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Identification Method of Hole Boundary Nodes in a Sustainable Service Manufacturing Network

Ziping Du*

Information Engineering College, Suzhou Industrial Park Institute Services Outsourcing, Suzhou 215123, China

The traditional identification method of hole boundary nodes in the sustainable service manufacturing network encounters redundant nodes repeatedly, this has the issues of low identification accuracy, poor generalization ability, large positioning error, high error detection rate and large energy consumption. Therefore, a new method of identifying the hole boundary nodes in a sustainable service manufacturing network is required. Based on the analysis of the user subnet, service provider subnet and product manufacturer subnet, a super network model of sustainable service-oriented manufacturing is constructed. According to the network model, the hole of the sustainable service manufacturing network is detected. The location algorithm, based on distance measurement, is used to locate the nodes in the hole, and the initial boundary triangle plane recursive expansion algorithm is used to identify the boundary nodes in the positioning nodes, so as to complete the research on the identification method of the hole boundary nodes in the sustainable service manufacturing network. Compared with the traditional method, the results show that the error of the proposed method is significantly smaller, and it has a higher recognition accuracy, reduces the energy consumption of the hole boundary nodes in the sustainable service-oriented manufacturing network, reduces the error detection rate, improves the generalization ability, and has good practicability.

Keywords: Sustainable; Service oriented manufacturing network; Network hole; Boundary nodes; Identification method.

1. INTRODUCTION

Under the background of the integration of the service industry and the manufacturing industry, a service-oriented manufacturing network is a new type of relationship co-operation network, based on the concept of specialization and refinement. The network has the characteristics of value-added, innovation and integration, and is a dynamic and efficient relationship network. It includes a supplier module, an integrator module and customer utility module nodes. There are co-operative relationships between the nodes that are both adaptive and constrained. The operational efficiency of the network is closely related to the level of decision-making. A sustainable service-oriented manufacturing network is a new collaborative network formed under the promotion of service-oriented manufacturing mode and sustainable development strategy, which has the characteristics of integration, value-added, innovation and sustainability, and can promote the co-ordinated development of the economy, environment and society [1]. In the process of integrating service and manufacturing, it can reduce the energy consumption of network operation, reduce environmental pollution, improve the social responsibility level of network, and achieve economic, environmental and social performance. In the long run, it can improve the co-operation level of the network, reduce network risk, and achieve sustainable goals. Therefore, the service-oriented manufacturing network can be defined as: in the production process of the product service system, value modules such as customers, producer service manufacturers (finance, law, insurance, accounting, management consulting, logistics, distribution, after-sales service), and service manufacturers (raw material suppliers, parts suppliers, product manufacturers) are based on the cooperation standard. The quasi interface structure and business process collaboration are

*Email of Corresponding Author: zipingdu@126.com

embedded in the value-added network, forming a production collaboration polymer with resource integration, value-added and innovation functions [2].

Coverage is an important index to reflect the quality of a sustainable service-oriented manufacturing network; this also reflects the quality of the node service ability in a sustainable service-oriented manufacturing network. Properly distributing nodes can optimize the resource allocation of a sustainable service-oriented manufacturing network, so as to better complete the task. When the nodes in the sustainable service-oriented manufacturing network are damaged, the regional nodes will fail, resulting in the loss of service in the coverage area of the original network, which is called a coverage hole [3]. With the expansion of the target area, the growth of the network scale and the complexity of the detection environment, the network nodes are likely to be damaged, and the sustainable service-oriented manufacturing network will inevitably produce holes. The general sustainable service-oriented manufacturing network will have more common coverage holes, and has the characteristics of randomness and limitation.

When the sustainable service-oriented manufacturing network is subject to sudden changes, due to the characteristics of instantaneous and destructive changes, a large number of nodes will fail at the same time, increasing the number of coverage holes and expanding the boundary scope of the holes, resulting in large-scale coverage holes.

Large scale coverage holes lead to the limited coverage of the sustainable service-oriented manufacturing network, and can even destroy the connectivity of the network, forming multiple disconnected network islands. This will lead to a global cascading failure, which will lead to the failure of large-scale coverage cavity repair. Moreover, due to the emergence of large-scale coverage holes, the network cannot collect complete and useful data, which will lead to the destruction of the normal functions of the network, the end of the network life cycle, and waste other unused resources left in the network. If an effective method can be proposed to detect these coverage holes, it can be targeted to repair and recover the network to full coverage. In reference [4], a method of dynamically determining the boundary of GNSS tomographic model and adaptive node parameterization is proposed. The boundary of the tomographic region and the node position of each tomographic era are adjusted by combining three grid technologies, namely boundary extraction, Delaunay triangulation and the force displacement algorithm. The new method is tested by using the GNSS data of Hong Kong in May 2015. Compared with the traditional node parameterization method, the performance of this method is verified. However, when the method is used to identify boundary nodes, the error of node location results is large and the error rate is high, which leads to inaccurate recognition results.

In reference [5], a key node identification method combining power tracking technology is proposed. According to the results of power tracking, a new system node connection strength index and load importance evaluation index are defined. Based on the system node connection strength and the actual power flow direction of the system, the power grid weighted digraph is established. The idea of PageRank algorithm based on link analysis is adopted to establish the power system The node importance evaluation calculation model of the network weighted digraph realizes the effective identification of key nodes. However, the recognition process of this method is more complex, which leads to a large energy consumption of nodes, poor generalization ability and low recognition accuracy.

In view of the above problems, this paper proposes a method to identify the hole boundary nodes in the sustainable service-oriented manufacturing network. Compared with the traditional method, the performance of the proposed method is better.

2. IDENTIFICATION METHOD OF HOLE BOUNDARY NODES IN SUSTAINABLE SERVICE MANUFACTURING NETWORK

2.1 Building a Super Network Model

In the general network model of a service-oriented manufacturing network, a unified node is usually used to represent the individual in the network, and the edge of the connecting node represents the relationship between nodes. Therefore, in the general sustainable service manufacturing network model, we can only know whether there is a relationship between any two individuals, but cannot express the relationship between multiple individuals. For example, in the service-oriented manufacturing network, customers, service producers and producer service providers are the main roles in the service-oriented manufacturing network. The service-oriented manufacturing mode emphasizes the co-operation of these three clusters to produce a product service system that meets the market demand, which cannot be expressed in the general network. On the other hand, the service-oriented manufacturing network includes the logistics network, information network, capital flow network, service network and value network. Based on the interaction between networks a special network is formed. Therefore, the general network model cannot fully describe such a network, and the super network architecture and model theory is proposed to solve this kind of network problem.

According to the participants, a service-oriented manufacturing super network mainly includes a user subnet, service provider subnet, product manufacturer subnet, parts manufacturer subnet and raw material supplier subnet. The partial definition of subnets in each layer is given according to the super network theory:

(1) User subnet: represents the demand relationship between users. Its node is the users of all kinds of product service systems, and constructs the edge E_{c-c} of the network based on the demand relationship between users. The user demand network model can then be expressed as:

$$H_c = (C, E_{c-c}) \tag{1}$$

Where $C = \{c_1, c_2, \ldots, c_n\}$ is the set of users of various product service systems; suppose that the boolean variable $\varphi(c_i, c_j)$ is used to indicate whether users c_i

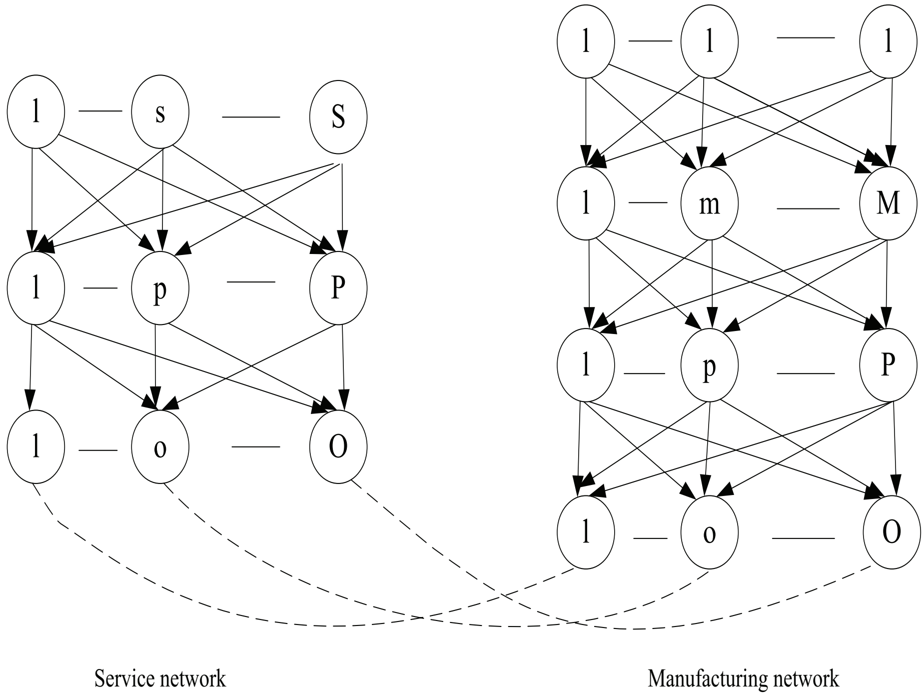

Figure 1 Super Network Model of Sustainable Service Manufacturing.

and c_j have the same requirements, when $\varphi(c_i, c_j) = 1$, there are the same requirements, when $\varphi(c_i, c_j) = 0$, the requirements are different. Therefore, the set of edge of user requirements subnet is:

$$E_{c-c} = \{(c_i, c_j)|\varphi(c_i, c_j) = 1, c_i, c_j \in C\} \quad (2)$$

(2) Service provider subnet: used to represent the competitive relationship between service enterprises. Modern service enterprises mainly include two aspects: consumer service and producer service. Producer service enterprises are one of the three cornerstones of the development of the service-oriented manufacturing mode and the main body of the service-oriented manufacturing network. The nodes of the service provider subnet are all kinds of service enterprises, including design companies, software companies, consulting companies, accounting firms, logistics companies and distributors. The edge E_{s-s} of the network is constructed by the competitive relationship between the service enterprises, so the service provider subnet model can be expressed as:

$$H_s = (S, E_{s-s}) \quad (3)$$

Where $S = \{s_1, s_2, \ldots, s_n\}$ is the set of all kinds of service enterprises. The boolean variable $\varphi(s_i, s_j)$ is used to indicate whether there is a competitive relationship between service enterprises s_i and s_j ; when $\varphi(s_i, s_j) = 1$, there is a competitive relationship; when $\varphi(s_i, s_j) = 0$, there is no competitive relationship. In this way, the set of service network edges can be expressed as:

$$E_{s-s} = \{(s_i, s_j)|\varphi(s_i, s_j) = 1, s_i, s_j \in S\} \quad (4)$$

(3) Product manufacturer subnet: its nodes are all kinds of product manufacturers, and the edge E_{p-p} of the network is constructed based on the competition relationship between product manufacturers, so the product manufacturer subnet can be expressed as:

$$H_p = (P, E_{p-p}) \quad (5)$$

Where $P = \{p_1, p_2, \ldots, p_n\}$ is the set of all kinds of product manufacturer enterprises. Similarly, the boolean variable $\varphi(p_i, p_j)$ indicates whether there is a competitive relationship between product manufacturing enterprises p_i and p_j, when $\varphi(p_i, p_j) = 1$ there is a competitive relationship, and when $\varphi(p_i, p_j) = 0$ there is a non-competitive relationship. The service network edge set is as follows:

$$E_{p-p} = \{(p_i, p_j)|\varphi(p_i, p_j) = 1, p_i, p_j \in P\} \quad (6)$$

From the perspective of member relationship, there is often a complex connection between members of the network organization. There are not only competitive relations but also co-operative relations among members. Therefore, the service-oriented manufacturing network organization is a unity of competitive and co-operative relations. Therefore, a super network model of sustainable service-oriented manufacturing is established as shown in the figure below [6].

In the above figure, within the service-oriented manufacturing network, L is the total number of raw material suppliers, $l \in \{1, \ldots, L\}$; M is the total number of component manufacturers, $m \in \{1, \ldots, M\}$; P is the total number of product manufacturers, $p\varepsilon\{1, \ldots, P\}$; S is the total number of service providers, $s \in \{1, \ldots, S\}$; O is the total number of users (demand market), $o \in \{1, \ldots, O\}$. After the super network model is constructed, the hole of sustainable service manufacturing network is detected.

2.2 Detection of Holes in Sustainable Service Manufacturing Network

In order to detect the holes in the sustainable service manufacturing network, the neighbor nodes of the source nodes need to be found first. According to the sustainable service manufacturing super network model established above, the nodes within the communication radius of each source node in the model are defined as the neighbor nodes of the source node, that is, the nodes whose Euclidean distance from the source node does not exceed its communication radius. According to the definition of neighbor node, the source node needs to find its own one unit distance node. As its own neighbor node, the source node first discovers the service request from the neighbor node; if a node receives the service request, the node ID is recorded in the service request, the service request replies to the node according to the ID in the service request, and attaches its own ID information. If it receives the service request with the ID, it will be discarded; the source node receives replies from other nodes, the neighbor node finds replies to the service request, records the additional ID information in the service request, and sends the neighbor node discovery confirmation request to the node. If the source node receives a duplicate request, it discards it. If the source node no longer receives the reply request, the neighbor node discovery algorithm of the source node ends [7]. After discovering neighbor nodes, the neighbor subgraph is constructed.

The process of determining the connectivity between neighbor nodes by communicating with each other is divided into two parts. The first part is the initial time that the source node constructs the neighborhood subgraph; the second part is when the source node updates its neighborhood subgraph according to the state change of its neighbor nodes in the redundant node detection stage. Firstly, the source node sends the neighbor node synchronization request to each neighbor node, requesting the neighbor node to inform the source node of its neighbor node; the neighbor node sends its neighbor node information to the source node after receiving the request sent by the source node; when the source node receives all the neighbor node's reply information, it traverses the neighbor node's reply information, and the data of neighbor nodes that are not source nodes are removed to form an adjacency table, which represents the neighbor subgraph of source nodes. In the redundant node detection phase, when the source node receives the state change message from the neighbor node, the source node updates the neighbor subgraph according to the state of the neighbor node. If a neighbor node sends a message to the source node and indicates that it is a redundant node, the source node marks the neighbor node as a redundant node and removes all items related to the node in its neighbor subgraph [8]. In the following steps, such as redundant node detection, void boundary detection, etc., it is necessary to traverse the adjacency table to construct the simplex of the specified dimension.

The process of constructing the neighbor subgraph is a process of information aggregation. The source node receives the neighbor information of neighbor node, extracts the information related to itself, and aggregates it into the connection relationship of vertices in neighbor subgraph.

After constructing the neighborhood subgraph, redundant nodes are detected. When detecting redundant nodes, each node judges whether it is a redundant node according to its neighborhood subgraph, in order to simplify the topology of the whole network. When the algorithm determines that a node is redundant, the node will not participate in the void boundary detection process. If it is a source node, it will never be a redundant node; secondly, the algorithm counts the number of effective neighbor nodes of the source node, that is, if there are redundant nodes in the neighbor nodes of the source node, the neighbor node is not considered as an effective neighbor node. By traversing the neighbor subgraph of the source node, the 1-simplex of the neighbor subgraph is constructed. After constructing the 1-simplex, the algorithm will expand the 1-simplex to 2-simplex according to the connectivity between the constructed 1-simplex and the vertices in the current neighbor subgraph. If a 1-simplex is found in the extension process, it cannot be expanded to a 2-simplex and the source node cannot be used as a redundant node, otherwise, the source node will be used as a redundant node, and its neighbors will be notified. After receiving the state change notification from the source node, the neighbor node reconstructs its own neighbor subgraph. This step is a simple process to detect whether neighbor subgraphs can be divided into 2-simplexes by not directly constructing the rings complex of neighbor subgraphs. The specific process of detecting redundant nodes is shown in Figure 2 [9–11].

In (a) of Fig. 2, the source node O has four neighbor nodes A, B, C and D. In (1) of Fig. 2, the connection relationship between the source node O and its neighbor nodes is represented, and in (2) of Fig. 2, the neighbor subgraph of the source node O is represented. When the source node O detects redundant nodes, it first judges the node type, the number of neighbor nodes and the connectivity of neighbor subgraphs, and finds that the graph (2) conforms to the characteristics of redundant nodes; it then constructs 1-simplex (A, B), (B, C), (C, D), (D) by traversing the neighbor subgraphs of the source node O. In the process of constructing 2-simplex, it is found that the degree of vertices in neighbor subgraphs of source nodes is 2, that is, the existing 1-simplex cannot be extended to 2-simplex. Therefore, the node is not a redundant node.

On the contrary, in (b) of Fig. 2, source node O still has four neighbor nodes A, B, C and D, in (3) of Fig. 2, it still represents the connectivity relationship between source node O and its neighbor nodes, in (4) of Fig. 2, it represents the neighbor subgraph of source node O. In (4) of Fig. 2, the algorithm first detects the node type and other factors, and then constructs 1-simplex (A, B), (A, D), (B, C), (B, D), (C, D). Finally, the algorithm tries to expand each 1-simplex into a 2-simplex. For example, 1-simplex (B, D) can be expanded into 2-simplex (A, B, D) and ((B, C), D). At the same time, the two 2-simplexes are checked, and it is found that 1-simplexes (A, B), (A, D), (B, C), (B, D), (C, D) are one of the two 2-simplexes. At this point, it is found that all the 1-simplexes in the neighborhood subgraph of source node O can be expanded to a 2-simplex, that is, the neighborhood subgraph of source node O can be divided into 2-simplex, so the node

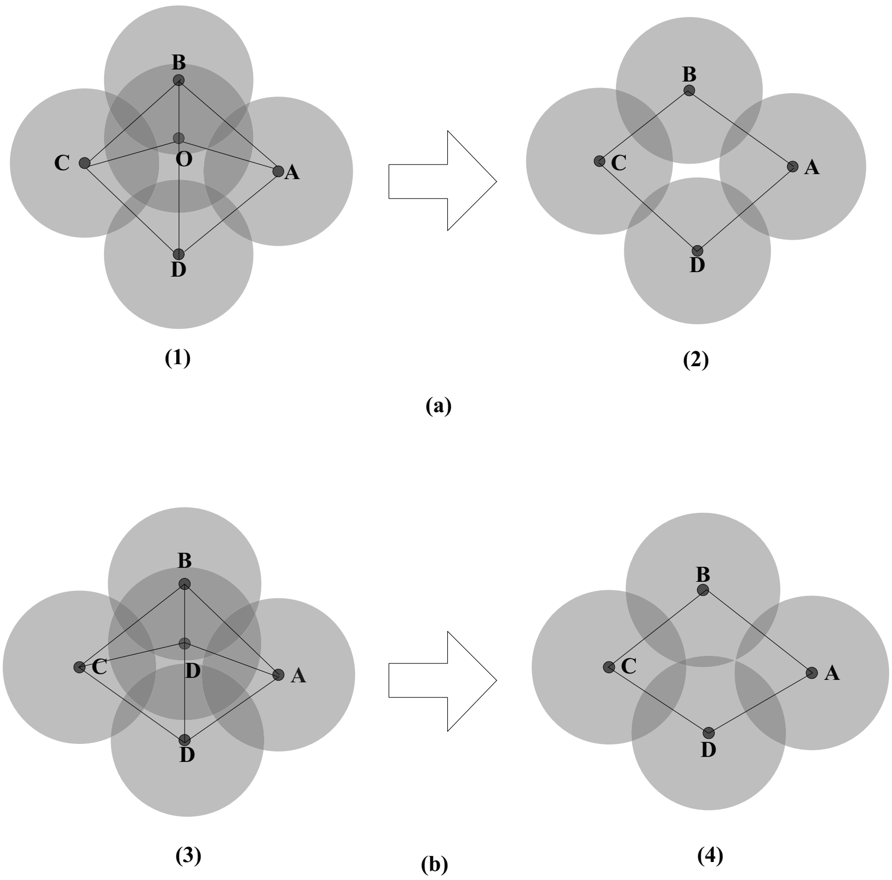

Figure 2 Redundant Node Detection.

can be regarded as a redundant node. After the redundant node detection, the whole network has been simplified into a simple network with simple topology, but its coverage performance is not affected.

The detection unit of coverage hole boundary is the source node and its neighbor node. Since redundant nodes in the network have been removed, the initiator of coverage hole boundary detection is the non-redundant node in the network [12]. In this process, the algorithm first traverses the entire neighborhood subgraph, counts the degree of each non-redundant neighbor node, and then finds the neighbor node with a degree of 1 or 0 in the non-redundant neighbor node, and connects with the source node to form an edge and records it. At this time, the recorded edge is a boundary covering the voids. When several detected boundaries are closed, the detection of network voids is completed. After detecting the holes in the sustainable service manufacturing network, the nodes in the holes are located.

2.3 Cavity Node Positioning

In this paper, the location algorithm based on distance measurement is used to locate the nodes in the network hole. The most commonly used location algorithm based on ranging is trilateral location. When a node in the hole receives three or more beacon signals, three non-collinear points are used to directly establish three binary quadratic equations by trilateral location method. With two subtractions, two binary first-order equations can be obtained, so that the unknown node can be uniquely located.

When a node in the cavity receives four or more beacon signals around it, it uses multilateral positioning to establish a ternary quadratic equation as follows [13]:

$$\begin{cases} (x-x_1)^2+(y-y_1)^2+(z-z_1)^2=d_1^2 \\ (x-x_2)^2+(y-y_2)^2+(z-z_2)^2=d_2^2 \\ \cdots \\ (x-x_n)^2+(y-y_n)^2+(z-z_n)^2=d_n^2 \end{cases} \tag{7}$$

Where the coordinates of three neighbor beacon nodes are $A_1(x_1, y_1, z_1)$, $A_2(x_2, y_2, z_2)$, ..., $A_n(x_n, y_n, z_n)$, $d_1, d_2, \ldots, d_n$ represent the distance from the unknown node to $A_1, A_2, \ldots, A_n$. The second to n equations in Equation (7) are different from the first equation. In this case, four beacon nodes are randomly selected from the n neighbor beacon nodes, and the coplanar combination number is excluded. The average value of each group of equations is then calculated using the four point linkage method, and the result is taken as the positioning result. When the unknown node receives the signal sent by three beacon nodes, for example, Formula (8) only has three ternary quadratic equations, which is transformed into two ternary first-order equations.

$$\begin{cases} (x-)^2+(y-)^2+(z-)^2=d_1^2 \\ (x-x_2)^2+(y-y_2)^2+(z-z_2)^2=d_2^2 \\ (x-x_3)^2+(y-y_3)^2+(z-z_3)^2=d_3^2 \end{cases} \tag{8}$$

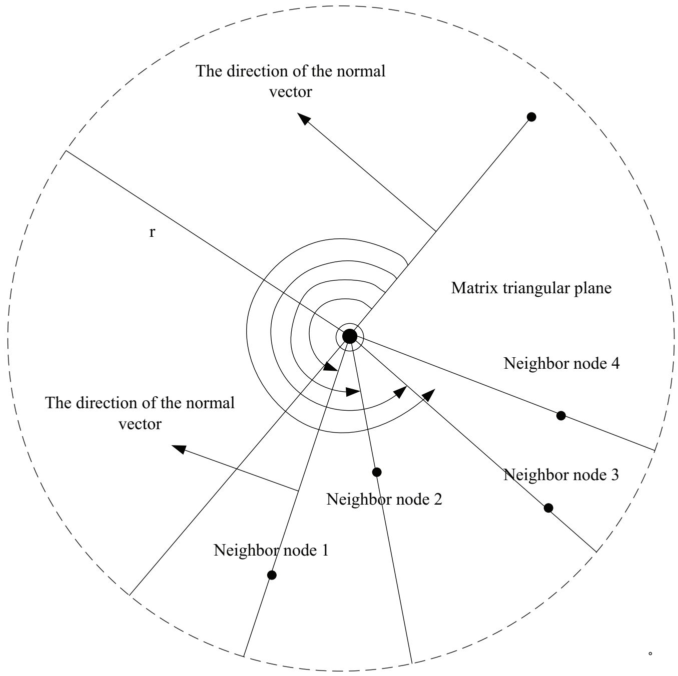

Figure 3 Profile of Triangle Turning.

Where the co-ordinates of three neighbor punctuation points are $A_1(x_1, y_1, z_1)$, $A_2(x_2, y_2, z_2)$, $A_3(x_3, y_3, z_3)$, and d_1, d_2, d_3 represents the distance of unknown node A_1, A_2, A_3. The second equation and third equations in Formula (8) differ from the first equation respectively, and the variance after the difference is solved jointly with the first equation in Formula (8). There are three possible solutions: no solution, only solution and two solutions.

The case of no solution shows that the constraint information is insufficient, and the maximum likelihood estimation method will result in a large error. Therefore, when the unknown node receives three beacon signals and has no solution, it indicates that the unknown node cannot be located. However, in the case of multiple solutions, the solution can be expressed as (x_i, y_i, z_i) (where $i \in 1, n$). In this case, the parameter $z = f(x, y)$ of the sustainable service manufacturing network model can be added as the constraint, the positioning offset can be calculated according to the following formula, and the solution (x_a, y_a) with the smallest offset can be selected as the final solution [14].

$$\begin{cases} \varepsilon_i = z_i - f(x_i, y_i) \\ \varepsilon_{\min} = \min(z - f(x_a, y_a)) \end{cases} \tag{9}$$

After detecting the nodes in the hole of sustainable service-oriented manufacturing network, the hole boundary nodes in the sustainable service-oriented manufacturing network are identified.

2.4 Hole Boundary Node Identification

In this paper, the identification of empty boundary nodes is completed based on the initial boundary triangle plane recursive expansion algorithm. The main idea of the algorithm is to use the edge of the triangle as the axis of the network to flip the plane on the premise of knowing an initial boundary triangle and its vertex order, so as to expand the boundary contour surface, and the points on the polygon vertices of the boundary contour are boundary nodes.

The triangles of the void boundary in the network are all vector triangles, divided into "positive" and "negative" faces. When looking at the sustainable service manufacturing network from the outside, all the boundary triangles should face outward. To meet this condition, all triangle vertex orders should follow the same clockwise direction, that is, when an edge is used to extend the next adjacent triangle, only the vertex order of the edge needs to be reversed. Therefore, there is a one-to-one correspondence between the order of triangle vertices and the positive normal vector. If one of them is determined, the other direction can also be deduced [15].

In the algorithm, the turning of triangles is realized by turning the original boundary points to find new boundary points. It can be said that the turning of triangles is the core idea of the algorithm. When expanding from the original boundary triangle, as shown in the figure below, there is a section view of the past along the direction of one edge of the original triangle. The basis for selecting a new point as the next boundary point is determined by the characteristics of the network boundary node. The new point must satisfy the condition that it is the neighbor node of the original boundary point, and it takes the edge used for expansion as the axis, the original triangle plane as the starting point, and flips the first neighbor node scanned, that is, neighbor node 1 in the figure.

After determining the direction of the new edge, the algorithm must judge whether the distance of the new edge is less than the communication radius. Finally, the sub body edge satisfying the communication radius continues to expand the boundary point until all the edges have completed the expansion operation. After the expansion operation, boundary nodes are identified. In the above figure, all neighbor nodes

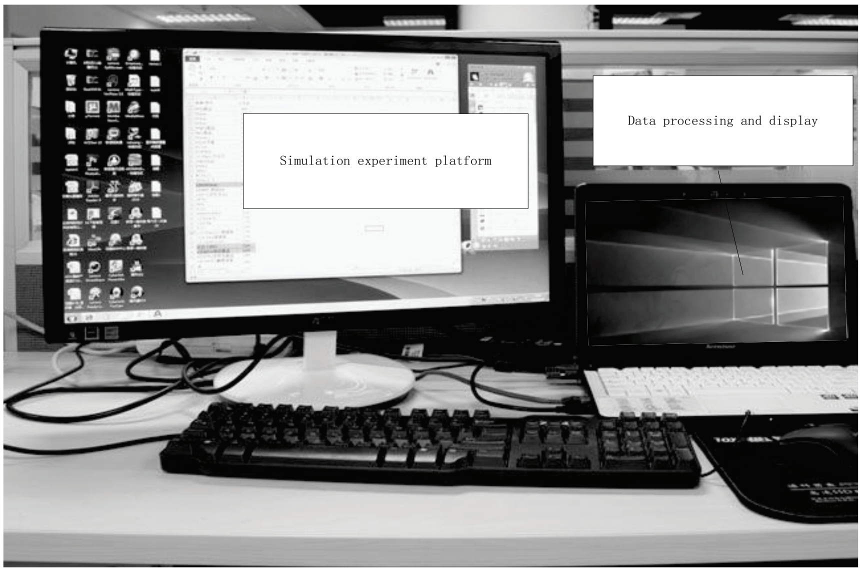

Figure 4 Computer Platform.

are located inside the triangle plane used for expansion (that is, the opposite side of the positive normal vector of the parent triangle plane), so the first point to be scanned is to traverse all neighbor nodes 1, 2, 3, 4. It must then judge whether the other neighbor nodes are in the inner side of the new plane by the new plane composed of the current neighbor node and the parent edge. If so, the neighbor node is the first point scanned, that is, the new boundary point. If not, the search continues to expand. The first point finally scanned is neighbor node 1. According to the above steps, after identifying all the nodes in the hole, the final result is the boundary node of the hole in the sustainable service manufacturing network. So far, we have completed the research on the identification method of the empty boundary node of the sustainable service manufacturing network.

3. EXPERIMENTAL RESULTS AND ANALYSIS

In this paper, the identification method of hole boundary node in sustainable service manufacturing network is studied.

3.1 Experiment Content

This experiment is a comparative simulation experiment based on Windows 10 and MATLAB 2016 B. The experimental comparison group are the methods provided in literature [4] and literature [5] respectively, and the experimental group is the hole boundary node identification method of sustainable service manufacturing network studied in this paper. The experiment is divided into five groups: the experimental group and the control group, respectively, to compare the recognition accuracy, generalization ability, positioning result error, node energy consumption and error detection rate. By measuring the experimental results of five groups of experiments, this paper evaluates the performance of the hole boundary node identification method in the sustainable service-oriented manufacturing network.

3.2 Setup Experiment Simulation Platform

The simulation process uses computer or other hardware devices to simulate and realize an event according to the instructions of the algorithm. Combined with the relevant knowledge, this paper builds a simulation platform for boundary node recognition on the computer platform as shown in the figure below.

The whole simulation platform is implemented in the C++ language, and the compiling and debugging tool is Microsoft Visual Studio 2008. As recursion is used in the algorithm extension, and the STL template library is integrated in Visual Studio, it is convenient for algorithm programming. QT 4.4.0 is used to realize the user interface of the simulation platform, because QT is a cross platform C++ open-source graphical user interface (GUI) library, which can be used for GUI development. The visualization is implemented in Open GL, which has strong independence and good compatibility with Visual Studio. It can ensure the reliability and correctness of the algorithm.

3.3 Experimental Process and Results

3.3.1 Recognition Accuracy

In the experiment, 30 different sustainable service manufacturing network model nodes are deployed. The nodes are set to send Hello messages every 6s to collect and update their neighbor information. The experimental environment is shown in Figure 5:

This paper uses the method to identify 30 different sustainable service manufacturing network model nodes, and the recognition results are shown in Figure 6.

Figure 5 Experimental Environment.

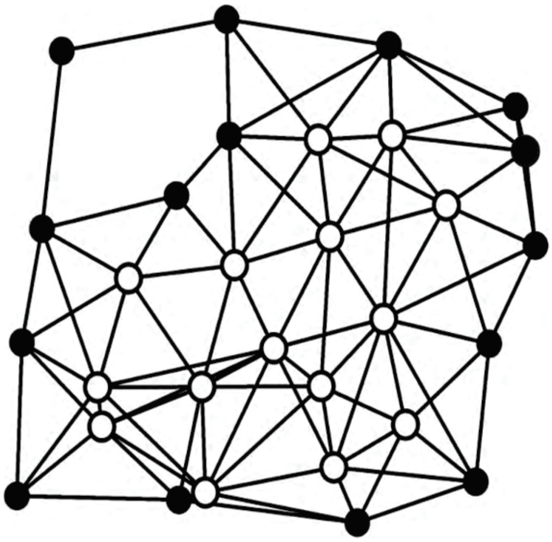

Figure 6 Node Identification Results.

Aa shown in Figure 6, the white nodes in the figure are the internal nodes, and the dark gray nodes are the boundary nodes. It can be seen that this method can accurately identify the sustainable service manufacturing network model node.

In order to further verify the accuracy of this method, different node scale and node density of the sustainable service manufacturing network model are setup, and three boundary node identification methods of experimental group and comparative group are used to identify different parameters of the network. The monitoring software of the virtual simulation platform is run, and the recognition accuracy of three methods under different network parameters is counted. Under different experimental parameters, the recognition accuracy of three kinds of boundary node recognition methods is shown in the table below. The data in the table is analyzed and relevant conclusions are drawn.

It can be seen from the above table that the recognition accuracy of the three methods is different when the number of nodes in the same network and the density of nodes are different. The recognition accuracy of literature [5] method is higher than that of literature [4] method, and lower than that of this method. When the number and density of different network nodes are the same, the recognition accuracy of literature [4] method and literature [5] method is far less than that of this method. At the same time, with the increase of node density, the recognition accuracy of boundary nodes is also increasing. This is mainly because the increase of node density results in the network coverage ability also increasing. From the aspect of topological connection and calculation, the accuracy is improved, so the recognition accuracy of nodes is also improved. This demonstrates that the method in this paper has higher recognition accuracy for the network void boundary nodes.

3.3.2 Generalization Ability

A sustainable service-oriented manufacturing network with 2000 nodes is randomly deployed. There is a coverage hole in the network. The comparison results of generalization accuracy of the three methods are shown in Figure 7.

According to Figure 7, the generalization accuracy of this method is between 45% and 80%, that of literature [4] method is between 25% and 60%, and that of literature [5] method is below 30%. The generalization accuracy of this method is higher than that of literature [4] and literature [5], which shows that the generalization ability of this method is stronger, as it can clearly describe the network boundary and the edge area covering the hole, thus improving the detection effect of the network hole boundary node.

Table 1 Recognition Accuracy of Three Methods {%}.

Serial number	The node size	The node density	Literature [4] method	Literature [5] method	Article method
1	50	8	58.3	63.7	90.8
2	100	10	56.6	62.4	91.1
3	100	12	64.7	71.1	92.4
4	100	14	64.9	72.2	89.9
5	200	14	60.2	73.3	91.5
6	200	18	65.1	73.3	93.2
7	200	20	67.6	73.7	89.6
8	300	22	65.3	74.4	90.7
9	300	24	67.3	77.2	89.4
10	300	26	69.1	78.1	92.2

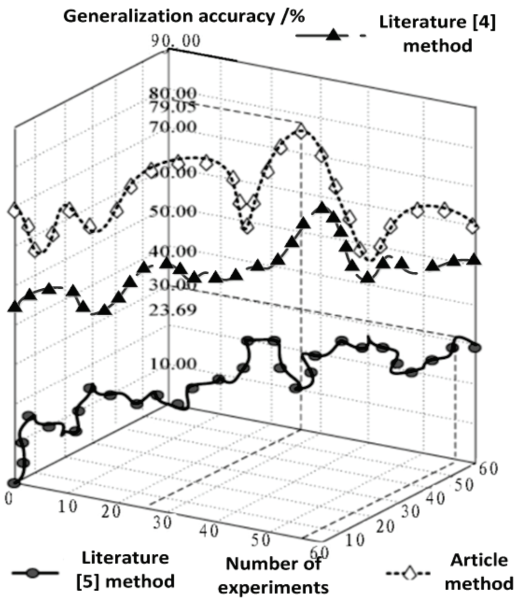

Figure 7 Generalization Accuracy.

3.3.3 Node Energy Consumption

The energy consumption of nodes during identification is the key index that affects the quality of identification methods. Parameters such as the number of nodes in the network, node density and communication radius are set. The figure below shows the energy consumption of three kinds of boundary node identification methods for network nodes during the identification of network empty boundary nodes.

It can be seen from the analysis of the above figure that with the increasing density of network nodes, the energy consumption of the nodes is also increasing when the three kinds of node identification methods identify the empty boundary nodes in the network. However, the increase speed of literature [5] method is smaller than that of literature [4], and larger than that of this method. In this experiment, with the increase of experimental parameters, the maximum node energy consumption of reference [4] method is 254 MJ, the maximum node energy consumption of reference [5] method is 173 MJ, and the maximum node energy consumption of this method is 121 MJ. It shows that the energy consumption of nodes is the least in this method.

3.3.4 Positioning Result Error

In order to verify the effectiveness of the method in this paper, the location results of three groups of methods for the hole boundary nodes of sustainable service-oriented manufacturing network are compared with the actual location results, and the comparison results are shown in Figure 9.

According to Figure 9, the fitting degree between the positioning results of the hole boundary nodes in the sustainable service manufacturing network of this method and the actual positioning results is 99.8%, while the positioning results of the hole boundary nodes in the sustainable service manufacturing network of literature [4] and literature [5] are quite different from the actual positioning results, this shows that the positioning results of this method have only a small error margin and can accurately identify the sustainable manufacturing network service-oriented manufacturing network void boundary node.

3.3.5 Noise Factor

In order to further verify the effectiveness of the method in this paper, the false detection rate of three groups of

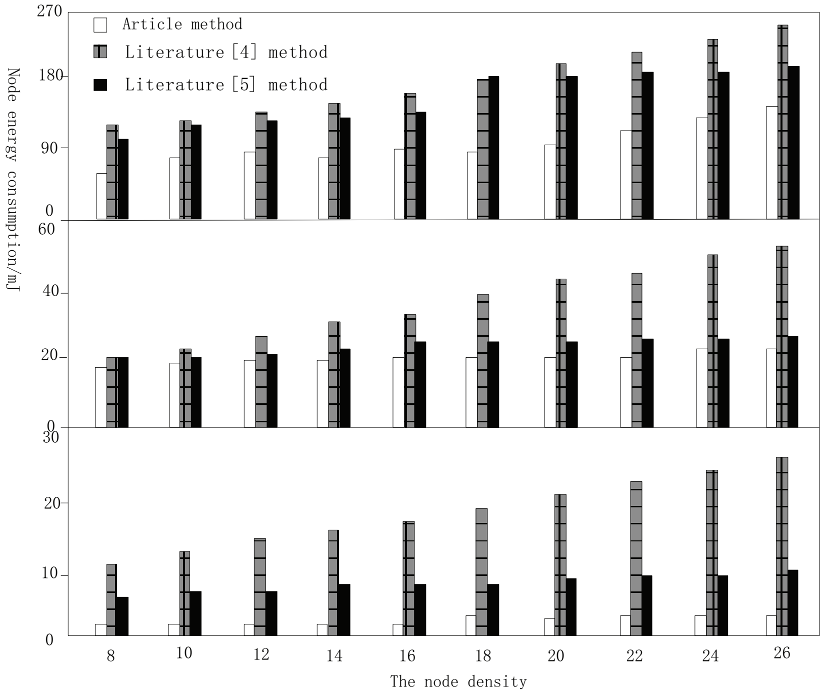

Figure 8 Comparison of Node Energy Consumption.

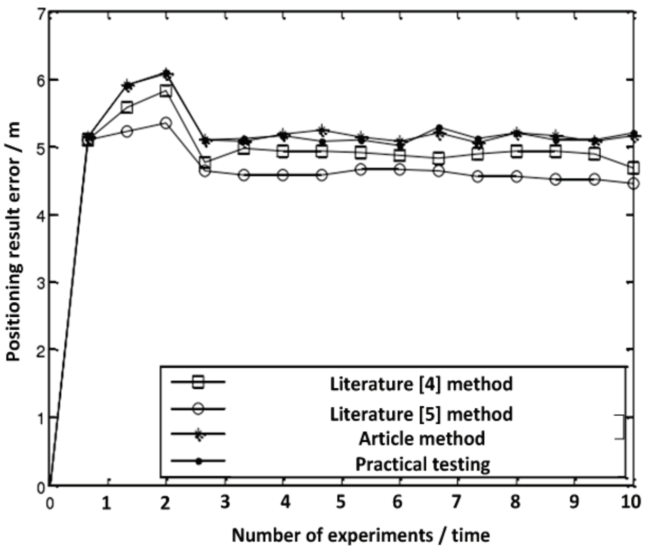

Figure 9 Error Comparison of Positioning Results.

methods for the hole boundary nodes in the sustainable service manufacturing network are compared, and the comparison results are shown in Figure 10.

According to Figure 10, the false detection rate of the hole boundary nodes in the sustainable service manufacturing network of this method is within 11%, while the false detection rate of the hole boundary nodes in the sustainable service manufacturing network of literature [4] method and literature [5] method are within 60% and 23% respectively, which shows that the false detection rate of the hole boundary nodes in the sustainable service manufacturing network of this method is lower than that of literature [4] method and literature [5].

To sum up, the identification method of the hole boundary nodes in the sustainable service-oriented manufacturing network studied in this paper has higher identification accuracy, excellent generalization ability, lower false detection rate, and less energy consumption for nodes and less node positioning error. Compared with the traditional node recognition method, the performance of this method is better.

4. CONCLUSIONS

The service-oriented manufacturing network is evolved on the basis of the service-oriented manufacturing model. The service-oriented manufacturing model has the characteristics of resource integration and collaboration. It is based on the concept of specialization and refinement of the division of labor, and pays attention to customer participation, so

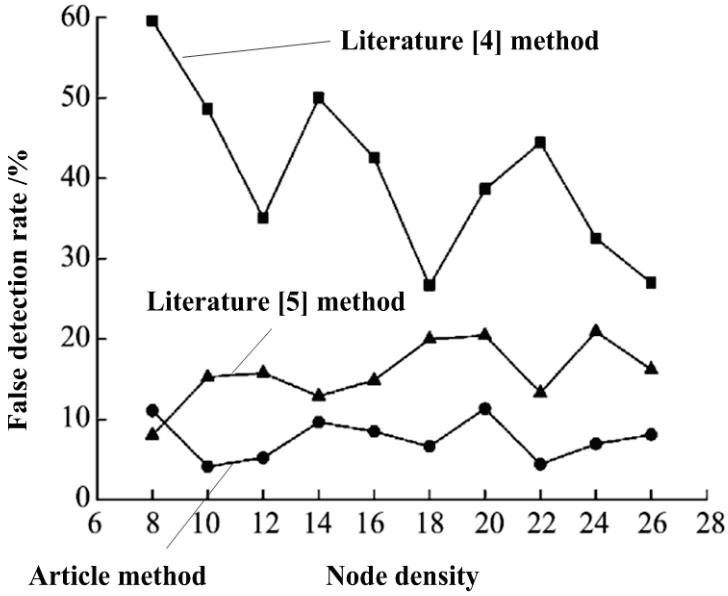

Figure 10 False Detection Rate of Boundary Nodes.

as to realize the value-added nature of each node in the supply chain in a more efficient collaboration. Service manufacturing is an innovative and efficient manufacturing mode. However, the service of the network will be affected by the hole, so it is very helpful to identify the hole boundary nodes by using appropriate methods in order to repair the hole in time. This paper studies the method of identifying the hole boundary nodes in the sustainable service-oriented manufacturing network, and proves that the performance of this method is better by comparing with traditional methods.

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