Grid Resource Discovery Algorithm of the Multi-layer Overlay Network Model Based on Distance

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***Abstract*—The resource discovery mechanism is a hot topic issue in grid environments and It has great impact on the efficiency of the resource sharing and cooperative computing. Based on the domain and resource routing nodes, a grid resource discovery model of multilayer overlay network was given in this paper. And on this basis, using a linear combination of the block distance and chessboard distance instead of Euclidean distance, grid resource discovery algorithm based on distance was proposed. Experiment shows that the algorithm has low cost, fast response and can obtain better success rate of lookup, as well as the effectiveness of the resource discovery algorithm.**

***Index Terms*—Grid; model; distance; resource discovery; multi-layer overlay network**

I. INTRODUCTION

Grid computing connects a large amount of geographically distributed heterogeneous resources to form a virtual network environment, enabling the users to share resources dynamically, which can effectively improve the utilization rate of resources and system performance. In the dynamic grid environment, resources are huge and have strong heterogeneity. The problems of resource management and lookup under ensuring high efficiency and using as possible as low cost become very complex. Grid resource discovery mechanism in grid system is the key to realize resources sharing. Grid resource discovery mechanism performance directly determines the performance of the grid system. So it is necessary to design grid resource discovery algorithm with a low cost, good scalability and high efficiency.

II. RELATED WORK

At present, many organizations and researchers both at home and abroad study grid resource discovery model from different perspectives and different levels. The unified strategy to manage resources in the grid is adopted in the Globus centralized model proposed in [1]. It has a good global control and high efficiency of resource discovery, but it lacks adaptability and extensibility in grid. Resources are managed through the interaction of different resource management systems in the P2P distributed model proposed in [2-4]. And just the opposite of the centralized model, it has a good scalability and lacks in the overall control. Besides, the communication costs of whole model are far higher than these of the centralized model. The flooding technology to find the resources is adopted in [5]. In the face of the grid dynamic environment, it has good fault tolerance and availability, but poor extensibility. The distributed resource discovery based on the virtual structure is adopted in the resource discovery mechanism based on Overlay Network (ON) proposed in [6] and Tree-Structured Overlay Network (TSON) in dynamic grid environment proposed in [7]. The ON and TSON can shield dynamic characteristics of grid resources and heterogeneity effectively. But they also have some deficiencies: because they partition Organizational virtual structured domain based on the physical area and use attribute matching method to find the resources, they cause large network consumption and poor efficiency. Using the combination of the layered structure and tree structure, the model based on Multi-Layer Overlay Network to discover resources is proposed in this paper.

III. RESOURCE DISCOVERY MODEL

Overlay network is a virtual network which is built on a physical network. It is connected by virtual or logical links. It can provide more reliable and better fault-tolerant application services without changing existing large-scale network architecture. Each layer of overlay network uses a structured P2P technology, which is advantageous to dynamically join, leave and forwarded services of the virtual node. Multi-Layer Overlay Network(MLON) resources organization mechanism proposed in this paper is made full use of the overlay network technology and resources which are large, widely distributed, heterogeneous and dynamically changed in the grid of

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P2P technology organizations to better meet the dynamic environment of the grid system.

A. Model Organization Structure

MLON uses the combination of the hierarchical structure and tree structure to organize overlay network. As the service nodes at the bottom, all the resources in the grid constitute the physical resource layer of the model framework. A large number of grid resources are classified according to the type of resources. The virtual organization with an internal structure is managed by the corresponding overlay network node. Multi-layer overlay network structure is shown in Figure 1.

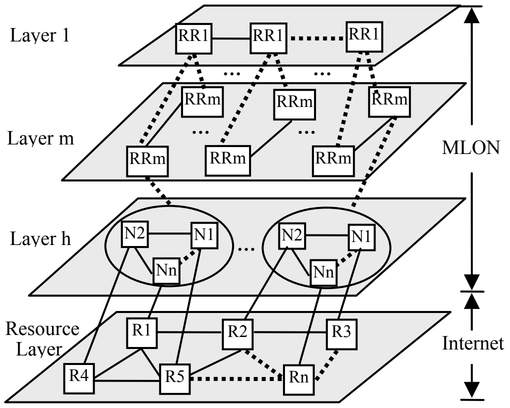

Figure 1. The frame of MLON

Overall, MLON structure will be divided into two levels: the upper layer is the overlay network layer, namely, MLON layer; the lower layer is the physical resource layer, namely, the Internet layer. MLON consists of multiple virtual layers. All nodes in each layer are classified by the resource type and belong to different domains, respectively. Each domain is independent, and each node in the domain uses the graph structure to connect each other in the form of structured peer-to-peer. Each layer adopts the method of the upper managing the lower. A virtual node of the upper manages a domain of the layer. Looking down from the top of a node, virtual nodes adopt tree structure to organize them.

Domain and layer as the basic logic unit is used in the MLON. A vast amount of resources are logically divided into several domains through the classification. Each domain is managed by the Resource Router. Resource router holds a large number of service information of the domain nodes. Resources belong to different domains by type. When virtual nodes of a domain increase to a certain number, the domain is divided into two or more smaller domains, which leads to the granularity of resource type small; on the contrary, when the nodes of a domain are reduced to a certain number, the domain nodes is merged, which leads to the granularity of resource type large. Thus a multilayer overlay network is formed.

B. The Basic Definition

Definition 1: Grid Resource $R=<ID,A,op()>$, where *ID* represents the resource *R* identifier; *A* represents the attribute collection of the resource *R*; *op()* indicates the set of operations of the resource *R*. When $r\in R$: $a_i(r)=\{a_{i1},a_{i2},\cdots,a_{ij}\}$, $op_i(r)=\{op_{i1}(r),op_{i2}(r),\cdots,op_{ik}(r)\}$.

Definition 2: Resource Management Model $G=<N_G,E,R,T>$, where N_G represents the set of all the nodes in the grid, that is to say $N_G=\bigcup_{i=1}^{n}n_i$; *E* denotes the set of edges in the network; *R* denotes the set of all resources in the grid, that is to say $R=\bigcup_{i=1}^{n}r_i$; *T* indicates the collection of the type of resource, that is to say $T=\bigcup_{k=1}^{m}t_k$. As $r_i\in R$, for $\forall$ i, $j\in[1,n]:r_i\cap r_j=\varnothing$. When the type of resource r_i is represented by $r_i(a)$, i.e. $r_i(a)=t_i$, $t_i\in T\Rightarrow R(A)\in T$, for $\forall$ i, $j\in[1,m]:t_i\cap t_j=\varnothing$.

Definition 3: Domain For each type of resource, the connected and structured P2P, called domain, is constructed by lots of information nodes which register with the type of resources.

Definition 4: Overlay Network Node $n_V=<VID,des,indexlist>$, where *VID* represents the virtual node n_V identifier in the overlay network; *des* indicates the description of the node n_V; *indexlist* indicates the pointer list of the node n_V, it contains pointers of linking to the parent nodes, the child nodes and the brother nodes, namely $indexlist=\{index\_f,index\_s,index\_b\}$. Each resource is assigned a globally unique *VID* address by overlay network, which is bundled with resource node *ID*. *VID* includes two parts of domain number (VID_r) and intra-domain node number (VID_s), then two parts are divided and each segment represents a certain type of resources.

Definition 5: MLON Model $G_V=<N_V,rf,IndexList>$, where N_V indicates the set of all the nodes in MLON, namely $N_V=\bigcup_{i=1}^{n}n_{Vi}$; *rf* is the function of resources registration; *IndexList* means the set of the pointer list in MLON.

Definition 6: Resource Router Define the non-leaf nodes in the MLON model as *RR*(Resource Router)

Definition 7: the function of resources registration *rf* The domain of the MLON is divided by resource type which is determined by resource properties. For each resource, whether it is static attribute or dynamic attribute, it is only active in a particular area[8]. If $a_j(r) \in [c,d]$, m control points are inserted in the interval $[c,d]$, when $c = c_0 < c_1 < \cdots < c_{m-1} = d$ and $b = (b_0, b_1, \cdots, b_{m-1}) = (0,0,\cdots,0)$, for any $a_j(r_i)$:

$$b_k = \begin{cases} 1, a_j(r_i) = [c_k, c_{k+1}) \\ 0, \quad else \end{cases} \tag{1}$$

On the basis of formula (1): $rf_j(a_j(r_i)) = b = (0,\cdots,1,\cdots,0)$, then $rf(a(r_i)) = \bigcup_{j=1}^{n} rf(a_j(r_i))$

According to the definition 1 and 2, the following assumptions are made:

Assumption 1: A resource belongs to only one type of resource, i.e. $|r_i(a)|=1$. A resource can be registered on multiple resource routers, one is the resource registration node, others are nodes of the copy.

In order to better describe the structure of the MLON model, according to the definition, the following assumptions can be made:

Assumption 2: The neighbor of the node n_V is only its brother, i.e. $index\_f(n_V) = index\_f(index\_b(n_V))$.

According to the definition and description, node n_{vi} in MLON has the following characteristics:

(1) $\forall n_{vi} \in N_V$, if $indexlist_i(n_{vi}) \neq \varnothing$, then $\exists indexlist_i \in IndexList$.

(2) $\forall n_{vi} \in N_V$, if $index\_s(n_{vi}) \neq \varnothing$, then $n_{vi} \in RR$.

(3) $\forall n_{vi} \in N_V$, if $index\_f(n_{vi}) = \varnothing$, then n_{vi} is the top-level resource router node in MLON.

(4) $\forall n_{vi} \in N_V$, if $index\_s(n_{vi}) = \varnothing$, then n_{vi} is the leaf node in MLON.

Non-leaf node (i.e. resource router) in MLON is only responsible for managing resource sub-tree which uses it as the root and provides the sub-tree information for the upper node. The nodes on the bottom are called leaf nodes and the leaf nodes correspond to resource nodes of the physical network, which contain all the information of resources. In MLON, leaf nodes and non-leaf nodes only distinguish logically.

Ⅳ. RESOURCE DISCOVERY ALGORITHM

Resource discovery algorithm focuses on resource searching. If the grid dynamic changes like the joining or exiting of the nodes are mastered, good resource discovery algorithm is able to resource search. Considered with the dynamic change of grid environment from the resource routing nodes service deployment and the resource nodes register, the resource discovery algorithm of the Multi-Layer Overlay Network model based on distance is obtained.

A. *Resource Routing Nodes Service Deployment*

RR nodes service deployment question [9] is that, which nodes of the physical network layer should be undertaken the resource routing service to make the sum of the cost of service provided by MLON as small as possible. At the same time, the cost to put the service and the withstood load of every *RR* should be considered.

When $N_G^{'}$ represents the physical node that can provide service, then $N_G^{'} \subseteq N_G$; $e: N_G \times N_G \to (0,\infty)$, $e(i,j)$ indicates the communication cost between node n_i and n_j, then $e(i,j) = e(j,i)$; $c \to (0,\infty)$ denotes the cost from deployment service to a node.

0-1 planning model of *RR* nodes service deployment question in MLON is the formula (2).

$$\min\Big(\sum_{n_j \in N_G - N_G^{'}} \sum_{n_i \in N_G^{'}} x_{ij} e(i,j) + \sum_{n_i \in N_G^{'}} y_i c(i)\Big) \tag{2}$$

For any $n_i \in N'_G$ and $n_j \in N_G - N'_G$, x_{ij} and y_i are the decision variable of *0-1* planning model, the constraint condition is that:

(1) $\sum_{n_i \in N_G^{'}} x_{ij} \ge 1$, $n_j \in N_G$;

(2) $\sum_{n_j \in N_G - N_G^{'}} x_{ij} \le k_i y_i, n_i \in N_G^{'}$, where k_i is the load coefficient.

(3) $x_{ij} \le y_i, n_i \in N'_G$, $n_j \in N_G - N'_G$;

(4) $x_{ij}, y_i \in \{0,1\}, n_i \in N'_G$, $n_j \in N_G - N'_G$.

where (1) we ensure each physical node has at least one overlay network node that provides service for the physical node. (2) we pledge that each overlay network node cannot exceed their carrying capacity. (3) we assure the validity of the association between overlay network nodes and physical nodes. (4) it specifies the value space of the decision variables.

The placement strategy of *RR* node of Overlay Network explains as follows:

$$y_i = \begin{cases} 1, Node\ i\ is\ chosen\ for\ node\ RR \\ 0, else \end{cases} \quad n_i \in N'_G;$$

$$x_{ij} = \begin{cases} 1, Node\ i\ provides\ overlay \\ \quad network\ service\ for\ node\ j \\ 0, else \end{cases} \quad n_i \in N'_G,$$

$n_j \in N_G - N'_G$.

B. *The Maintenance of Multilayer Overlay Network*

Because of the dynamic of the resources in the grid environment, MLON must be able to self organize and maintain. It mainly includes the registration of resources, the cancellation of resources, the update of resources information and the failure and exception handling of resource nodes.

B1. Resource Registration

When node n_i issues resources, it sends registration request with the URSL (Unification Resource Specification Language) to the node $n_i^{'}$ which is the nearest from n_i and joins the MLON, then $n_i^{'}$ transmits the request of n_i towards *RR*. On the basis of resource registration function *rf* , *RR* generates the VID_r .Then on the basis of VID_r , MLON lets resources join the same category of resource domain and distributes VID_S ,then generates logic node n_{vi} of the resource and set the service status of n_{vi} as valid.

B2. Resource Cancel

The resource node n_{vi} sends canceled report to the father node $index\_f(n_{vi})$ and adjacent node $index\_b(n_{vi})$. If the node is not *RR* node, the father node and adjacent node will delete its information from information table. Otherwise, the node must transfer service task to backup resource nodes, and then cancel the resource service.

B3. Resource Information Update

During operation of any resource node n_{vi}, it should regularly send update information which should include the current property $a^{'}(r_i)$ and status $op^{'}(n_{vi})$ to the parent node *RR*. Then on the basis of update information of reception, *RR* handles the type of n_{vi}.

B4. Resource Node Failure and Exception Handling

If the resource nodes n_{vi} can not emit any updated information within a specified time slice, its father node $index\_f(n_{vi})$ sends timeout detection to n_{vi}. If it can not get the response of n_{vi}, the parent node sends a report to MLON, then do invalid or exception handling.

C. Resource Discovery Algorithm

C1 The Problem Description

Definition 8: Grid resource discovery model for request processing $K = \{G, request(R(A)), l\}$, where $request(R(A))$ signifies the search request, it defines the various attribute constraints which the resources of finding should be met; *l* denotes the request-forward strategy in the process of resource searching; *K* indicates the collection of resources found in resource discovery process, which matches the search request.

It has a lot of similarity among resource nodes in each domain of virtual network. When looking for resources, users are usually not concerned about a resource or a certain type of resources, but only pay attention to the most relevant *k* results with the needs. The proposed resource discovery algorithm in this paper combines Source Searching Technique Based on Style Matching Routing (SMRT) with Source Searching Technique Based on Topk Algorithm (TopkT) to finally find the collection of resources *K* which match the search request of user.

Definition 9: Euclidean distance The $P_1 = (x_1, x_2 \cdots, x_n)$ and $P_2 = (y_1, y_2 \cdots, y_n)$ are regarded as the point in V_n , so we can define the formula of Euclidean distance $d(P_1, P_2)$ as follows:

$$d(P_1, P_2) = \|P_1 - P_2\| = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \tag{3}$$

Definition 10: Blocks distance For any $P_1 = (x_1, x_2 \cdots, x_n)$ and $P_2 = (y_1, y_2 \cdots, y_n)$, $P_1, P_2 \in R^n$, so we can define the formula of Blocks distance $d_s(P_1, P_2)$ as follows:

$$d_s(P_1, P_2) = \sum_{i=1}^{n} |x_i - y_i| \tag{4}$$

Definition 11: Chessboard distance For any $P_1 = (x_1, x_2 \cdots, x_n)$ and $P_2 = (y_1, y_2 \cdots, y_n)$, $P_1, P_2 \in R^n$, so we can define the formula of Chessboard distance $d_c(P_1, P_2)$ as follows:

$$d_c(P_1, P_2) = \max_{1 \le i \le n} (|x_i - y_i|) \tag{5}$$

Theorem 1: For any $P_1 = (x_1, x_2 \cdots, x_n)$ and $P_2 = (y_1, y_2 \cdots, y_n)$, $P_1, P_2 \in R^n$,then $d_c(P_1, P_2) \le d(P_1, P_2) \le d_s(P_1, P_2)$.

After the user requests resource, grid system can quickly find the resource domain which matches the request of user, because the *RR* in the resource domain is responsible for assigning the most appropriate resources. Resources in the resource domain can be uniformly represented with a point of the m-dimensional coordinates. Searching a resource can be seen seeking a point that satisfies the query conditions in the m-dimensional coordinates. So, $request(R(A))$ can be converted into seeking the *k* resources which satisfy the query conditions and whose distance is nearest from enquiry point in the m-dimensional coordinates.

By the Euclidean distance formula, m-dimensional resource attribute query can be converted into a one-dimensional distance query to meet the grid resource discovery mechanism principles of multiple attribute queries. According to the formula (3), (4), (5), it can be seen that the calculation of d_s and d_c is simpler than the calculation of d. According to theorem 1, if we use d_s instead of d, the calculated value will be larger; if we use d_c instead of d, the calculated value will be smaller; deviation value of the two methods are often large. So we can consider using an appropriate linear combination of the d_s and d_c instead of d. This will not only improve the efficiency of calculation, but also make the deviation value smaller. According to the proposed method in [10], we can calculate $\alpha(d_s + d_c)$ instead of d.

When searching for resource, users often have a preference for a certain attribute, so the resource attributes are weighted according to users' need when they query. Let $W(w_{m-1}, \cdots, w_1, w_0)$ be the attribute weight of resource r_i, where $\sum_{i=0}^{m-1} w_i = 1$. So the distance between resource r_i and enquiry point r is given below.

$$d_i = \alpha\left(\sum_{j=0}^{m-1} \left(\left|a_j^i - a_j\right| \times w_j\right) + \max_{0 \le j \le m-1}\left\{\left|a_j^i - a_j\right| \times w_j\right\}\right) \tag{6}$$

The method that uses an appropriate linear combination of Blocks distance and Chessboard distance instead of Euclidean distance reduces multiplication operation and has a high operation speed, thereby improving the efficiency of resource discovery.

C2. Algorithm Description

Resource discovery algorithm based on MLON can be divided into two parts: the user's request is passed among nodes *RR*; the request is transferred and searching for resource in matching types of resource domain.

After $request(R_i(A))$ is submitted, the Resource Router in the network generates VID_i by the function rf, then it makes and operation with bitwise between VID_i and VID of node *RR*. If the result is equal to VID, it shows that the resources of query are in resource domain which is managed by node *RR*, i.e. if $\exists(VID_i \wedge VID) = VID$,then $r_i \in R(VID)$. Otherwise, the request is passed, until the resource domain that accords with the request is found or Time To Live (TTL) of request message is zero.

When the bottom resource router RR_j receives a request, $request(R_i(A))$ will be transponded towards each node of its management domain by the router. When receiving the request, the leaf node first tests itself whether meet the requirements of the query. If it meets, the distance d_i between local resource and query point is calculated. Then d_i is returned to the resource router. Based on the optimal matching principle, the nearest *k* resources with $request(R_i(A))$ will be returned to the user by the resource router according to d_i. The resource discovery algorithm of the Multi-layer Overlay Network model based on distance (DIS-MLON) is given below.

Algorithm: The resource discovery algorithm of the Multi-layer Overlay Network model based on distance (DIS-MLON)

Inputs: $W, request(R_i(A))$, *k*, *ttl*;

Outputs: The optimal *k* resources.

DIS-MLON ($W, request(R_i(A))$, *k*, *ttl*)

Begin

(1) user sends $request(R_i(A))$ to MLON;

(2) $r_i(a) = request(R_i(A))$;

(3) $VID_i = rf(r_i(a))$;

(4) While ($(VID_i \wedge VID) \ne VID$) { /*search the domain of matching resources*/

(5) *ttl*-1, if *ttl* is less than 0, then the identifier which represents the end of the life cycle of registration message is returned.

(6) If ($index\_f(VID) \ne Null$)

(7) Node *RR* delivers $request(R_i(A))$ and VID_i towards father node;

(8) Else

(9) Node RR delivers $request(R_i(A))$ and VID_i towards brother node by the best neighbor strategy; }

(10)While($index\_s(index\_s(VID)) \ne Null$) { /*search father node RR_j of matching resources */

(11) *ttl*-1, if *ttl* is less than 0, then the identifier which represents the end of the life cycle of registration message is returned.

(12) Node *RR* delivers $request(R_i(A))$ and VID_i towards child node, the request is passed by the best neighbor strategy in the domain; }

(13) RR_j transmits the request towards child node;

(14) The distance d_j between leaf node r_j and $r_i(a)$ is calculated by leaf node, then returns d_j;

(15)Return TopK = $SelectMinD(d_0, d_1, \cdots, d_n)$;

End

Ⅴ. The Experimental Evaluation

Experiment employs GridSim[11] simulation toolkit to simulate experiment about the grid resource discovery algorithm DIS-MLON and grid resource discovery algorithm based on flooding[12]. Use the JDK and JCreator as the programming environment. The program is running on Windows XP platform.

A. Experimental Environment Settings

The experiment only simulates computing resources in the grid, not considering other grid resources. In the process of simulation, we need to ignore the change of network topology in resource discovery at a time, and all the resource information should be kept stable and effective in the network.

Supposing the number of resource nodes of the model is 50000, namely $|N_G| = 50000$, $|R| = 50000$; the number of resource type is 10, $|T| = 10$, Various types of resources are evenly distributed; In flooding resource discovery mechanism, an average degree between nodes is 4 with life cycle in the way of TTL controlling request information in the network.

B. Simulation Analysis

In the process of simulation experiment, experiment runs many times with different user requests, and simulation results are the average of the experiment results. There are three important performance indexes of the resource discovery algorithm: the number of nodes involved in the process of resource discovery, response time and the success rate of lookup. This section mainly compares DIS-MLON resource discovery algorithm with flooding resource discovery algorithm through the three indexes.

B1. The Comparison of the Number of Nodes Involved in the Process of Resource Discovery

The comparison of the number of nodes in the resource searching for the two kinds of resource discovery algorithm is shown in Figure 2. Seen from the Figure 2, with the increase of density of resources, the number of nodes involved in DIS-MLON resource discovery algorithm is far less than flooding algorithm. Especially when the density is small, DIS-MLON algorithm has more obvious advantages.

B2. The Comparison of Response Time

Response time is the average time from a resource request to receiving a successful response by user. Judge the response time according to hops in the path in which service request is forwarded. The comparison of the number of hops in the resource searching for the two kinds of resource discovery algorithm is shown in Figure 3. Seen from the Figure 3, the hops of the DIS-MLON resource discovery algorithm are less than the hops of flooding algorithm. But with the increase of density of the network resources, resources satisfying the requests in the system increase, and the hops of two kinds of resource discovery algorithm become smooth and consistent.

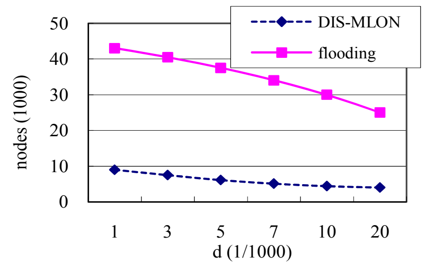

Figure 2. Referenced nodes

B3. The Comparison of the Success Rate of Lookup

The comparison of the success rate of lookup for the two kinds of resource discovery algorithm is shown in Figure 4. Seen from the Figure 4, two algorithms can always find the resources with the increasing of lifecycle of information. The DIS-MLON algorithm discovery resources get more effectively when TTL value is small.

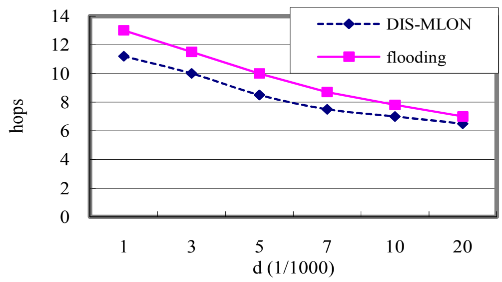

Figure 3. Hops

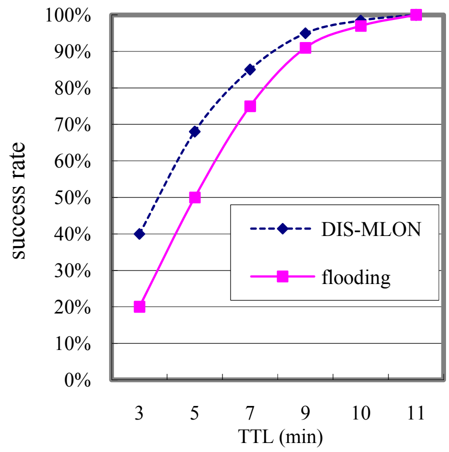

Figure 4. Research success rate

In addition, resource search results of two algorithms are found: grid resource discovery algorithm based on flooding that adopts the resource search method of comparison of the attributes often returns to results with deviation of attribute too much; grid resource discovery algorithm based on DIS-MLON supports multiple attributes and range search, and it can return to the *k* most appropriate resources according to customer requests, so it has the highest customer satisfaction.

Ⅵ. THE CONCLUSION AND FUTURE WORK

Because of the disadvantage that layered resource discovery mechanism is strongly dependent on resource routing nodes in the grid, a grid resource discovery model based on MLON is proposed. At the same time, some issues about resource management are discussed, such as the service deployment of resource routing nodes, resources registration and update and resource discovery. And on the basis of MLON, the grid resource discovery algorithm based on distance is proposed by using a linear combination of the block distance and chessboard distance instead of Euclidean distance. Through performance analysis and simulation results, the model has fault tolerance and scalability. And it also meets the requirements of the grid dynamics, distribution and scalability. Then it can shield heterogeneity among the resources. The next step is to deploy the model to experiment in real grid environment.

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