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Maintaining tight junction to virtual network based on mapping algorithm

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ABSTRACT

Since the traditional node mapping algorithm in virtual network only took a simple approach, it reduced the utilization of underlying resource and the acceptance rate of virtual network request, so this paper proposes the mapping algorithm of maintaining tight junction. In mapping algorithm, it takes node mapping and link mapping together into consideration. Firstly, to make all nodes which meet the computing power requirements meanwhile through the 1-cut test together and composed them as a candidate host clusters in the node mapping phase, then, to form node mapping by selecting one node from each cluster as a host. Experimental results show that: This algorithm can effectively improve the utilization of resource and the acceptance rate of virtual network request.

KEYWORDS

Network; Clusterin; Minimum exact cover; Node.

INTRODUCTION

Virtual network mapping is essentially a kind of resource allocation problems. It is different from the general resource allocation problem, for it has many new features, such as, the resource request has network structure and it needs to meet the constraints of nodes and edges, Yu M made a detailed analysis and summary for the above features[1]. Virtual network mapping is a complex problem, it constrained space from different angles in early studies and on this basis to propose different algorithms to solve. For example, Jing Liang F[2] Only considered the bandwidth limitations, LU J[3] defined a network request as a specific virtual network structure, Hou Y[4] presented a backtracking search algorithms based on graph isomorphism and looked for mapping scheme on approximation algorithms in graph isomorphism. In response to the high complexity of graph isomorphism, the author define the path length of search and the solution space. Although such a algorithm which add additional restrictions help simplify the problem, it greatly restricts the performance and applicability of these algorithms[5].

Yu M, et al first analyzed he characteristics of the virtual network mapping in detail and gave the meeting constraints of solving virtual network mapping problem, and proposed a two-stage method for mapping virtual network mapping, and that took account of all constraints of virtual network mapping[6]. Yu M proposed the idea of dividing the underlying network supports streaming, making the link mapping problem to be transformed into multi-commodity flow problem, and simplify the complexity of the link map. However, in order to improve the probability of finding workable link mapping in link mapping stage, Yu took strategy of bandwidth priority in node mapping stage, and preferred the large physical node of network bandwidth as the host. While this strategy helps to improve the current request acceptance rate, but not conducive to the acceptance of a subsequent request, and it is not conducive to optimal allocation of resources from the overall situation.

Hou Y, who focused on the relationship between point mapping and link mapping, proposed a method to test that whether it exists a viable link mapping corresponding to ode mapping, and proved the necessary and sufficient conditions[5]. Because the necessary and sufficient conditions for the validation of computationally is infeasible, the authors further proposed a simplified test methods. Simplified approach is the necessary condition which the link mapping is feasible corresponding to node mapping and the calculation is simple. Based on this, the authors proposed a virtual network mapping method of random mapping plus detection. However, the author did not propose an effective node mapping method, and the lack of a simple random strategy considering the overall optimization of resources is not conducive to the improvement of resource utilization, affecting the acceptance rate of the virtual network requests.

Virtual network consists of virtual nodes which were connected together by virtual links. A plurality of virtual networks can be simultaneously run on the same physical resources, but they are isolated from each other. Network virtualization technology has become an important means to solve many problems, it can enhance the flexibility, security, and manageability of network. Internet researchers used it to build a new network architecture, to deployment new network protocols, and to enhance the support capability of quality service[7]. Cloud computing researchers use it to generate a virtual network environment on dynamically demand, which means to maximize the utilization of physical resources while meeting the needs of users.

Virtual Network Mapping is one of the most fundamental problems in network virtualization. It is responsible for allocating resources for the virtual network requests, to make the virtual nodes mapped to a physical node (so call the host of virtual node) and to make virtual links mapped to one or more paths in physical network. Also, the virtual network mapping is different from the best-effort internet strategy, which take resource reservation mechanism for virtual network requests allocated in full resource to protect the quality of service. Since the physical resources are limited, how to improve the utilization of underlying resource in premise of meeting needs has become the key to the virtual network mapping[8-10].

Also, Virtual network mapping is a challenging problem. Virtual network requests the diversity of network structure, so a virtual network mapping must be able to adapt to different topologies and meet the resource requirements of link and nodes while allocating resources. And Virtual network requests strong dynamic, it can not be informed of information what subsequent –reach virtual network requested while allocating resources[11]. Even if we can in advance predict all of the information what virtual network requested, the virtual network mapping problem is also an NP-hard problem which can be transformed into the demultiplexer problem. Further, even if we can predetermine nodes mapping under the indivisible flow, the virtual link mapping remains a NP-hard problem which can be transformed into an integral flow.

The researchers made a variety of heuristic algorithms to solve the virtual network mapping problem. But, most of these studies focused on the link map, looking for optimal and possible link mapping conditions, they only take simple strategies to nodes mapping, such as bandwidth priority, random, etc. However, the nodes mapping determines the beginning and end of the link map, it has a huge impact to the link mapping and the entire virtual networks mapping. There were two main problems existing in previous node mapping algorithms.

First, although the policy of preferring physical nodes with more bandwidth resources as host can improve the current request acceptance rate to some extent, it is always the first node occupied with the most abundant bandwidth resources, generating a huge impact on the subsequent request and is not conducive to request-acceptance rate on the overall. Shown in Figure 1, based on bandwidth priority policy, the virtual node a, b, c are respectively mapped to a physical node D, E, B with more bandwidth resources, and when the virtual network request 2 arrives, there will be no nodes with sufficient bandwidth resource to be a host of the virtual node d. But the node mapping in Figure 2 can effectively prevent the occurrence of this situation.

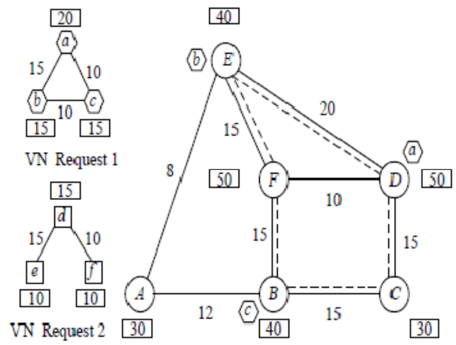

Figure 1: Node mapping of bandwidth priority

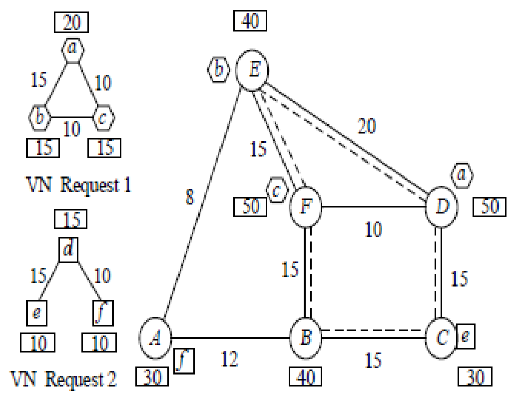

Figure 2: Compact node mapping

Secondly, the previous mapping algorithm completely separated the node mapping and link mapping which may lead to that logical adjacent virtual nodes will distribute in dispersion after mapped to the physical node, resulting in the virtual link uses more network resources. For example, the distribution of virtual nodes of the virtual network request 1 in Figure 1 is more dispersed than Figure 2, so the virtual link b_c and c_a in Figure 1 occupy more network resources than that of Figure 2.

Measuring the compact degree of virtual nodes distribution after mapping by evenly distributed distance of virtual nodes prove that, the most compact node mapping in the circumstance of bandwidth resources are not limited is the optimal node mapping. The complexity of virtual network mapping problem itself determines the calculation of the most compact node problem is not a simple one, and, the most compact node mapping problem is proved to be NP-Complete problem instead of APX problem, i,e, the polynomial time approximation algorithm without constant boundary. Therefore, we designed a heuristic algorithm LS-SDM to seek an approximate solution to the problem of the most compact node mapping [12-15].

Meanwhile, in the clustering process, we require the candidate host not only to meet the demand for computing power but also to make node mapping of LS_SDM algorithm exist feasible link mapping corresponding with large probability through a 1 - cut test. Based on this, we have designed a virtual network mapping algorithm with compact node, the algorithm firstly to look for compact node mapping by LS-SDM, then to find the corresponding link mapping. If there is a feasible link map to correspond, the virtual network request mapping could be completed; if not, then executed again to find new compact node mapping by LS_SDM algorithm, repeat the above process. If it still failed after several independent mapping, then the probability of without feasible mapping existing in virtual network request closes to 1. Finally, it verifies the effectiveness of the algorithm through a series of experiments. Experimental results show that, the distribution of mapping virtual nodes in the proposed algorithm is more compact, taking up less resources, can significantly improve the acceptance rate of the virtual network requests.

This paper mainly does expand and innovative work in the following areas

(1) Against to the issues of which the traditional node mapping algorithm only take simple approach in virtual network mapping and reduce the utilization of underlying resource and the acceptance rate of virtual network request, this paper proposes the mapping algorithm of maintaining tight junction. First, making all physical nodes in accordance with the

conditions of preselected for each virtual node as candidate host and organize them to cluster, then selected one node from each cluster as the host corresponding to the virtual host, this can effectively expand the host choice for each node, instead of always occupying the nodes with the most bandwidth resources. All these are conductive to rational allocation of resources and improve the request-acceptance rate overall. Second, taking full account of resource occupancy from link mapping while choosing cluster head, to select the physical nodes with compact distribution as the host, to make logically adjacent nodes mapped to neighboring physical nodes, then reducing the network resources what virtual link occupied and improving resource utilization.

(2) To further validate the correctness and validity which the proposed mapping algorithm of maintaining tight junction, the experimental physical resources and the network topology of virtual network requests are generated by GT-ITM. Physical resources are composed by 100 nodes and 300 edges, the computing power and physical link bandwidth of physical nodes are uniformly distributed on［60,800］ and its topology remains unchanged during the experiment. With the increased of T_{try}, the acceptance rate also increased, when T_{try} more than a certain value, the acceptance rate is not significantly improved. As the load continues to increase, the average path length is growing. The obtained approximate solution of CNN problem which searched by the maximum gradient along the direction of local algorithms is superior to greedy algorithm.

The simulation results show that: the algorithm can effectively improve resource utilization and the acceptance rate of virtual network request.

VIRTUAL NETWORK

Virtual network mapping is a process of deploying virtual network request to physical resources and assign resources for it. An undirected graph with right could be used to describe the physical resources and virtual network request. Physical resources can be described as $GP\left(NP, EP, A_N^P, A_E^P\right)$, Where NP represents the set of physical nodes, EP represents the set of physical link, right $A_N^P\left(NP\right)$ represents the property of Node $NP \in nP$, as computing power; right $A_E^P\left(EP\right)$ represents the property of Link $EP \in eP$, as Bandwidth size. Similarly, the virtual network request can be described as $GV = \left(NV, EV, A_N^V, A_E^V\right)$, where right A_N^V and right A_E^V are respectively represent the demand for resources of virtual node and link, such as the computing power and network bandwidth which seek for distribution.

Definition 1 (average path length of mapping)

Given virtual network mapping $M : G_V \to G_P$, defined the average path length of M as:

$$\begin{aligned} M_i &= \frac{M_{1total}}{q\pi\left(r_i^2 - r_{i-1}^2\right)} \\ &= \frac{q\pi c\left(r_k^2 - r_{i-1}^2\right)\left(\partial_1 + \partial_2 r_1^a\right) + q\pi c\left(r_k^2 - r_i^2\right)\partial_3}{q\pi r_1^2\left(2i-1\right)} \\ &= \frac{q\pi c r_1^2\left(k^2 - i^2 + 2i - 1\right)\left(\partial_1 + \partial_2 r_1^a\right) + \left(k^2 - i^2\right)\partial_3}{2i0-1} \end{aligned} \tag{1}$$

Mapping M maps the virtual link mapping to the path of GV, h is the average length of these paths, it can reflect the amount of resource which mapping occupied. When h is smaller, the mapping M occupied fewer resources. For example, as virtual network request 1 in Figure 1, the average path length is $\left(16\times1+11\times2+11\times2\right)/\left(16+11+11\right)=1.59$, the average path length in Figure 2 is 1.

Although the average path length l can greatly reflect the amount of resource which mapping occupied, it can calculate only after node mapping and link mapping completed and can not exactly calculate the amount of resource which link mapping occupied in the node mapping stage. For that, the concept that the average distributed distance of virtual node will be introduced.

Definition 2 (Feasible Mapping)

If the virtual network mapping $M : G_V \to G_P$ both to meet the resource demand of G_V (that is consistent with formula (1), (2)), and do not exceed the capabilities of G_P (that is consistent with formula (3)), then M is feasible.

If node mapping M_N both satisfy formula (1) and (3), then claimed it as a feasible mapping. If link mapping M_E both satisfy formula (2) and (3), then claimed it as feasible link mapping. Node mapping M_N determine the beginning and end of virtual link in mapping stage. The feasible node mapping M_N and a corresponding feasible link mapping M_E make up a feasible mapping $M = (M_N, M_E)$. Clearly, given a feasible node mapping, there is not necessarily feasible link mapping to correspond.

Given a feasible virtual network mapping $M = (M_N, M_E)$, denoted the resource which virtual node n_v occupied as $\cos t = (M_N, n_v)$, then is

$$\cos t = (M_N, n_v) = f_n\left(n^p, n^v\right) \tag{2}$$

Denoted the resource after virtual link e_v deployed as $\cos t = (M_N, n_v)$, then is:

$$\begin{aligned} M_{1total} &= q\pi c\left(r_k^2 - r_{i-1}^2\right)\left(\partial_1 + \partial_2 r_1^a\right) + q\pi c\left(r_k^2 - r_i^2\right)\partial_3 \\ &= q\pi c r_1^2\left(k^2 - i^2 + 2i - 1\right)\left(\partial_1 + \partial_2 r_1^a\right) \\ &= q\pi c r_1^2\left(k^2 - i^2\right)\alpha_3 \end{aligned} \tag{3}$$

Where $|p|$ is the path length of p. The resource which the entire virtual network request for GV is:

$$\cos t\left(M, G^v\right) = \sum_{m^v \in E^v} \cos t\left(M_E, e^v\right)$$

Definition 3 (optimal mapping)

If the virtual network mapping M is feasible and it takes up the least amount of resources, then it is called optimal virtual network mapping, referred to as the optimal mapping, denoted by $M*$.

Node mapping M_N and link mapping M_E corresponded to the optimal mapping $M* = (M_N, M_E)$ are respectively the optimal node mapping and link mapping, denoted as M_N^* and M_E^*.

Although the optimal mapping M_N^* and other feasible node mapping M_N occupied the same node resource, different node mapping determines the different beginning and end of the link mapping, making the link mapping occupies minimal network resources.

THE ALGORITHM OF COMPACT NODE MAPPING

Firstly introduce the indicators which reflect the property of virtual network mapping to give the definition of node mapping compactness, and in-depth analysis the issues of the most compact node mapping, then proposed a compact mapping algorithm based on the analysis.

Analysis of the most compact node mapping

Definition 1 (Virtual Network Mapping)

Deploying virtual network request $GV = \left(NV, EV, A_N^V, A_E^V\right)$ to physical resource $GP\left(NP, EP, A_N^P, A_E^P\right)$ is the virtual network mapping, referred mapping and denoted $M : GV \to GP$. Virtual networking mapping can be decomposed into node mapping MN and link mapping EP.

The node mapping $M_n : N^v \to N^p$;

Link mapping $M_E : E^v \to P^p$

Node mapping MN map virtual node $N_V \in n_V$ to physical node $N_P \in n_P$, namely $n_P = MN\left(n_v\right)$. The node resource which physical node n_P allocates for N_V is $f_n\left(n_p, n_v\right)$; Link mapping ME map virtual link $e_v = \left(m_v, n_v\right) \in e_v$ into one or more paths in physical network, namely $M_e\left(e_v\right) = M_E\left(m_v, n_v\right) \subseteq p_p\left(M_N\left(M_v\right)\right)$, where $p_p\left(s,t\right)$ represents the set of all paths which connect node s and node t in physical network. The bandwidth resources which path $p \in M_E\left(e_v\right)$ allocate for e_v is $f_e\left(p_p, e_v\right)$.

In order to meet the resource demand of GV, the resource which allocate to virtual e_v and virtual link should be consistent:

$$M_{1total} = q\pi c\left(r_k^2\partial_1 + r_k^2\partial_2 r_1^a + r_1^2\left(k^2 - 1\right)\partial_3\right) \tag{4}$$

Denoted the set of virtual nodes which mapping to physical node $n_p \in N_P$ as $\Omega N\left(n_p\right)=\left\{n_v \middle| MN\left(n_v\right)=n_p, n_v \in E_v\right\}$; Denoted the set of paths after link mapped through physical link e_p as $\Omega F\left(e_p\right)=\left\{p \middle| p\left(m_e\right), p \in p, e_v \in E_v\right\}$. Physical nodes and links provide services outsider limited by their own resource, so they can not exceed its capacity and should meet the following constraints:

$$
\begin{aligned}
M_1 &= \frac{M_{1total}}{q\pi r_1^2}=\frac{q\pi c\left(r_k^2\partial_1+r_k^2\partial_2 r_1^a+r_1^2\left(k^2-1\right)\partial_3\right)}{q\pi r_1^2} \\
&= c\left(k^2\partial_1+k^2\partial_2 r_1^a+\left(k^2-1\right)\partial_3\right)
\end{aligned}
\tag{5}
$$

Definition 2 (average distributed distance of virtual node)

Given node mapping $M_N : N_V \to N_P$, defined the average distributed distance corresponded to node mapping M_N as:

$$
\frac{M_i}{M_1}=\frac{q\pi c r_1^2\left(k^2-(i-1)\left(\partial_1+\partial_2 r_1^a\right)+\left(k^2-i^2\right)\partial_3\right)}{(2i-1)\left(k^2\partial_1+k^2\partial_2 r_1^a+\left(k^2-1\right)\partial_3\right)}
\tag{6}
$$

Where $dist\left(u,v\right)$ represents the distance between node u and $v \in n_p$, but here it will be defined as the shortest path length between nodes. Average distributed distance w reflected the compactness which virtual node distributed in physical network, the smaller w is means the more compact distribution is. For example, the virtual node of virtual network request 1 in Figure1 and Figure2 respectively are 1.57 and 1, in Figure 2, the distribution is more compact. When w is the minimum value, the corresponding node mapping M_N known as the most compact node mapping.

Definition 3 (the most compact node mapping problem, closest node mapping, CNM)

Known the set of point is $N=\left\{n_i\right\}$, the distance between any two points is $w_{ij}=dist\left(n_i,n_j\right)$, the set of node cluster is $M=\left\{m_1,m_2,...,m_k\right\}$, $m_i \subseteq N$, $i=1,2,...,k$, The demand for inter-cluster is $s=\left\{s\times x\right\}$, $s\times x \ge 0$, $1\le x$, $y\le k$, $x\ne y$ and constant w. Question: whether there is a point sequence $o=\left\langle o_1,o_2,...,o_k\right\rangle$ to satisfy that $s_i \in o_i$, $1\le i\le k$, if $i\ne y$, then $s_i \ne s_j$, and

$$
\frac{k^2-i^2}{k^2\left(2i-1\right)}\le\frac{M_i}{M_1}\le\frac{k^2-\left(i-1\right)^2}{\left(2i-1\right)\left(k^2-1\right)}
\tag{6}
$$

CNM question depicts the most compact node mapping on $G_V \to G_P$. Define the set of points N as the set of physical nodes N_P in G_P, define $s_i \in s$ as the set of all candidate host of virtual node $n_i^v \in n_v$, define $x\times y \in s$ as the bandwidth demand $A_E^V\left(N_X^V,N_Y^X\right)$ between virtual node N_{VX} and N_{VY}, Point sequence v is a node mapping, it maps n_i^v to v_i. when the $p\left(s,o\right)$ is the minimum value, the average distributed distance of corresponding virtual node d is also the minimum value, so the node mapping v is the most compact node mapping.

We use a quintuple $CNM=\left(N,s_{ij},C,R,W\right)$ to describe the problem CNM. Without the limitation of formula (6), CNM problem will become a new problem, we define it as a cluster choosing problem (Cluster Header, CH). CH problems are only interested in whether to choose one from each cluster point as cluster head, and these cluster head distinct, does not care whether the distribution of these cluster head are compact or not. What CH problem looking for is a feasible solution of CNM problem, not an optimal solution. Here, CH problem will be described with a triplet CH=(N,C,R).

Theorem 1 When bandwidth is not limited, the most compact node mapping is the optimal nodes mapping.

Proof: let CNM problem instance CNM portrayed from $G_V=\left(N_V,E_V,A_N^V,A_E^V\right)$ to the most compact node mapping $G_P=\left(N_P,E_P,A_N^P,A_E^P\right)$, the solution is V. Optionally a virtual link $e_x^v=\left(n_v^i,n_j^v\right)\in E_v$, it will be mapped to $p_p\left(v_i,v_j\right)$. Because bandwidth is not limited, so e_x^v must be mapped to the shortest path which connected v_i and v_j. According to formula (5), its occupied network resource is $dist\left(v_i,v_j\right).r_{ij}$. Obviously, this is the least bandwidth resources what virtual link $\left(n_i^v,n_j^v\right)$ occupied. Each virtual link is taken to the mapping algorithm can construct a viable link map M_E, the total bandwidth resource is $p(s,o)$. When $p(s,o)$ take the minimum value, M_E occupied the minimal bandwidth resources, so M_E is the optimal nodes mapping. So, V and M_E can be composed of the optimal virtual network mapping, so V is the optimal nodes mapping.

Theorem 2 CNM problem is a NP-Complete problem

Proof: First, given any a CNM instance $ICNM$ and a point sequence V, then can verify whether V satisfy conditions or not in polynomial time, so CNM problem is N_P problem.

Next, reducing a $N_P - complete$ problem to CNM problem, considering the following $N_P - complete$ problem Minimum exact covering (Minium Exact Set Cover, MXSC). It knows the set of Set u and the subset of u.
Close S, function size: $s \to q+$ and constant $r_{i-1}^2 - r_1^2$. Question: whether there is a separate collection （disjoint set） $s's$ to make s' covering u, and

$$q\pi c\left(r_{i-1}^2 - r_1^2\right) \tag{7}$$

It will prove in the following that $MXSC$ problem can be reducible to CNM problem in polynomial time. Any given an instance of $MXSC$ problem $\mathrm{Im}\times S_C$, where $q\pi c\lambda_i\left(r_k^2 - r_{i-1}^2\right)\partial_3$, $q\pi c r_{i-1}^2\left(\partial_1 + \partial_2 r_1^a\right)$. And CNM can construct a problem instance $M_{1ltotal} = M_{txli} + M_{ertl}$.

$$\begin{aligned} M_{1ltotal} &= M_{txli} + M_{ertl} \\ &= q\pi c\lambda_i\left(r_k^2 - r_{i-1}^2\right)\left(\partial_1 + \partial_2 r_1^a\right) + \\ &\quad q\pi c r_{i-1}^2\left(\partial_1 + \partial_2 r_1^a\right) + \\ &\quad q\pi c\lambda_i\left(r_k^2 - r_{i-1}^2\right)\partial_3 + q\pi c\left(r_{i-1}^2 - r_1^2\right)\partial_3 \end{aligned} \tag{8}$$

Among, $\left(s_j, u_i\right), \left(s_q, u_p\right) \in N$; $\varepsilon \succ 0$, are arbitrary constant.

$C = \left\{c_i \middle| 1 \le i \le t\right\}\left\{c_i + t \middle| 1 \le i \le t\right\}$, among,

$$\begin{aligned} M_{lt} &= \frac{M_{litotal}}{q\pi r_1^2} \\ &\left(q\pi c((\lambda_i r_k^2 - \lambda_i r_{i-1}^2 + r_{i-1}^2\right)\left(\alpha_1 + \partial_2 r_1^a\right) + \\ &\partial_3\left(\lambda_i k^2 - \lambda_i\left(i-2\right)^2 + \left(i-1\right)^2 - 1\right) - \left(\partial_1 + \partial_2 r_1^a + \partial_3\right) \\ &= \frac{\left(\lambda_i k^2 - \lambda_i\left(i-1\right)^2 + \left(i-1\right)^2 - 1\right)\left(\partial_1 + \partial_2 r_1^a + \partial_3\right)}{k^2\left(\partial_1 + \partial_2 r_1^a + \partial_3\right)} \\ &= \lambda_i + \frac{\left(1-\lambda_i\right)\left(i-1\right)^2 - 1}{k^2} \end{aligned}$$

Among, $\lambda_i + \dfrac{\left(1-\lambda_i\right)\left(i-1\right)^2 - 1}{k^2} \le \dfrac{M_{il}}{M_1} \le \lambda_i + \dfrac{\left(1-\lambda_i\right)\left(i-1\right)^2}{k^2}$ (9)

It can be proved, there is a I_{CNM} which satisfies conditions of the point sequence V while there exists a set S' to satisfy $IM \times S_C$. It is not difficult to know that, the above construction process can be complete in polynomial time, so $MXSC$ problem can be reducible to CNM problem in polynomial time.
In summary, CNM issues are NP-Complete problem.

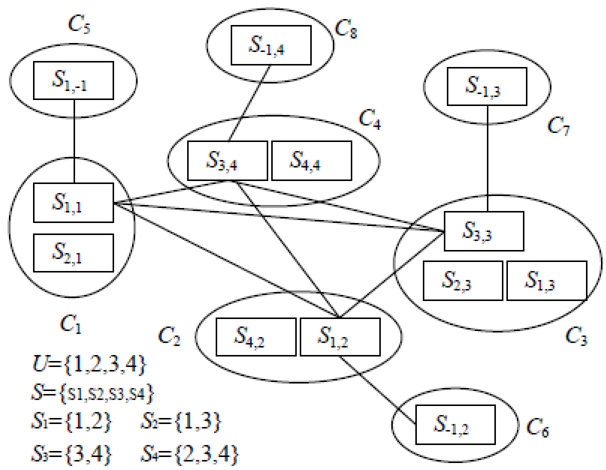

Figure 3: Example of constructing $ICNM$ **according** $MXSC$

Theorem 3 If $CNM \in APX$, then $P = N_P$.

Proof: For any instance $IM \times S_C$ of $MXSC$ problem, it can construct a corresponding instance I_{CNM} of CNM. The proof of Theorem 2 shows that.

$$\begin{aligned} T &= (1-\lambda_i) T_i = (1-\lambda_i) q\pi \left(r_i^2 - r_{i-1}^2\right) \\ &= q\pi r_1^2 (1-\lambda_i)(2i-1) \end{aligned} \tag{10}$$

Which, $opt(I_{CNM})$ represents the optimal solution I_{CNM} .
Also, if $CNM \in APX$, based on APX definition, there will be a $\partial - appro \times imation$ algorithm A for any CNM instance I_{CNM} to satisfy:

$$A(I_{CNM}) \le \alpha.opt(I_{CNM}) \tag{11}$$

If there exists a feasible solution for $IM \times S_C$, I_{CNM} also has feasible solution. To integrate formula (12), (15), and let $\varepsilon = \alpha$ in formula (14), there will be:

$$A(I_{CNM}) \le \alpha.opt(I_{CNM}) = \alpha B \tag{13}$$

If there is no feasible solution for $IM \times S_C$, I_{CNM} won't have feasible solution either. And based on formula (14), there will be:

$$\lambda_i = 1 - \frac{T}{q\pi r_1^2 (2i-1)} \tag{14}$$

And because $opt(I_{CNM})$ is the optimal solution, then $A(I_{CNM})$ $opt(I_{CNM})$, i,e .:

$$A(I_{CNM}) \succ opt(I_{CNM}) \ge (1+\alpha) B$$

It is known from formula (13) that, we can determine whether there is a feasible solution of $IM \times S_C$ through the results of $A(I_{CNM})$. And because the algorithm A is polynomial time algorithm, $IM \times S_C$ problem belongs to $N_P - Complete$ problem. So if $NCH \in APX$, then $P = N_P$. The proof is completed.

It is known from theorem 1 and 2 that, even without bandwidth limitations, it is still very difficult to find the optimal node mapping and the most compact node mapping. In theorem 3, it further shows that, the most compact node mapping problem is not constant polynomial-time approximation algorithm borders. So, later we will design a heuristic algorithm to find the proximate solution to the most compact node mapping.

VIRTUAL NETWORK MAPPING OF MAINTAINING TIGHT JUNCTIONS

In the last process of solving the compact node mapping, we assume that node clustering has been completed. In this section, we first cluster nodes and take full consideration to the constraints of virtual network mapping by combining with cutting test theories during clustering. Then proposed the virtual network algorithm of maintaining tight junctions based on that.

Node clustering

Definition 1 (cut): The partition of the node set N from net G=$\left(N, E, A_N, A_E\right)$ is called the CUT of G.

The $CUT(S,\bar{S})$ cuts N into the two parts S and $\bar{S} = N - S$, then the $CUT(S,\bar{S})$ is called a $|s|$ CUT of net G. If $e = (u,v)$ satisfied $u \in s, v \in \bar{s}$, then claimed Side e passes $CUT(S,\bar{S})$. The bandwidth sum of all sides which pass the $CUT(S,\bar{S})$ is called the capacity of $CUT(S,\bar{S})$, denoted as $\psi(G,S)$.

Definition 2 (k-cut test): $M_N : N_V \to N_P$ is the node mapping between $G_V = \left(N_V, E_V, A_N^V, A_E^V\right)$ and $G_P = \left(N_P, E_P, A_N^P, A_E^P\right)$, constant $K \in \left[1, |N_V|\right]$. If M_N satisfied formula (18), then claimed that M_N pass the K-CUT test.

$$\psi\left(G^V, S\right) \le \psi\left(G^P, M_N(S)\right); \forall S \subset N^V, |S| = K \tag{18}$$

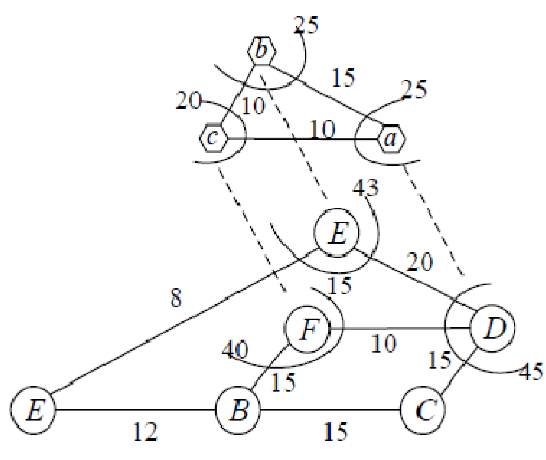

Figure 4: Shows the example of 1-cut tests

The virtual network mapping algorithm of maintaining tight junction

In this section, it proposes a virtual network mapping algorithm of maintaining tight junction. Given the request G_V and resource G_P, the algorithm will cluster candidate host firstly, then to find a compact node mapping M_N by algorithm LS_SDM. After that, modeling link mapping to multi-commodity flow problem based on YU'S study to solve the optimal link mapping M_N which corresponding to M_N, then find the virtual network mapping solution $M\left(M_N, M_E\right)$. If there is not a M_E corresponding with M_N, then to resolve a new compact node mapping M_N, then to do link mapping and repeat the above process. If it still can not find a viable virtual network mapping algorithm after T try times, the algorithm terminates. The specific algorithm is as follows:

Algorithm 1 virtual network mapping algorithm of maintaining tight junction

Algorithm CNM_LS_SDM

Input: $G_P = \left(N_P, E_P, A_N^P, A_E^P\right), G_V = \left(N_V, E_V, A_N^V, A_E^V\right)$

Output: M

Construction of CNM problem instances, an approximate solution is obtained

1) build and CNM instance I_{CNM}
2) for $$\begin{aligned} T &= (1-\lambda_i) T_i = (1-\lambda_i) q\pi \left(r_i^2 - r_{i-1}^2\right) \\ &= q\pi r_1^2 (1-\lambda_i)(2i-1) \end{aligned}$$

3) $\lambda_i = 1 - \dfrac{T}{q\pi r_1^2 (2i-1)}$
4) $q\pi c\left(r_k^2 - r_1^2\right)(1-\lambda)\left(\partial_1 + \partial_2 r_2^a\right)$
5) $T-0$, attempts at zero
6) Solve the $I_{CNM}.v = l_s\_SDM\left(I_{CNM}\right)$
7) //CNM Solution to the problem Ω , can not complete the node mapping
8) If $(v == \Omega)(m = \Omega)$
9) // The create the node mapping
10) For $\left(1 \le i \le |N_v|\right) M_N\left(n_i^v\right) \to n_v$
11) }else{ //MCF The problem has no feasible solution
// If there is no more than the maximum number of attempts, return mapping
12) If $\left(r_k^2 - r_1^2\right)${
13) $T++.$ go to 5
// If more than the maximum number of mapping attempts failed
14) } else {
15) $M = \Omega$,go to 17
16) }
17) }

EXPERIMENTAL SIMULATION AND ANALYSIS

Environment

Use general algorithm of virtual network mapping study to do experimental verification. The network topology of physical resources and virtual network requests are generated by GT-ITM.

Physical resources are composed by the 100 nodes and about 300 edges, the computing power of Physical node and the bandwidth of the physical link are uniformly distributed on [60,80], its topology remains unchanged during the experiment. Virtual network requests generated randomly and each virtual network node is uniformly distributed between $\left[0.8\times E[scale]\right], 1.3\times E[scale]$. Virtual network node and edge weights are respectively uniformly distributed between $\left[0.8\times E[scale]\right], 1.3\times E[scale]$ and $\left[0.8\times E[b_w]\right], 1.3\times E[b_w]$. Experiment lasted for a 1000-unit time, the survival time of the virtual network requests comply negative exponential distribution, it is mathematical expectation is a 200-unit time. In the process of virtual network requests arrive accord Poisson, the number of requests at a average time of 100-unit is $E[CON]$.

Compare the proposed algorithm （denoted as $CNM - l_s - s_{dm}$, algorithm proposed by YU M （denoted as $b_w - firs$) and the $cnm - greedy$ algorithm, Specific parameters are shown in TABLE 1.

TABLE 1: Experimental parameters

parameter	meaning
T_{try}	CNM_LS_SDM The maximum number of attempts algorithm
$E[scale]$	Mathematical expectation of each request virtual node number
$E[cpu]$	Virtual nodes on mathematical expectation for computing requirements
$E[b_w]$	Virtual link mathematical expectation of bandwidth resource requirements
$E[con]$	An average of 100 per unit of time to the number of requests

Experimental results and analysis

Experimental results show that the proposed algorithm has good performance, the mapping of the average path length is shorter, can effectively improve the utilization of resources, and significantly improve the acceptance rate of the virtual network requests. The main results are described below:

Increase the maximum number of attempts T_{try} , can improve the performance of the algorithm CNM_LS_SDM; when it exceeds a certain value, further increasing T_{try} , the performance improvement is not obvious.

First examine the performance of the maximum number of attempts T_{try} to the algorithm CNM_LS_SDM. Setting experimental parameters to make system load at a reasonable level and then changes T_{try} in the experiment, and observe the changes of virtual network request acceptance rate, the experimental results is shown in Figure 5. With the improvement of T_{try} , the acceptance rate also increased, when T_{try} exceeds a certain value, the accept rate will not significantly improved.

This result is consistent with previous analyzes. As can be seen from Figure 5, $T_{try=5}$ is a critical value, so in the following experiments, the maximum number of attempts is set to 5.

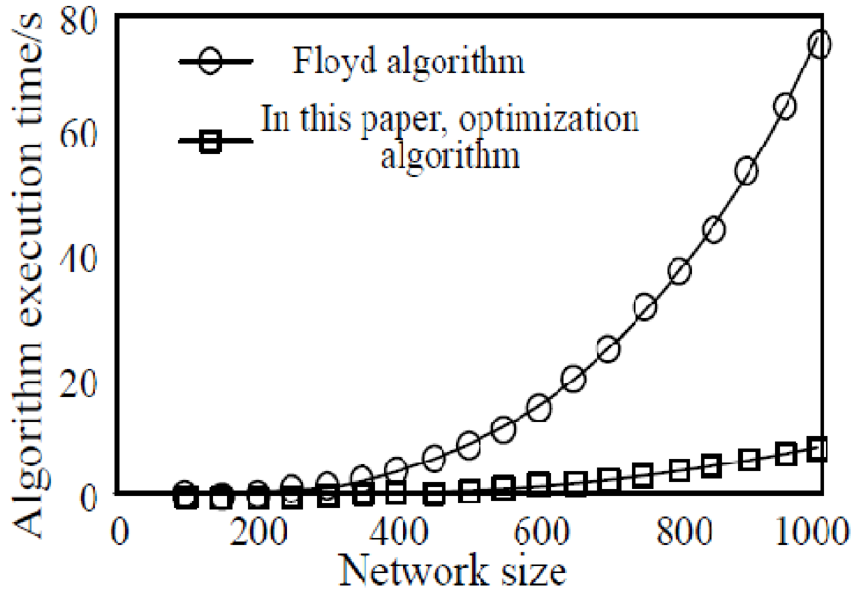

Figure 5: Performance of the maximum number of attempts for CNM_LS_SDM algorithm

CNM_LS_SDM algorithm can significantly reduce the average path length, and improve resource utilization.

Under normal circumstances, the more compact the Virtual node distribute, the smaller the average path length will be in accordance with the link mapping completed of the multi-commodity flow algorithm. After virtual network mapping, we will look at the changes of the average path length which the virtual link mapped to the physical path. Average path length reflects the mapping of bandwidth resources, the smaller the average path length is, the fewer the bandwidth resources occupied, and the higher the resource utilization will be. The results (Figure 6) shows that, the average path length of CNM_LS_SDM algorithm is the minimum, then $cnm-greedy$ followed, this indicates that the mapping solution based on CNM model can improve resource utilization. It also can be found from the experimental results that, with the constantly increasing of loading, average path length is growing which indicates that, when the load increases, it requires a greater allocation of resources to meet the needs of virtual network requests.

The compact virtual network node mapping algorithm can significantly improve the acceptance rate of the virtual network requests; the result of solving CNM problem by LS_SD algorithm is better than greedy algorithm.

Finally, we examine the performance of the algorithm through the acceptance rate of the virtual network request to. it can be seen from the experimental results (Figure 7), in each experiment, the acceptance rate of the CNM_LS_SDM algorithm is the highest, the $cnm-greedy$ algorithm followed. This shows that the proposed virtual network mapping algorithm of maintaining tight junction is effective and can improve the acceptance rate of network request stability overall. There are two main reasons for this result: a) We expand the options range of host in node mapping phase rather than just focus on those nodes with sufficient bandwidth resources, that help to increase the acceptance rate of request overall. b) We take node mapping and link mapping together into consideration, to map the adjacent neighboring virtual nodes to the physical nodes, to make the node distribution be more compact and take up less bandwidth resources.

The main difference between CNM_LS_SDM algorithm and $cnm-greedy$ is the approximate solutions of solving CNM. As can be seen from Figure 7, the approximate solution which locally search CNM problem along the direction of Maximum gradient is superior to greedy algorithm. Both of the acceptance rate of them is higher than the results in $b_w - first$, this verifies the proposed idea of maintaining tight junction mapping is validity.

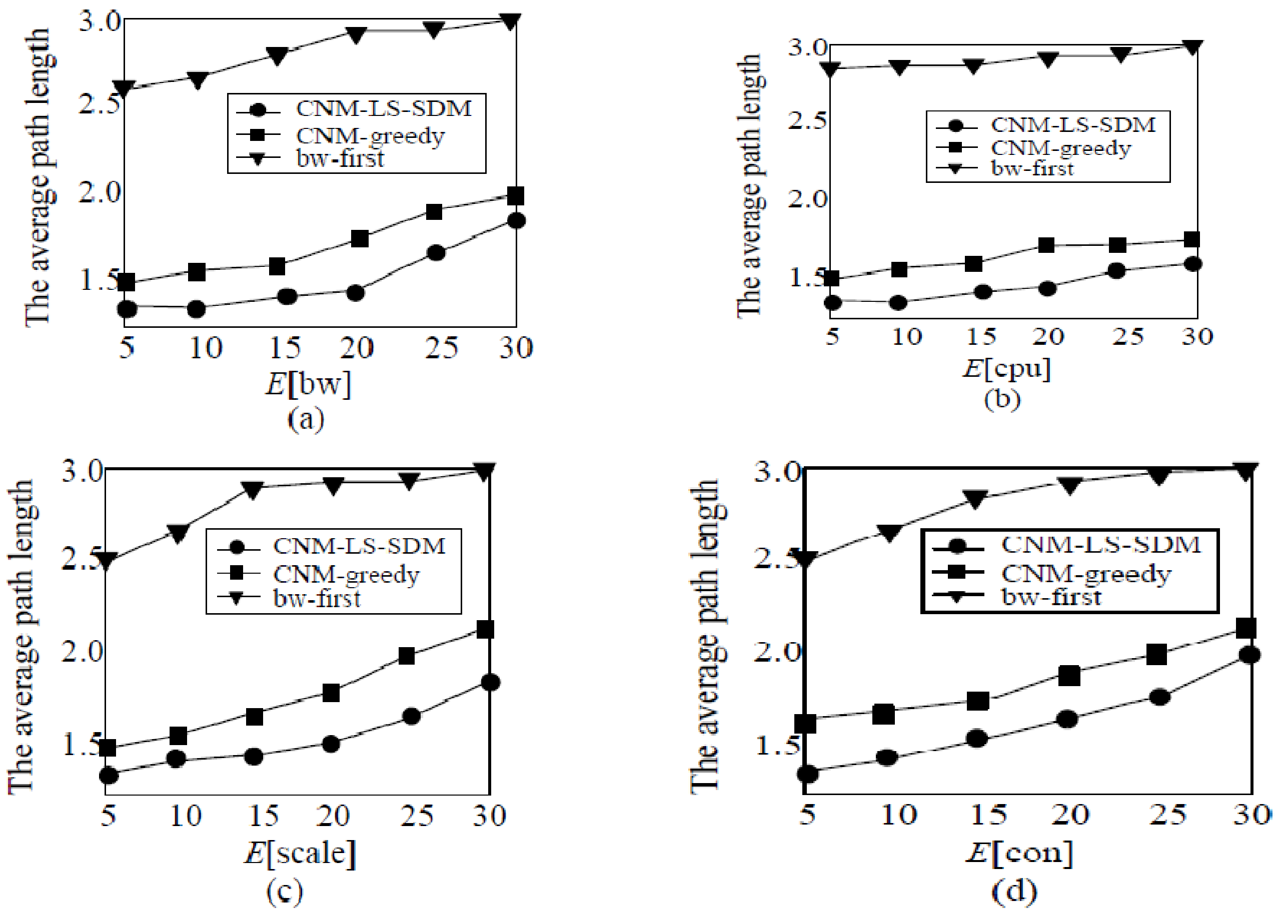

Figure 6: The average path length of various experimental parameters

CONCLUSION

The virtual network mapping algorithm of maintaining tight junction takes the two stages node mapping and link mapping together into consideration. Different from the strategy which traditional algorithm preferred larger bandwidth nodes, this paper makes all nodes which satisfy all requirements and computing power and through a 1 - cut test as candidate host to compose clusters in node mapping stage, to expand the host's choice and be conducive to enhance the acceptance rate of virtual network requests overall. Then, it selects one node from each cluster as host to form node mapping. Considering the network resource amount of link mapping cost while selecting host, then to select those tight node mapping. It proves that the most compact node mapping is the optimal nodes mapping while without bandwidth resources limitation. However, the complexity of virtual network mapping problem itself determines the infeasibility of the most compact node mapping in computationally. It proves that the most compact node mapping is $N_P - Complete$ problem and there is no approximation algorithm in polynomial time of constant borders. Therefore, it proposes a heuristic algorithm to solve approximate solution of the most compact node mapping, and present a virtual network mapping algorithm based on this.

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