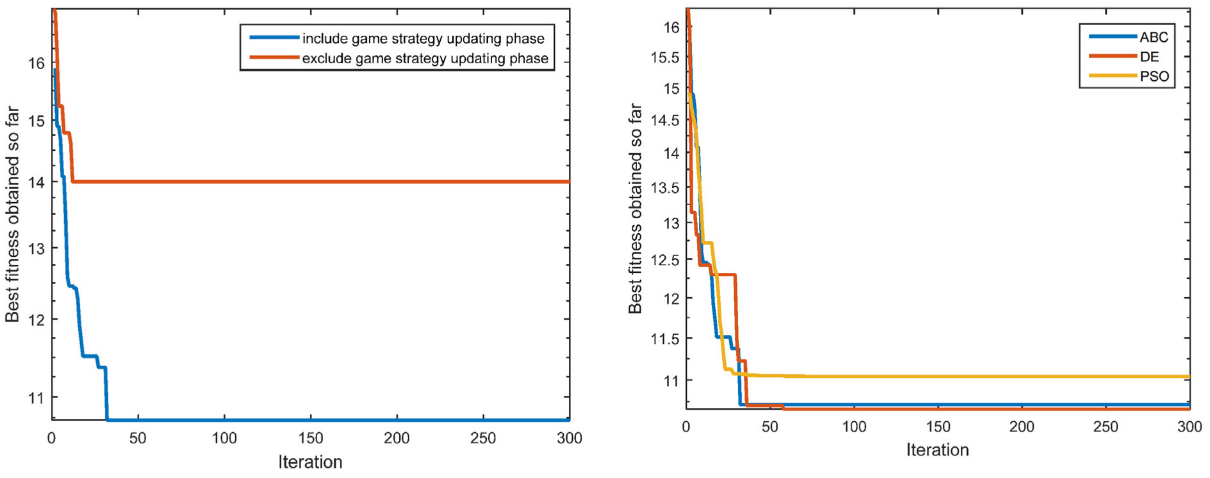
6.1 Profit Maximization of Service Organizer

Another metric for evaluating the effectiveness of metaheuristic algorithms is the computational time complexity. An algorithm with lower computational time complexity to accomplish the same solution task means that the algorithm can accomplish the task with less computational power.

The time complexity of assigning the initial value at the beginning of the algorithm is $O(1)$; the time complexity of calculating the fitness value of the initial solution is $O(N)$; the time complexity of hiring bees to search at the current honey source location and update the location of the honey source is $O(N^2)$; the time complexity of calculating the probability of each honey source being selected is $O(N)$; the process of observer bees selecting a honey source and improving it is the same as that of hiring bees, so that the time complexity is also $O(N^2)$; the time complexity of comparing the number of times each nectar source is revalued and the size of the limit is $O(N)$; if a nectar source is discarded, the worst time complexity for the scout bee to randomly search for a new nectar source is $O(N)$. Thus the time complexity required for one iteration of the standard ABC algorithm: $O(1)+O(N)+O(N^2)+O(N)+O(N^2)+O(N)+O(N)$.The simplification is $O(N^2)$. In the same way, the time complexity of the PSO and DE algorithms can be calculated as $O(2^N)$ and $O(N^2)$, respectively.

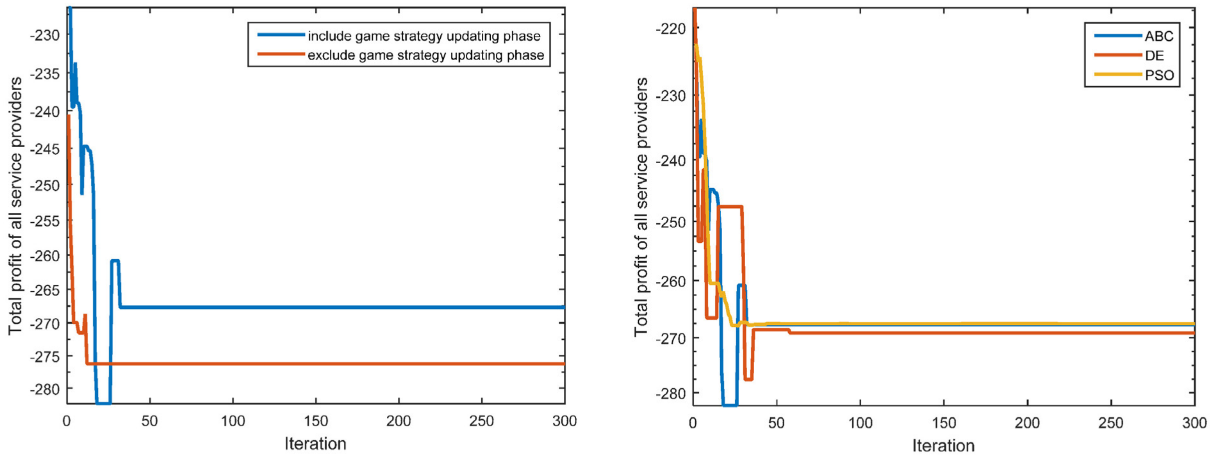
According to the system model presented in Fig. 1, five tasks are published. For each task, service organizers can obtain composite services from five service providers by adopting a centralized or distributed strategy. Notice that, each service provider can provide composite services to accomplish a specific task. During each iteration of the proposed algorithm, service organizers and each service provider will update their strategies to constitute a renewed game strategy, to increase the profit of service organizers on the premise of minimizing the loss of each service provider. To describe the advantage of the proposed algorithm, some simulation results are presented in Fig. 2 to Fig. 6.

In Fig. 2(a), Fig. 3(a), and Fig. 4(a), the game strategy updating phase is excluded from the proposed algorithm to make a comparison. Based on the proposed algorithm, the profit of service organizers is increased, meanwhile, the loss of each service provider is decreased. In Fig. 2(b), Fig. 3(b), and Fig. 4(b), particle swarm optimization (PSO) and differential evolution (DE) algorithms are adopted to compare with the proposed algorithm, the corresponding parameters are defined in Table 2. Compare to PSO algorithm, the proposed algorithm can bring more profit to service organizers on the premise that the loss of each service provider almost remains the same. Compare to DE algorithm, the proposed algorithm can reduce the loss of each service provider on the premise that the profit obtained by service organizers almost remains the same.



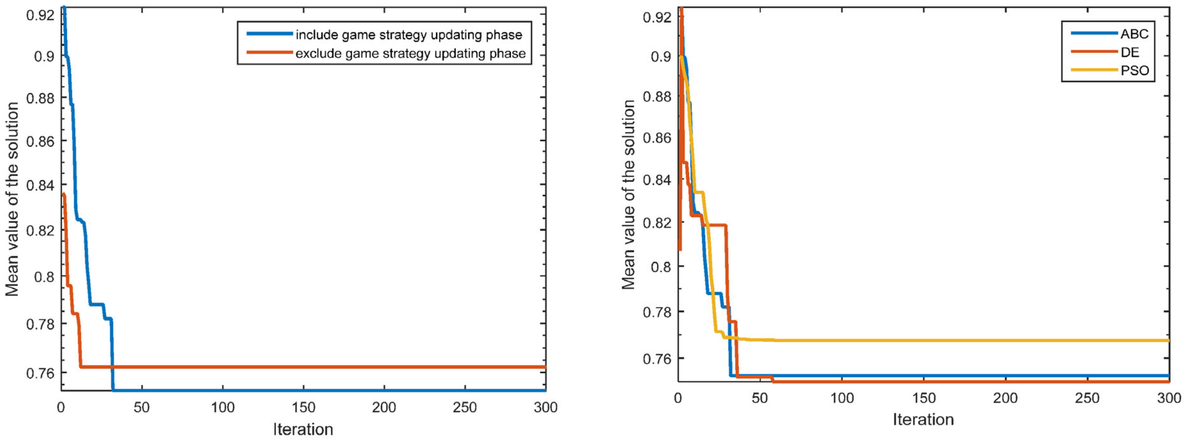
(a) (b)

Fig. 2. Convergence graph of profit of service organizer



(a) (b)

Fig. 3. Convergence graph of total profit of all service providers



(a) (b)

Fig. 4. Convergence graph of mean value of price factor

Table 2. Parameters of three algorithms

Parameter	ABC	DE	PSO	Description
nPop	300	300	300	Population size
MaxIt	300	300	300	Max number of iterations
ε, ε', ε''	0.6, 0.3, 0.9	0.6, 0.3, 0.9	0.6, 0.3, 0.9	Satisfaction of consumer
L	100	-	-	Trial limit
F_{min}	-	0.2	-	Lower bound of scaling factor
F_{max}	-	0.8	-	Upper bound of scaling factor
CR	-	0.2	-	Crossover probability
ω	-	-	1	Inertia weight
ω_{damp}	-	-	0.99	Inertia weight damping ratio
C_1	-	-	1.5	Personal learning coefficient
C_2	-	-	2	Global learning coefficient

Combined with Fig. 2(b), Fig. 3(b), and Fig. 4(b), as the price factor decreases, the profit of service organizer increases, however, the total profit of all service providers do not decrease monotonically, which demonstrate that game strategy updating phase plays an important role in the proposed algorithm.

From Fig. 2(b), the comparison among ABC, DE, and PSO shows that there is no very big difference among the three, and from Fig. 2(a), it can be seen that the difference between the algorithm with the game strategy update phase and the algorithm without the game strategy update phase. The algorithm with the game strategy update phase takes a faster time and the final result is very superior compared to the original algorithm. As can be seen from Fig. 3, the ABC algorithm, DE, and PSO algorithms all save the service provider's cost to some extent, but it is clear that the inclusion of the gaming strategy update phase guarantees the service provider's profit more. It can also be seen from Fig. 4 that the algorithm after adding the game strategy update reaches the average solution faster and brings better results.

Moreover, for anyone in five tasks, Fig. 5 shows the profit of service organizers does not always increase monotonically, which means the partial reduction is acceptable to ensure the profit maximization of service organizer.

6.2 Profit Maximization of Service Organizer with Perturbation

When considering the case that the perturbation occurs in the profit maximization process of service organizers, we re-implement the simulation by adopting the same parameter as described in the previous subsection. As can be seen from Fig. 7, Fig. 8, and Fig. 9, the perturbation occurred twice, once in the 100-th iteration and another in the 200-th iteration. When perturbation occurs, the profit of service organizers will be affected correspondingly, and to the profit of each service provider and price factor. However, they will gradually return to the original state during the next five iterations, which validate the effectiveness of the proposed algorithm.

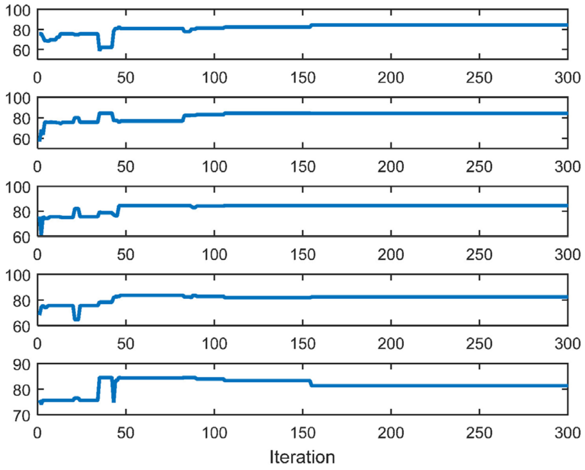


Fig. 5. Profit of service organizer in each task

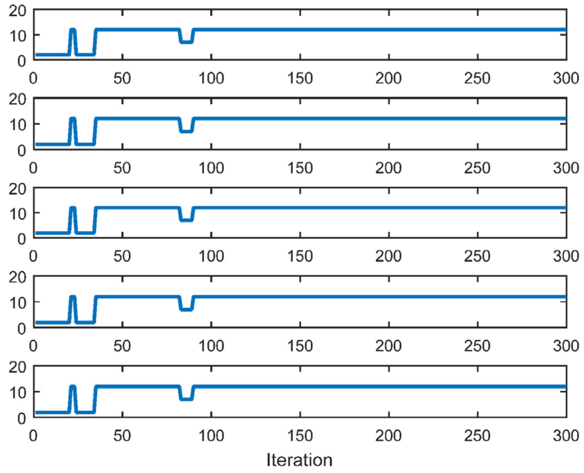
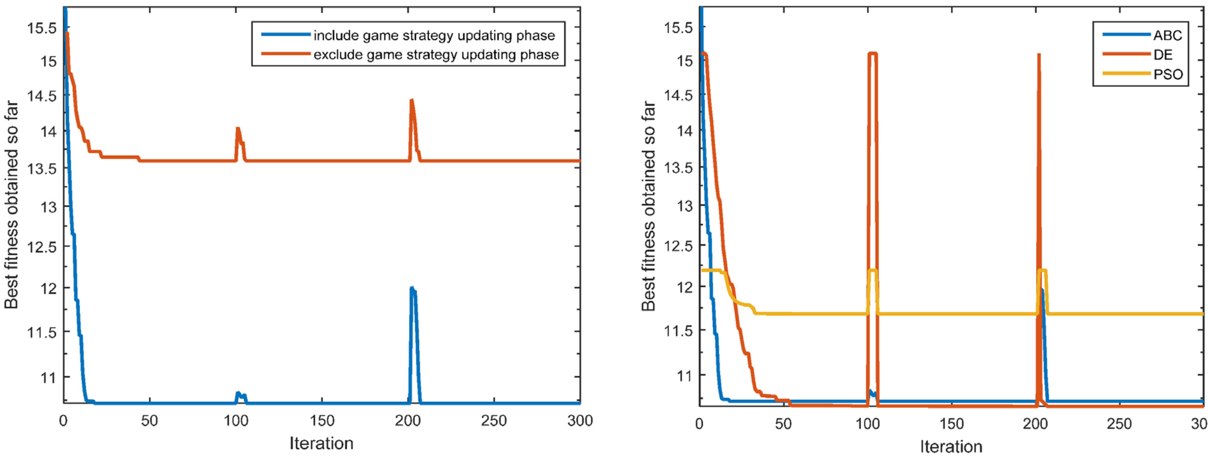


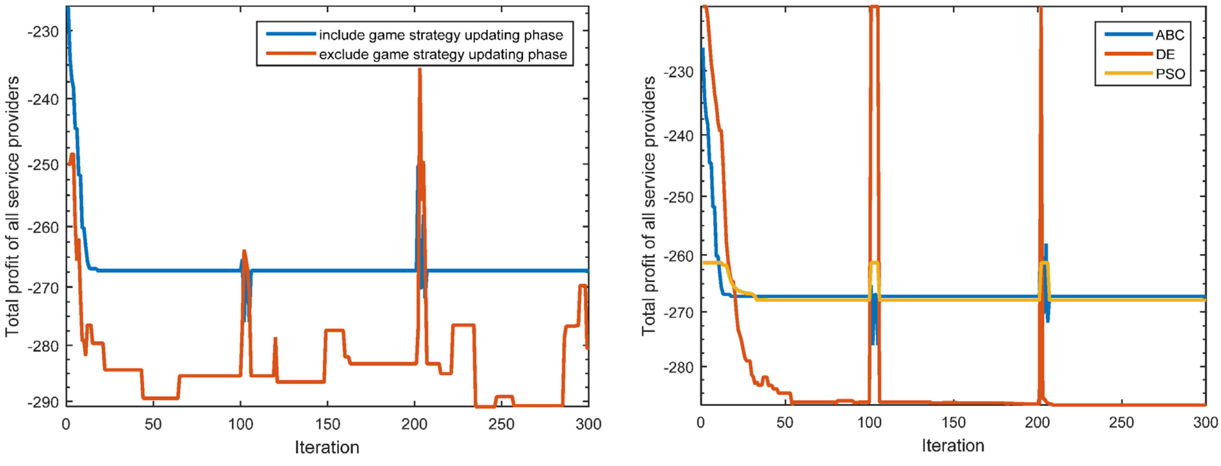
Fig. 6. Game strategies adopted by service organizer and each service provider in each task



(a)

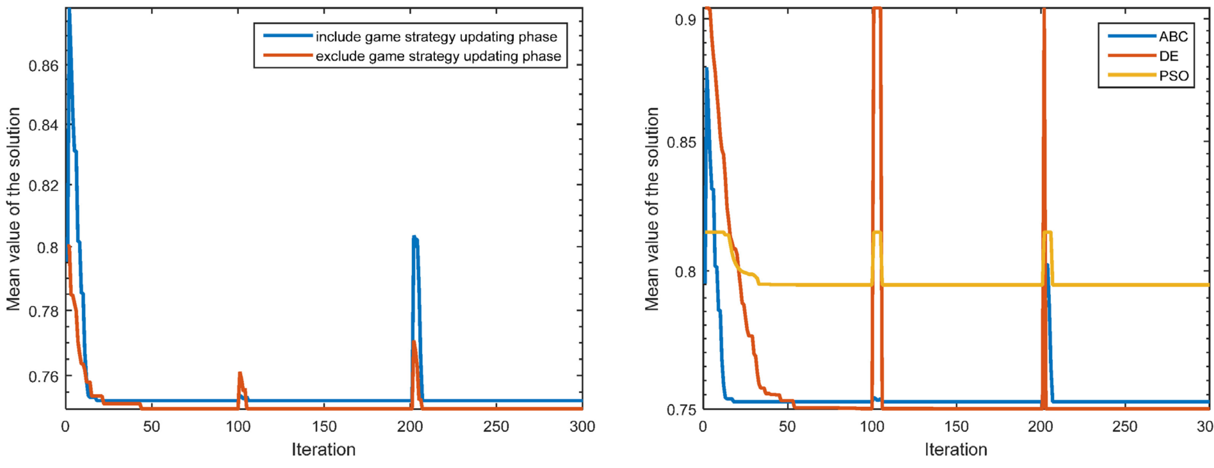
(b)

Fig. 7. Convergence graph of profit of service organizer



(a) (b)

Fig. 8. Convergence graph of total profit of all service providers



(a) (b)

Fig. 9. Convergence graph of mean value of price factor

Combined with Fig. 7, Fig. 8, and Fig. 9, it can be seen that the algorithm incorporating the game strategy update phase is significantly less affected after the perturbation is added compared to the original algorithm, which also largely indicates that the algorithm incorporating the game strategy update phase is more stable. As can be seen from Fig. 10 and Fig. 11, the variation of game strategies and the profit obtained by service organizers in each task are similar to the case presented in Fig. 5 and Fig. 6, which also validate the effectiveness of the proposed algorithm.

7 Conclusions

By introducing game behavior, the service interaction process between service agent and service provider is simulated, and the feasible game strategy solution set of each side is proposed by analyzing various factors affecting the value of service agent and service provider under the guarantee of science and technology service quality, and a game model of service agent and service provider is established to track the whole process of science and technology service from demand, response, the collaborative organization to completion. Subsequently, by using an artificial swarm optimization algorithm combined with the game strategy, the collaborative value optimization of both parties is achieved. There are still

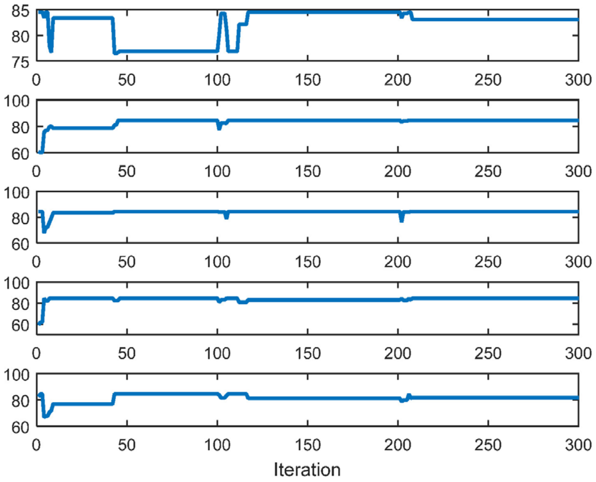


Fig. 10. Profit of service organizer in each task

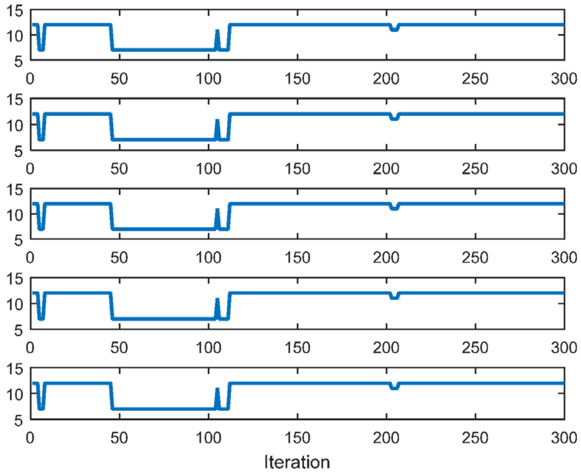


Fig. 11. Game strategies adopted by service organizer and each service provider in each task

shortcomings in existing programs: in the study of collaborative optimization for service agents and service agents, there are a large number of subjective factors of preconditions to constrain the model, and there is a lack of research on extreme conditions and model generalization. At the same time, the study lacks in-depth research on the value of service providers. In the next step, we will consider evolving from the current two-party game between service agents and service providers to a multi-party game with dynamic strategies between service agents and multiple service provider, and try to adopt dynamic pricing strategies for different game strategies, to achieve a deeper multi-party value synergy optimization.

Acknowledgements

This work has been supported by the [National Key Research and Development Project] under Grant [number 2018YFB142900]; [General Project of Education Department of Hunan Province] under Grant [number 18C0091].

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