Service Capability Optimization Algorithm for Power Communication Network Service Providers in Competitive Game Environment

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Abstract. In order to solve the problem of low resource utilization rate of multiple power communication network service providers, this paper proposes a power communication network resource management system, which consisting of the self-built power communication network service provider, the third-party power communication network service provider, a power communication network resource allocation center, and the demand side of power communication network. Secondly, the competitor's service cost coefficient is solved to obtain the competitor's competitive strategy, using the predictive mechanism of the service cost coefficient probability density function; and the reaction function based inference process is transformed to obtain the Jacobin iterative formula of service capability. Finally, a service capability optimization algorithm based on Jacobi iteration is proposed. In the simulation experiment part, the competition game model is simulated, which proves that the algorithm is more in line with the real environment than the competition game under the complete information. It is more practical for the power company to choose the power communication network service provider.

Keywords: Power communication network · Service provider · Resource allocation · Game

1 Introduction

In the power sector, with the rapid development of smart grid services, the demand for power communication networks is increasing [1]. The network infrastructure built by the power company is gradually unable to meet the development needs of the smart grid business. In the network-as-a-service environment, the network serves as a service, and the network builder provides services to the society. With the development of technologies such as network virtualization and network management, network as a service has been gradually applied to various fields [2]. In this context, the power company can adopt the self-built power communication network to transmit power services according to business needs, and can also lease third-party communication network resources to

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meet the needs of power communication services. Based on this, the service providers that provide the power communication network are divided into Self-built power communication network Service Providers (SSP), Third-party power communication network Service Provider (TSP).

Aimed at the problem of low resource utilization caused by the dynamics and complexity of the network environment, a network weight training algorithm based on the gradient descent algorithm is proposed [3].The literature [4], for the QoS constraint problem of power communication service, a game model consisting of resource allocation center, resource demand side and resource provider is proposed, and a resource allocation mechanism that can achieve the balance of interests of all parties in the game. Literature [5] models the use of network resources at various times, and analyzes the resource utilization of different time periods. Based on this, a Bayesian-based virtual network resource allocation strategy is proposed to model the network resource allocation problem. The resource allocation problem for time and energy perception significantly improves resource utilization. Aiming at the problem of excessive network energy consumption, an energy-saving transmission strategy for cached wireless networks is proposed [6]. Aiming at the problem of low revenue for network resource providers, a joint optimization algorithm for resource allocation under heterogeneous networks is proposed [7]. Aiming at the problem of network resource waste, a task-oriented service quality resource demand forecasting method is proposed [8].

From the analysis of existing research results, it is known that power companies urgently need to obtain network resources through various channels to meet the development of smart grid services. Network as a service has become a trend. However, how electric power companies choose to build their own power communication networks and rent third-party communication networks has become an urgent problem to be solved. In order to solve this problem, this paper first constructs a game model of power communication network service provider in network as a service environment. Secondly, it analyzes how to realize the resource allocation algorithm of power company's revenue maximization under incomplete information. Finally, the rationality of the model is verified by simulation experiments.

2 Model Design

The power communication network resource management architecture is shown in Fig. 1. It includes SSPs, TSPs, power communication network resource allocation centers, and demand side of power communication network (DS). DSs can make resource requests to the power communication network resource allocation center. The power distribution network resource allocation center provides DS with network resources with certain network service capabilities according to resource requirements and resource status of SSPs and TSPs.

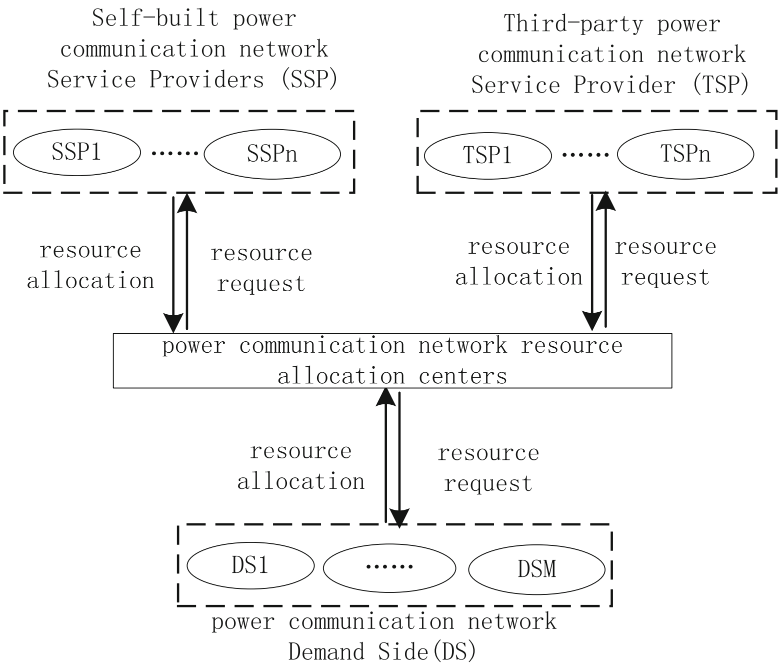

Fig. 1. Resource management architecture

The power communication network resource management architecture is shown in Fig. 1. It includes SSPs, TSPs, power communication network resource allocation centers, and demand side of power communication network (DS). DSs can make resource requests to the power communication network resource allocation center. The power distribution network resource allocation center provides DS with network resources with certain network service capabilities according to resource requirements and resource status of SSPs and TSPs.

In terms of resource demand, the resource demand indicated by the mth power service to the resource allocation center is used, and based on this, the total resource demand submitted by the m power services to the resource allocation center is $\Lambda = \sum_{m=1}^{M} \lambda_m$.

In the provision of power communication network services, it is considered that the purpose of providing services by the power communication service providers is to obtain profits. The difference between a cooperative game and a non-cooperative game is whether there is a binding agreement between the interacting parties. If there is, it is a cooperative game; if not, it is a non-cooperative game. The game theory that economists talk about generally refers to non-cooperative games. Since cooperative game theory is more complicated than non-cooperative game theory, its theoretical maturity is far less than non-cooperative game theory. Therefore, this paper uses a non-cooperative game model to describe the competitive relationship between power communication network service providers. The way to compete is generally to increase the quality of network services by increasing investment, or to attract more customers by lowering prices. Use indicates the total, quantity, where the quantity is expressed in terms of the quantity used $r - m$.

In different time periods, the operation of *SSPi* and *TSPj* needs to invest different funds. In this paper, $c_k^{s,i}$, $c_k^{t,j}$ is used to represent the operating cost of s at time k, The calculation is performed using Eq. (1), where k_1^s, k_1^t represent input factors for customer service and human resources, k_2^s, k_2^t represent input coefficients for network construction and operation. Use $u_k^{s,i}$ and $u_k^{t,j}$ to represent the network data processing capacity of *SSPi* and *TSPj*. The larger the processing capacity, the better the performance of the network, and the constraint condition is $0 < u_k^{s,i} < 1, 0 < u_k^{t,j} < 1$. Use q to represent *SSPi*, *TSPj* for the receiving rate of the service request, the higher the receiving rate, the better the network quality of *SSPi*, *TSPj*. Since the third-party network service provider needs to rent the interface of the power company communication network, it can be integrated with the power communication network service. Therefore, the relationship between k_2^s, k_2^t is $k_2^t > k_2^s$.

$$\begin{cases} c_k^{s,i} = k_1^s u_k^{s,i} + k_2^s q \\ c_k^{t,j} = k_1^t u_k^{t,j} + k_2^t q \end{cases} \tag{1}$$

In the resource allocation center, resource allocation is performed according to the resource demand quantity of the power communication network, the price of the service provider, and the quality of service. The final determined resource allocation ratios for each service provider are calculated using Eq. (2). Where $f_k^{s,i}$ and $f_k^{t,j}$ are used to represent the market proportion of *SSPi* and *TSPj*, and $f_k^{s,i} + f_k^{t,j} \leq \Lambda$. Use a_i and a_j^* indicate the relationship between the service quality of *SSPi*, *TSPj* and $f_k^{s,i}, f_k^{t,j}$. Use b_{ij}, b_{ji}^* to indicate the probability that *SSPi*, *TSPj* can substitute each other.

$$\begin{cases} f_k^{s,i} = a_i u_k^{s,i} - \sum_{l=1,l\neq i}^{m} u_k^{s,l} - \sum_{j=1}^{r-m} b_{ij} u_k^{t,j} \\ f_k^{t,j} = a_j^* u_k^{t,j} - \sum_{h=1,h\neq j}^{r-m} u_k^{t,h} - \sum_{i=1}^{m} b_{ji}^* u_k^{s,i} \end{cases} \tag{2}$$

Based on the above analysis, $U_k^{s,i}$ and $U_k^{t,j}$ are used to represent the effects of *SSPi*, *TSPj*, and the formula (3) is used for calculation. Use $\pi_k^{s,i}$ and $\pi_k^{t,j}$ to represent the profit of *SSPi* and *TSPj*, and use formula (4) to calculate.

$$\begin{cases} U_k^{s,i} = P^s - c_k^{s,i} \\ U_k^{t,j} = P^t - c_k^{t,j} \end{cases} \tag{3}$$

$$\begin{cases} \pi_k^{s,i} = f_k^{s,i} \cdot U_k^{s,i} \\ \pi_k^{t,j} = f_k^{t,j} \cdot U_k^{t,j} \end{cases} \tag{4}$$

3 Competitive Game Objective Function

In the current market economy environment, the service price of the power communication network is relatively consistent and open. Therefore, the competitive approach of

SSPi and *TSPj* is to improve the quality of service as much as possible. However, improving the quality of service requires more human and material resources, which affects the cost of services and thus the value of k_1^s and k_1^t. In order to win in the competition, k_1^s and k_1^t of *SSPi* and *TSPj* will be kept as confidential as possible. In the process of competition, *SSPi* and *TSPj* will estimate their competitor's competitive strategy by collecting historical data of competitors. In this paper, the prediction mechanism of the probability density function based on the service cost coefficient is used to solve the competitor's service cost coefficient, so as to obtain the competition strategy of the competitor.

Use $f(k_1^s)$ to represent the probability density function of k_1^s for *SSPi*, and k_1^s has a value range of (a, b) (where, $0 < a < b$), so $\int_a^b f(k_1^s)d(k_1^s) = 1$. Use $f(k_1^t)$ to represent the probability density function of k_1^t for *TSPj*, and k_1^t has a value range of (c, d) (where, $0 < c < d$), so, $\int_c^d f(k_1^t)d(k_1^t) = 1$. So, the expected values of k_1^s and k_1^t are calculated by formula (5).

$$\begin{cases} E(k_1^s) = \int_a^b k_1^s \cdot f(k_1^s)d(k_1^s) \\ E(k_1^t) = \int_c^d k_1^t \cdot f(k_1^t)d(k_1^t) \end{cases} \tag{5}$$

Based on the expected values of k_1^s and k_1^t, the service capability expectation and the service provider's benefit function are shown in Eqs. (6) and (7), respectively.

$$\begin{cases} E(u_k^{s,i}) = \int_a^b u_k^{s,i} \cdot f(k_1^s)d(k_1^s) \\ E(u_k^{t,j}) = \int_c^d u_k^{t,j} \cdot f(k_1^t)d(k_1^t) \end{cases} \tag{6}$$

$$\begin{cases} E(\pi_k^{s,i}) = \int_a^b \pi_k^{s,i} \cdot f(k_1^s)d(k_1^s) \\ E(\pi_k^{t,j}) = \int_c^d \pi_k^{t,j} \cdot f(k_1^t)d(k_1^t) \end{cases} \tag{7}$$

In order to maximize profits, *SSPi* and *TSPj* can maximize the profit by adjusting the service cost coefficient to improve the service quality and ultimately maximize the market share. So, the objective function of *SSPi* and *TSPj* is shown in Eq. (8).

$$\begin{cases} \max\{E[\pi_k^{s,i}(u_k^{s,1}, \ldots, u_k^{s,m}, u_k^{t,1}, \ldots, u_k^{t,r-m})]\}, i \in \{1, 2, \ldots, m\} \\ \max\{E[\pi_k^{t,j}(u_k^{s,1}, \ldots, u_k^{s,m}, u_k^{t,1}, \ldots, u_k^{t,r-m})]\}, j \in \{1, 2, \ldots, r-m\} \end{cases} \tag{8}$$

Since the service capabilities of *SSPi* and *TSPj* are fixed at a certain moment, this paper maximizes the profit by solving the optimal service capability $(u^{s,i})^*$, $(u^{t,j})^*$ at a certain moment.

$$\begin{cases} (u^{s,i})^* = \arg\{E[\max(\pi_k^{s,i} = f_k^{s,i} \cdot U_k^{s,i})]\}, i \in \{1, 2, \ldots, m\} \\ (u^{t,j})^* = \arg\{E[\max(\pi_k^{t,j} = f_k^{t,j} \cdot U_k^{t,j})]\}, j \in \{1, 2, \ldots, r-m\} \end{cases} \tag{9}$$

Considering that the game parties need to reach the final Nash equilibrium through multiple games, this paper uses Jacobian iterative formula to calculate service capability [9]. Based on the inference process of the reaction function [10], the Eqs. (2), (3) and (4) are transformed to obtain the Jacobian iterative formula of service capability as shown in formula (10).

$$\begin{cases} u_k^{s,i} = \frac{P^s - k_2^s q}{2k_1^s} + \frac{\sum_{l=1,l\neq i}^{m} u_{k-1}^{s,l} + \sum_{j=1}^{r-m} b_{ij} u_{k-1}^{t,j}}{2a_i} \\ u_k^{t,i} = \frac{P^t - k_2^t q}{2k_1^t} + \frac{\sum_{h=1,h\neq j}^{r-m} u_{k-1}^{t,h} + \sum_{i=1}^{m} b_{ji}^* u_{k-1}^{s,j}}{2a_j^*} \end{cases} \tag{10}$$

4 Resource Allocation Algorithm

The flowchart of the service capability optimization algorithm is shown in Fig. 2. The algorithm includes: (1) Service provider *SSPi* and *TSPj* service capabilities $u_k^{s,i}$ and $u_k^{t,j}$ initialization. (2) For each service provider *SSPi* and *TSPj*, use the Jacobian iteration formula to solve the optimal service provider service capabilities. (3) Find the expected value of each service provider *SSPi* and *TSPj* service capability. (4) Determine the outcome of the competition game until an equilibrium state is obtained. (5) The resource allocation center allocates resources based on the service capabilities of each service provider. The details are described below.

(1) Service provider *SSPi* and *TSPj* service capabilities $u_k^{s,i}$ and $u_k^{t,j}$ initialization: When initializing, assign an initial value to each service provider's service capabilities. $u_0^{s,i} = v_i^s \in (0, 1)$, $u_0^{t,j} = v_j^t \in (0, 1)$, among them, $i \in \{1, 2, ..., m\}$, $j \in \{1, 2, ..., r - m\}$.
(2) For each service provider *SSPi* and *TSPj*, use the Jacobian iteration formula to solve the optimal service provider service capabilities: The Eqs. (2), (3), and (4) are transformed to obtain the Jacobian iteration formula (10). The service provider's service capabilities are calculated using Eq. (10) to obtain service capabilities.
(3) Find the expected value of each service provider *SSPi*, *TSPj* service capability. Use Eq. (6) to find the expected value of service capability $E[u_k^{s,i}]$, $E[u_k^{t,j}]$.
(4) Determine the outcome of the competition game until an equilibrium state is obtained. The expected values of service capabilities $E[u_k^{s,i}]$, $E[u_k^{t,j}]$ are determined. If the convergence condition $\left|E[u_{k+1}^{s,i}] - E[u_k^{s,i}]\right| < \varepsilon \; or \; \left|E[u_k^{s,i}]\right| \geq 1$, $\left|E[u_{k+1}^{t,i}] - E[u_k^{t,i}]\right| < \varepsilon \; or \; \left|E[u_k^{t,i}]\right| \geq 1$ is satisfied, the calculation is stopped and the optimal service capability $(u_k^{s,i})^* = E[u_k^{s,i}]$, $(u_k^{t,j})^* = E[u_k^{t,j}]$ is output, at which time the competition game reaches an equilibrium state. If the condition is not met, the k + 1th iteration is performed until the value of the model Nash equilibrium is obtained.
(5) The resource allocation center allocates resources based on the service capabilities of each service provider. The resource allocation center uses the formula (2) to calculate the *SSPi*, *TSPj* market ratios $f_k^{s,i}, f_k^{t,j}$ to achieve resource allocation.

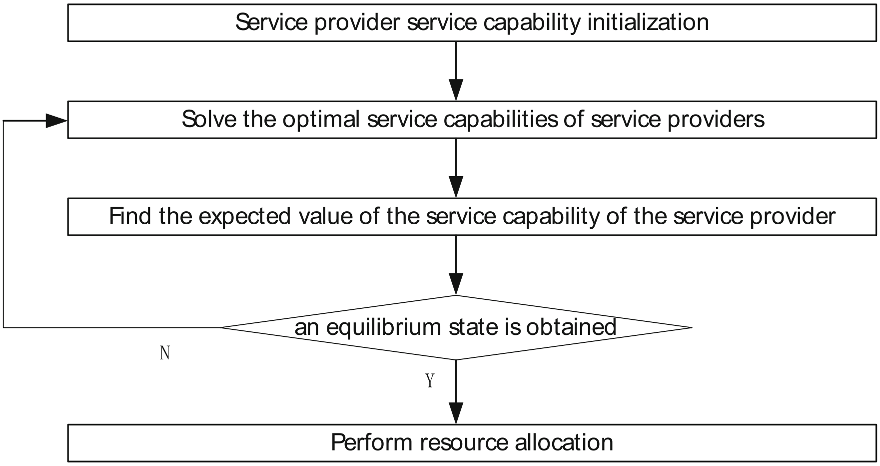

Fig. 2. The flowchart of the service capability optimization algorithm

5 Performance Analysis

In order to verify the results of the algorithm optimization of the power communication network service provider service capabilities. Three competitive game models of competition between *SSP*, competition between *TSP*, and competition between *SSP* and *TSP* were simulated using MATLAB tools. Because the content of the competitive environment is more in line with the actual situation, that is, each service provider cannot know the service cost coefficient of the other party. In the experiment, this environment was compared to an unrestricted environment. Among them, the algorithm in this paper is called the competition game under incomplete information, and the environment without restriction is called the competition game under complete information.

In the simulation environment, the parameter is set to $q = 0.8$, $P^s = 1$, $k_2^s = 1$, $P^t = 0.8$, $k_2^t = 0.8$, $u_0^{s,1} = 0.65$, $u_0^{t,1} = 0.35$. In addition, in the competition game under incomplete information, set $E(k_1^s) = k_1^s = 1$, $E(k_1^t) = k_1^t = 1$, In the competitive game under complete information, $k_1^s = k_1^t = 0.85$. Using the competition between $SSP1$ and $SSP2$ to simulate the competition scenario between *SSP*, set $a_1 = 2.5$, $a_2 = 2.9$, and the experimental results are shown in Fig. 3. It can be seen from the figure that under the incomplete information and the complete information, when the competition starts, $SSP1$ and $SSP2$ do not know the resource input of the other party, so the service capability is not fixed. However, as the number of iterations increases, the service capabilities of $SSP1$ and $SSP2$ gradually converge. The service capabilities of $SSP1$ and $SSP2$ under full information are lower than those under incomplete information. It shows that under incomplete information, both $SSP1$ and $SSP2$ have invested more resources to achieve equilibrium in the competition.

Use the competition between $TSP1$ and $TSP2$ to simulate the competition scene between *TSP*, set $a_1^* = 2.5$, $a_2^* = 2.9$, and the experimental results are shown in Fig. 4. Using the competition between $SSP1$ and $TSP1$ to simulate the competition scenario between *SSP* and *TSP*, set $a_1 = 2.5$, $a_1^* = 2.5$, $b_{11} = 0.5$, $b_{11}^* = 0.6$, and the

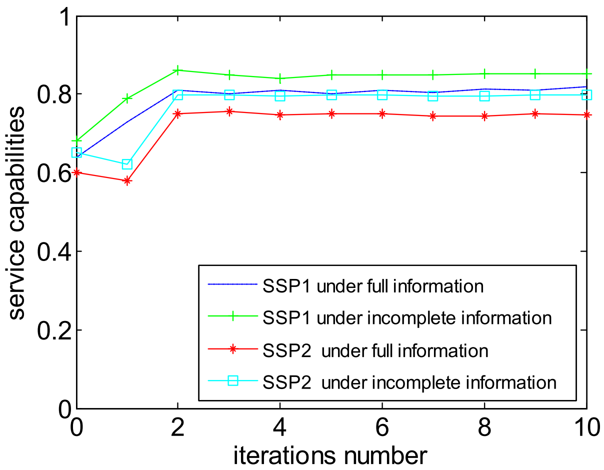

Fig. 3. Service capabilities in a competitive environment

experimental results are shown in Fig. 4 and Fig. 5. As can be seen from the figure, the convergence and resource input of $TSP1$ and $TSP2$, $SSP1$ and $TSP1$ are the same as those in Fig. 3. Therefore, Nash equilibrium is achieved in the two scenarios of competition between *TSP* and competition between *SSP* and *TSP*, and it is more in line with the actual production environment.

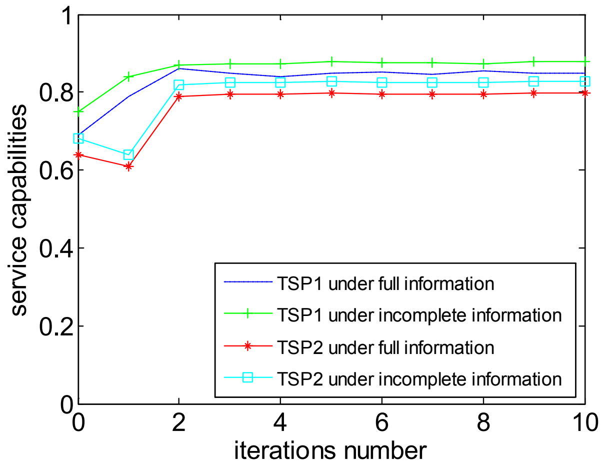

Fig. 4. Service capabilities in a competitive environment

Through the comparative analysis of Fig. 3, 4 and 5, it can be seen that the service optimization algorithm of power communication network service provider in the competitive game environment proposed in this paper can compete between *SSP*, between *TSP*, and between *SSP* and *TSP*. The competition game model is convergent and more realistic than the competition game under full information, so it is more practical for the power company to choose the power communication network service provider.

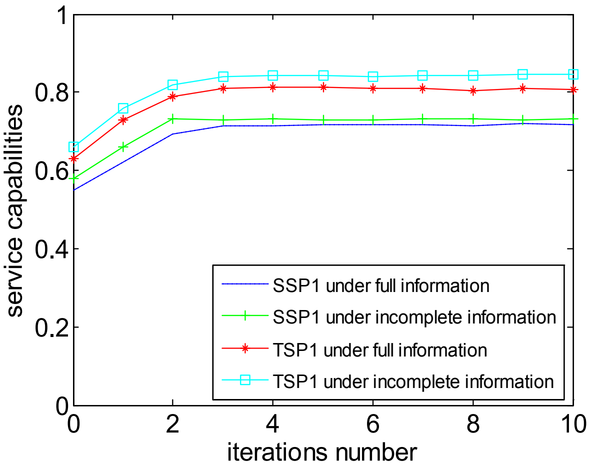

Fig. 5. Service capabilities in a competitive environment between *SSP* and *TSP*

6 Conclusion

With the increasing demand for power communication networks, the network infrastructure built by power companies is gradually unable to meet the development needs of smart grid services. In order to solve this problem, this paper proposes a power communication network resource management architecture, and analyzes how to realize the resource allocation algorithm of power company's revenue maximization under incomplete information. Secondly, the rationality of the model is analyzed through simulation experiments. The simulation results show that the research results of this paper have more practical significance for the power company to choose the power communication network service provider. Although the algorithm is suitable for the real environment, the algorithm only verifies that the model has Nash equilibrium characteristics, and does not analyze the resource utilization in depth. In the next step, based on the model proposed in this paper, we will study how to improve the resource utilization rate of the power communication network.

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