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An Improved OSPF Routing Algorithm Based on Quotient and Granularity Space Theory

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Abstract

As the rapid increasing of Internet users from all over the world, it is necessary to enhance the reliability and compatibility of network when large number of data transferred frequently. One of the most important services is routing method since enormous data are transferred and exchanged within the network. This paper introduces an improved OSPF routing algorithm which uses the quotient and granularity space theory. Based on the simulation and experiments, several key findings are observed. Firstly, using the improved algorithm, the convergence time is much less than the no hierarchical network and the performance is better in terms of OSPF response. Secondly, it is found that the bandwidth utilization reaches 30Kbit/s, comparing with the network without hierarchy, the improvement is 40% that the bandwidth utilization increased from 18Kbit/s to 30 Kbit/s. The hierarchical network outperforms the one without layers.

Keywords: *Routing Algorithm, Quotient Space, Granularity, OSPF*

1. Introduction

Currently, as the rapid increasing of Internet users from all over the world, it is necessary to enhance the reliability and compatibility of Internet protocols and data standards [1]. Basic research on network plays an important role in improving the Internet since more and more computers and mobile devices are connecting to the Internet [2-5]. The services from Internet are becoming more and more critical as people uses large number of devices to get in touch with the Internet for different applications and purposes. Thus, that causes the decreasing of Internet service quality in terms of velocity, reliability, and correctness. How to make full use of the Internet resources based on the quality of service (QoS) is a hot research topic.

One of the most important services is routing method since enormous data are transferred and exchanged within the network [6]. Traditional shortest path first (SPF) algorithms such as Dijkstra focus on how to find out a best route which is able to meet the requirement or maximum satisfy the requirement [7-8]. However, the overall utilization of network resources is ignored so that the global optimization cannot be achieved. In such cases, some sub-network could be jammed, resulting the QoS level of a network or whole Internet service.

Large number of studies have been carried out for improving the routing QoS in theoretical perspective. Bellman-Ford algorithm has been used for solving the routing problem with two parameters like network bandwidth and link transfer delay [9-11]. This algorithm assumes that each router in the network is based on the scheduling approach using transmission speed of data. From the calculation formula used for figuring out the delayed time from one node to another, it could be observed that the determinations of link delay are two main factors: link transfer delay and network bandwidth. In order to improve the Bellman-Ford algorithm, Orda *et al.*, introduced a network topology model which is based on different bandwidth [12]. Within each topology network, the shortest

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path is worked out according to the different link length. Thus, a route will be selected according to the minimum transfer delay. This algorithm maximize the network utility utilization so as to meet the QoS requirement at a specific time. However, this algorithm does not consider the cost for achieving this purpose. For example, in order to establish the topology network to meet the flow rate, some links with limited bandwidth are cut down. That may influence the utilization of total network resources and the balance of usage of network utilities. In such situation, when more and more requests arrive, especially in the high pressure of network loading, the later arriving requests may not be dealt with since most of the bandwidth has been occupied. That may finally cause serious decreasing of network reliability [13]. Additionally, if the goal of loading balance algorithm is to achieve the maximum utilization, the transactions or requests cannot receive the calculation delay brought by the complex operations. That may cause the unbalanced status of network.

In order to fulfill this research gap, this paper uses two factors which indicate the two balance network utilization so as to optimize the network resources. Based on the existing SPF algorithms such as Dijkstra, an improved optimized shortest path first (OSPF) routing algorithm is proposed. This algorithm uses quotient and granularity space theory for considering the QoS transfer route and balanced cost of network resources so as to avoid the over-take the bottleneck link.

The following sections are organized as follows. Section 2 presents the description of mathematical model based on the two balanced factors. Section 3 presents the granularity space-based routing algorithm in a hierarchical network. Several definitions are given to facilitate the algorithm with a matrix representation. Section 4 talks about the simulation experiments to examine the feasibility of the algorithm. Discussions are highlighted in this section to compare the network with and without the hierarchy strategy. Section 5 concludes this paper by giving our future research directions.

2. Mathematical Description of Two Balanced Factors

The optimization of network resources aims to keep the resource utilization under a balanced status so as to ensure the QoS service quality to improve the acceptance of network request. A network could be expressed as a directed graph $G = <V, E>$, V presents the node set of the routers in network and E indicates the set of links of routers. Assume that the links in the network is m. $|E| = m$. The link l with the bandwidth capacity is C_l, the rest bandwidth is R_l. The resource idle ratio of link l could be expressed as:

$$Id_l = \frac{R_l}{C_l} \quad (1)$$

The average ratio of the resource idle in the network link is

$$E(B) = \frac{\sum_{l=1}^{m} B_l}{m} \quad (2)$$

Using the network loading balance for presenting the deviation of the $E(B)$ and B_l, D_u is used for descripting the degree. Thus, when D_u is smaller, the network resources are more balanced.

$$D_u = \frac{\sum_{l=1}^{m} (B_l - E(B))^2}{m} \quad (3)$$

The request acceptance rate is used for measuring the capacity of accepting the request in the network, which is labeled as:

$$R_a = \frac{C_a}{C_r} \quad (4)$$

Where C_a is the quantity of received request and C_r is the total number of requests received within a time period. For the entire network, under the guarantee of QoS, if the loading is trended to be consistent, the R_a will be higher. That means the entire network has the optimized utilization.

2.1. Routing Algorithm Based on QoS

The routing algorithm is based on some assumptions. According to the classic SPF algorithm like Dijkstra, QoS based algorithm is proposed for optimizing the network resources using quotient and granularity space theory. Two main assumptions are proposed. Firstly, each link has an exact bandwidth. P_{st}^{k} presents the no. k shortest path from start s to the destination t. Q_{st}^{k} means the data traffic of the no. k path. Secondly, a special scheduler is used in each network node. Weighted fair queuing scheduler or rate controlled earliest deadline first scheduler are used for ensuring the delayed time upper boundary of path P:

$$D(P) = \frac{\sigma}{\rho} + \frac{cn}{\rho} + \sum_{l \in P} dl \quad (5)$$

Where σ is the flow's burst, c is the maximum packet size, dl is the static delay which is the broadcast delay in the link l. ρ is the bandwidth speed. n is the phase number of the link. P is the selected transfer path.

Then, the problem description could be as follows: for a network $G = <V, E>$, there is a request $R = (s, t, \rho^{new}, D^{new})$. For finding some paths from start node s to the destination t with the objectives that the rest of the bandwidth of a path or the sum of the paths' bandwidth is not smaller than ρ^{new} and their delays are not bigger than D^{new}.

2.2. Network Optimization in the QoS-based Routing Algorithm

According to the previous analysis of the request of the flow rate, using the SPF routing algorithm, the linkage and transmission path required by the path delay are calculated. Then, for each path with remained bandwidth, the loading balance degree is calculated and the path with minimum loading balance degree is selected. If the selected paths do not have enough remained bandwidth, the re-routing strategy is used for adopting the second minimum loading balance degree path as an option. The network optimization approach based on QoS routing algorithm is as follows:

Step 1. When the request of flow rate occurs, the bandwidth request is ρ^{new} and delay request is D^{new};

Step 2. Based on the adjacency matrix A of useful bandwidth in the network, the shortest path p_{st}^1 satisfying the delay is worked out from entrance node s to the exit node t, second shortest path $p_{st}^2, \ldots, p_{st}^m$;

Step 3. If the available path set is null, the request of the flow rate will be rejected then go to Step 6. Otherwise, the loading balance degree under different paths are calculated D_u^1, $D_u^2, \ldots, D_u^m$, mark $TD_u = \{D_u^i \le i \le m\}$;

Step 4. Select the minimum loading balance degree from the following operations:

$D_u^k = \min TD_u$, mark the associated path is p_{st}^k;

$$q_{st}^k = \min\{\rho^{new}, \min_{l \in p_{st}^k}\{R_l\}\}$$

$$\rho^{new} = \max\{0, \rho^{new} - q_{st}^k\}$$

$$R_l = R_l - q_{st}^k \qquad l \in p_{st}^k$$

Step 5. If $\rho^{new} \ne 0$, $TD_u = TD_u - \{D_u^k\}$, go to step 4; if $\rho^{new} = 0$, go to Step 6.

Step 6. End.

2.3. Analysis of the Complexity and Feasibility of Proposed Algorithm

From the above illustration, it could be observed that the complexity of calculating the first shortest path within a network is $O(n^3)$, the complexity for the second one is $O(n^4)$ …, the complexity for the no. m is $O(n^{m+2})$. According to the request flow rate and bandwidth, the complexity of the algorithm is determined by the complex $O(n^{m+2})$ of no. m shortest path. If $m = 1$, the algorithm is the same with classic SPF solution. In the real-life application cases, m could be confined within an interval so that the complexity of calculation could be controlled.

The feasibility of the proposed algorithm is evaluated by the factor of loading balance degree. Under the satisfaction of QoS delay, the light loading link is preferred so as to avoid using the link with heavy traffic. Meanwhile, the re-routing strategy is used for dispatching the heavy flow rate with better link. Thus, the bottleneck link could be avoid for balancing the network loading. The network throughput will be increased and the congestion could be delayed.

3. Granularity Space-based Routing Algorithm in Hierarchical Network

As the increasing scale of a network, the routing selection table will be increased with certain proportion. The increasing table not only takes large number of storage memory, but also needs more CPU time to scan the table so as to send the statuses with bigger bandwidth. In a moment, the network could be so large that the routing table identifying from one link to another could not be worked out. Thus, different granularity at different layers could be used for dealing with this problem. For the Internet, two layers are not enough, thus it is necessary to grouping the domain. Based on the granularity space theory, this paper presents an division mechanism for dispersing the network into different clusters, zones, group granular through the topological structure which is shown in Figure 1.

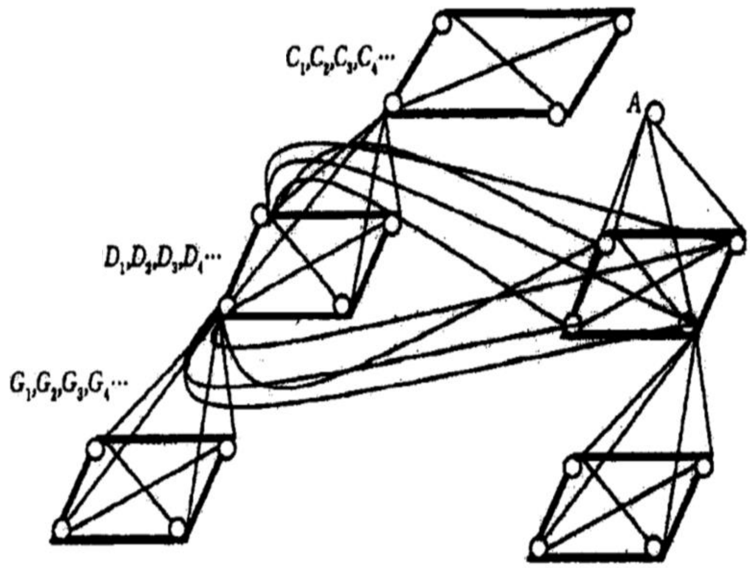


Figure 1. Topological Structure Chart for Cluster, Zone, and Group Granular

From the Figure 1, the network could be divided into cluster, zone and group granular based on the topology, node location, and relation of the nodes. In Figure 1, several connected nodes form a group, several connected groups generate a zone, and some zones form a cluster. In this algorithm, several definitions are given:

Definition 1: With the same attributes like bandwidth in a same group, the connected nodes are regarded as equivalent class. Each group presents a set of nodes. If there are some connections within two groups, there are some edges for bridging these two groups, forming group routing network.

Definition 2: The connected groups with same attributes are regarded as a zone. Nodes in a zone are equivalent class. Each zone represents a zone node. If there are some routes connected, some edges are used for connecting the zone nodes, forming zone routing network.

Definition 3: The connected zones with same attributes are treated as a cluster. Some cluster nodes are regarded as equivalent class. Each cluster represents a cluster node. If there are some connections between two clusters, some edges exist so as to form the cluster routing network.

Based on the granularity space, the routing network could be expressed by a weighted graph, assume a network $G < V, E >$, V is the node set which has limited elements. E is the edge set. $t: E \to R^{+}$, $t(e) \in [0, d]$ is the weight of edge e . $\{d_1 > d_2 > \ldots > d_n\}$. The equivalent relationship is $R(d_i)$:

$$x \sim y \Leftrightarrow \exists x = x_1, x_2, \ldots x_m = y, \; t(x_j, x_{j+1}) \geq d_i, \; j = 1, 2, \ldots, m-1, \; i = 1, 2, \ldots, n$$

Definition 4. The quotient space associated with $R(d_i)$ is $X_i = \{x_1^i, x_2^i, \ldots, x_k^i\}$. Let $X = X_0$, the elements in the quotient space are sequenced. Assume $z \in X$, the integer with $n+1$ dimensions is expressed as $z = (z_0, z_1, \ldots, z_n)$.

Based on definition 4, $p_i : X \to X_i$ is the nature projection. Let $p_i(z) = x_t^i$, the no. i coordinate of x is $z_i = t$. If z is the number t element in X_i , then $z_i = t$. The edge set of X is $E_0 : e = (x_j^0, x_i^0) \in E_0 \Leftrightarrow t(x_j^0, x_i^0) \geq d_1$, an edge is represented by $e(x_j^0, x_i^0) = (x_j^0, x_i^0)$, (X_0, E_0) . Similarly, the edge set of X_1 is $E_1 : (x_j^1, x_i^1) \in E_1 \Leftrightarrow \exists x_j^0, x_i^0 \in X, x_j^0 \in x_j^1, x_i^0 \in x_i^1, t(x_j^0, x_i^0) \geq d_2$, and the edge meets:

$$e(x_j^1, x_i^1) = \{((x_j^0, p_1(x_j^0)), ((x_i^0, p_1(x_i^0))), \forall x_j^0, x_i^0 \in X, x_j^0 \in x_j^1, x_i^0 \in x_i^1, t(x_j^0, x_i^0) \geq d_2\}$$

$e(x_j^1, x_i^1)$ is the edge set of X , which is marked as e_{ji}^1. Thus, the quotient space (X_1, E_1) is the edge set E_1 defined in X_1.

$$(x_j^i, x_t^i) \in E_i \Leftrightarrow \exists x_j^0 \in x_j^i, x_t^0 \in x_t^i, t(x_j^0, x_t^0) \geq d_{i+1}$$

$$e(x_j^i, x_t^i) = \{((x_j^0, p_1(x_j^0)), \ldots, p_i(x_j^0) = x_j^i), (x_t^0, p_1(x_t^0), \ldots, p_i(x_t^0) = x_t^i)), \forall x_j^0 \in x_j^i, x_t^0 \in x_t^i, t(x_j^0, x_t^0) \geq d_{i+1}\}$$

It is marked as e_{jt}^i and the quotient space is $(X_i, E_i), i = 1, 2, \ldots, n-1$.

3.1. Representation of X_i Space Matrix

The representation of X_i is based on a definition and a lemma as follows.

Definition 5. $\forall x, y \in X, d_i, x, y$ and d_i is connected $\Leftrightarrow$ there is a path from x to y in X whose weight $\geq d_i$.

Lemma 1. $\forall x = (x_0, x_1, \ldots, x_n)$, $\forall y = (y_0, y_1, \ldots, y_n) \in X, d_i$, x, y is connected with d_i $\Leftrightarrow$ $x_i = y_i$, where $x = (x_0, x_1, \ldots, x_n)$, $y = (y_0, y_1, \ldots, y_n)$ is the layered representation.

Proof. Assume $x_i = y_i$, according to the definition 5, x, y and d_i is connected. Thus, $p_{i-1}(x), p_{i-1}(y)$ is connected with d_i in (X_{i-1}, E_{i-1}) , and $p_{i-2}(x), p_{i-2}(y)$ is the connected set with d_{i-1} in X_{i-2}. According to the fidelity, $p_{i-2}(x), p_{i-2}(y)$ is connected with d_i in X_{i-2} . So, x, y and d_i is connected in X . Conversely, assume that x, y and d_i is connected in X , $p_i(x) = p_i(y)$. So we can get $x_i = y_i$.□

For each elements x_m^i in (X_i, E_i), a matrix Ma_m^i is established. Assume that x_m^i is consisted by the s elements in X_{i-1}, a $s \times s$ dimensional matrix Ma_m^i could be defined as:

$$Ma_m^i(tj) = \begin{cases} e(x_t^{i-1}, x_j^{i-1}), x_t^{i-1}, x_j^{i-1} \in E_{i-1} \\ \varnothing \quad Others \end{cases} \qquad m = 1, 2, \ldots, n_i \tag{6}$$

The topology of X_i could be presented by $\{Ma_j^i, j = 1, 2, \ldots, m\}$. Figure 2 shows the quotient space granular representation of topological structure according to the matrix definition given from this paper.

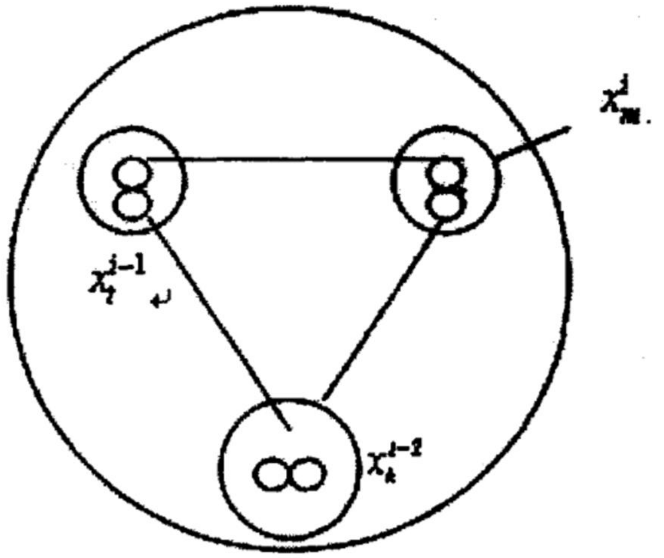


Figure 2. Representation of Topological Structure for the Quotient Space Granular

In Figure 2 the largest circle presents an element x_m^i in X_i, it is formed by connecting several dots in X_{i-1}. When there are some edges for connecting x_t^{i-1}, x_k^{i-1}, according to the definition 5, some edges exist to connect the nodes x_t^{i-2}, x_k^{i-2} in X_{i-2}. Thus, the path (x_t^{i-1}, x_j^{i-1}) is consisted by several edges from X_{i-1}.

3.2. An Improved OSPF Routing Algorithm

Given $x = (x_0, x_1, \ldots, x_n)$ and $y = (y_0, y_1, \ldots, y_n)$, assume that $x_i = y_i$, $x_j \neq y_j$, $j < i$, the connected path of x, y in X. Node x could be presented $x = (p_0(x), p_1(x), \ldots, p_n(x))$, $p_i : X \to X_i$, $i = 0, 1, \ldots, n$, $X = X_0$. Given the start node $x = (x_0, x_1, \ldots, x_n)$ and $y = (y_0, y_1, \ldots, y_n)$, assume that $x_k = y_k$,thus, these two nodes are connected in (X_{k-1}, E_{k-1}).

For $Ma_{x_k}^k$, the path $e(x_{k-1}, y_{k-1})$ from x_{k-1} to y_{k-1} could be obtained. The node a_k is inserted into x and y sequentially. Thus, a sequence with $a_k + 2$ nodes will be got. There are edges for connecting the $2i$ node and $2i+1$. Meanwhile, there is not edges to connect the node $2i-1$ and $2i$, here $i = 1, 2, \ldots, a_k + 1$. However, the coordinate of $k-1$ is the same. As a result, they are connected in (X_{k-2}, E_{k-2}). Let $k \leftarrow k-1$, the connected path will be calculated from the corresponding nodes.

For the connection of x, y in (X_{k-1}, E_{k-1}) is $e(x_{k-1}, y_{k-1})$, the endpoints are $x^1 = (x_0^1, x_1^1, \ldots, x_{k-1}^1 = x_{k-1})$, and $x^2 = (x_0^2, x_1^2, \ldots, x_{k-1}^2 = y_{k-1})$. x^1 and x^2 are inserted then we can get (x, x^1, x^2, y). As the coordinates of x, x^1 and x^2, y are the same, the connection of them in (X_{k-2}, E_{k-2}) could be worked out.

3.3. Demonstrative Examples

Based on the algorithm, a demonstrative example is presented as follows. Figure 3 shows a network with the quotient granular space topology. There are totally ten nodes in this network which is marked as $\{1,2,3,4,5,6,7,8,9,10\}$ with the weights of each edge is $\{1,3,5,10\}$. The quotient granular space representation could be worked out.

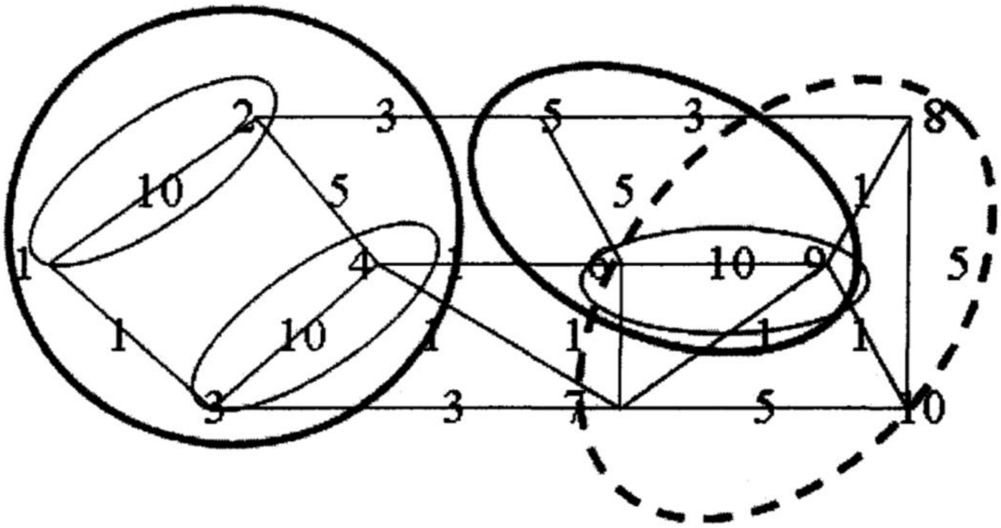


Figure 3. A Network with the Quotient Granular Space Topology

As shown in Figure 3, the ten nodes in (X_0, E_0) could be expressed as follows: $x_1^0 \to x_2^0, x_3^0 \to x_4^0, x_6^0 \to x_9^0, x_5^0, x_7^0, x_8^0, x_{10}^0$. The equivalent class $R(10)$ could get the quotient set is:

$$X_1 = \{x_1^1 = (1,2), x_2^1 = (3,4), x_3^1 = (5), x_4^1 = (6,9), x_5^1 = (7), x_6^1 = (8), x_7^1 = (10)\}$$

There are 7 elements in the quotient set and the associated matrixes are:

$$Ma_1^1 = \begin{pmatrix} 1 & (1,2) \\ & 1 \end{pmatrix},\ Ma_2^1 = \begin{pmatrix} 1 & (3,4) \\ & 1 \end{pmatrix},\ Ma_3^1 = \begin{pmatrix} 1 & (6,9) \\ & 1 \end{pmatrix}$$

$$Ma_4^1 = Ma_5^1 = Ma_6^1 = Ma_7^1 = (1)$$

The quotient space (X_1, E_1) could be got and shown as follows.

$x_1^1 - x_2^1$ $\quad x_3^1 - x_4^1$

x_5^1 $\quad x_6^1 - x_7^1$

The equivalent class $R(5)$ could get the following set:

$$X_2 = \{x_1^2 = (1,2,3,4), x_2^2 = (5,6,9), x_3^2 = (7,8,10)\}$$

There are three elements whose matrixes are

$$Ma_1^2 = \begin{pmatrix} 1 & ((2,1),(4,2)) \\ & 1 \end{pmatrix},\ Ma_2^2 = \begin{pmatrix} 1 & ((6,3),(9,4)) \\ & 1 \end{pmatrix}$$

$$Ma_1^2 = \begin{pmatrix} 1 & 0 & ((7,5),(10,7)) \\ & 1 & ((8,6),(10,7)) \\ & & 1 \end{pmatrix}$$ and the quotient space is (X_2, E_2). $\begin{matrix} x_1^2 & - & x_2^2 \\ | & / & \\ x_3^2 & & \end{matrix}$

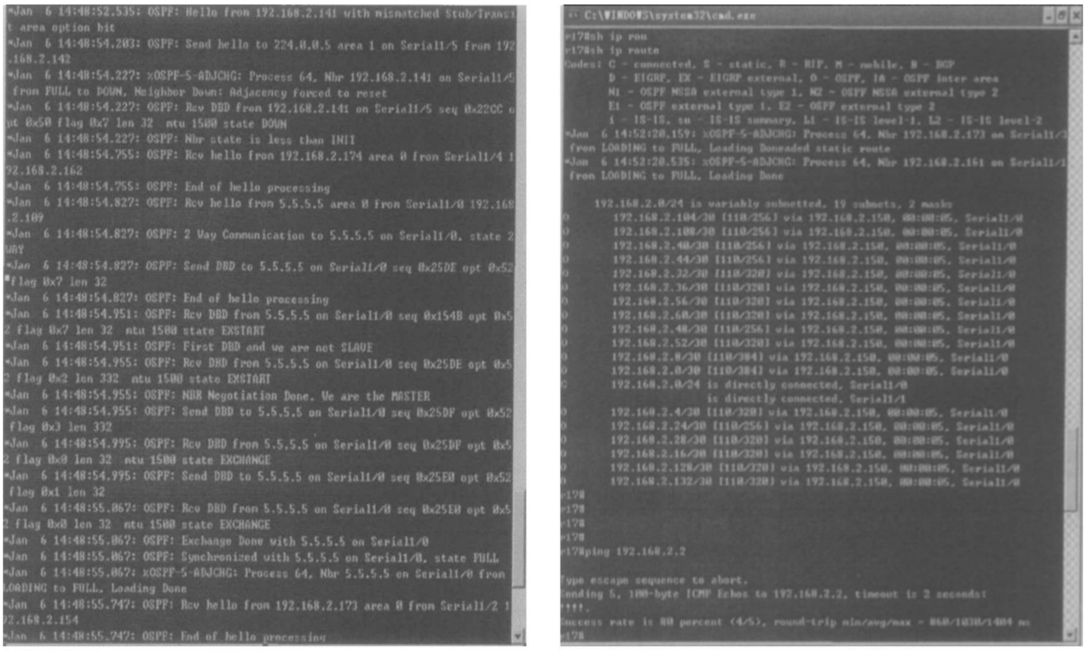
The layer number of each node is finally calculated as follows:

$1 = (1,1,1,1), 2 = (2,1,1,1), 3 = (3,2,1,1), 4 = (4,2,1,1), 5 = (5,3,2,1),$

$6 = (6,4,2,1), 7 = (7,5,3,1), 8 = (8,6,3,1), 9 = (9,4,2,1), 10 = (10,7,3,1)$

4. Simulations and Discussions

In validating the proposed improved OSPF routing algorithm, the simulation is based on 5 computers, which are used for establishing an experimental simulation environment. Each computer is equipped with Winpcap 4.0 and 21 router mappings of 7200 series from Cisco Company. IP addresses are configured and four key performance indicators (KPIs) are considered in this experiments. They are convergence time, reliability, transmission delay, and bandwidth utilization. Convergence time refers to the time of a router from starting to the convergence of the whole network or the time when the network link changes, which are reflected by the debug IP ospf events command. The reliability and transmission delay are used for examining if the network has package lost when transferring the data. They are given by PING command. The bandwidth utilization is based on two tests. One is the average transmission delay of PING package. The other one is testing from some software. For example, it is able to simulate the downloading of FTP, from Router 2 to Router 17 for downloading some files. The transmission delay of the network could be tested. Meanwhile, the flow rate generating software could be used for testing the bandwidth utilization. There are 21 router nodes in the network topology which is based on the proposed layered granular space approach.



(a) Granular network convergence (b) Package lost phenomenon

Figure 4. Experiment Results

The simulations are carried out from several steps. Firstly, the convergence time is examined by the debug IP ospf events command. The whole network is set to convergence, then one of the connection line is cut off. Before that, debug IP ospf events command is used for supervising the convergence speed of OSPF. Figure 4(a) shows the granular network convergence of no hierarchical layers. Secondly, examination of the package lost phenomenon is simulated to evaluate the reliability. PING command is used for this purpose and Figure 4 (b) indicates that, the package lost phenomenon will happen after cutting off a connection. Using the Router 17 to PING Router 2, it could be found that not only the package lost phenomenon will be occurred, the network transmission delay is large, which makes the low reliability of the granular network. Thirdly, the bandwidth utilization is tested by the software which is used to simulate the FTP downloading from Router 2 to Router 17. The network transmission delay will be examined through client machine. The configurations of client machine and routers are as follows and the experiment data are shown in Figure 5:

Reading from 'send.data' now…
The file must be strictly in the following format:
Print/noprint no_of_connection Des_IP
(connection 0) SRC_port Des_port Data_Rate_in_Kbps
(connection 1) SRC_port Des_port Data_Rate_in_Kbps
Data rate sent for connection 0 is 50.00(Kbps)
Data rate sent for connection 1 is 50.00(Kbps)
Data rate sent for connection 2 is 50.00(Kbps)
Data rate sent for connection 3 is 50.00(Kbps)
Data rate sent for connection 0 is 50.00(Kbps)
Data rate sent for connection 1 is 50.00(Kbps)
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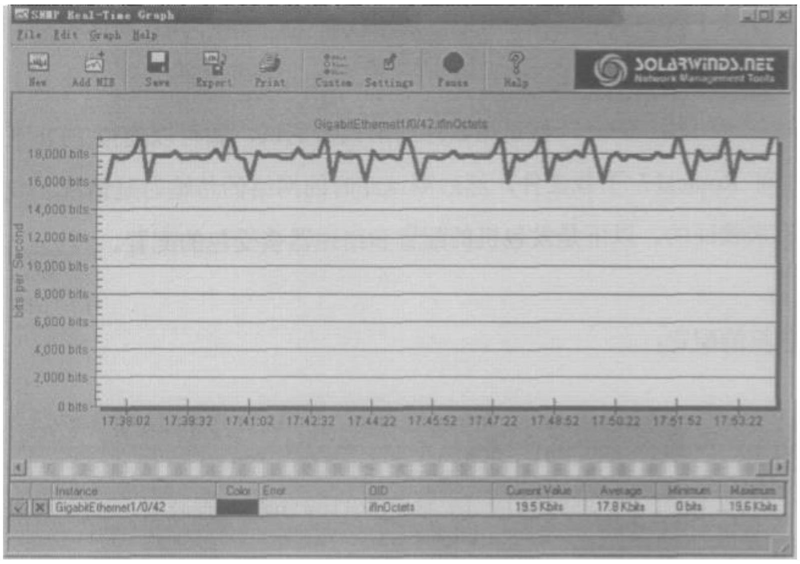
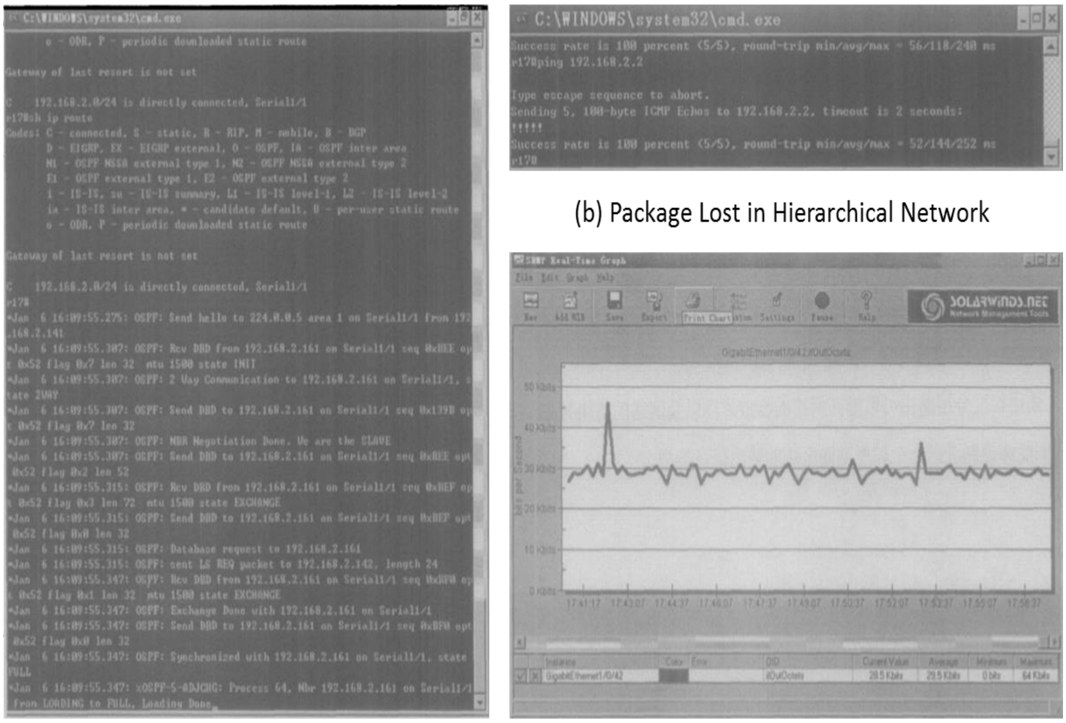


Figure 5. Bandwidth Utilization

It could be observed from the Figure 5, the network with no hierarchical layers do not have bandwidth utilization with average 18Kbit/s.

Using the same methodology, the improved OSPF routing algorithm is tested. The previous network is layered in to three hierarchies as follows. Layer 1: Router 17, main layer: Router 5, 6, 7, 8, 13, 15,15, and 16. Layer 2: Router 1, 2, 3, and 4. The experimental results are shown in Figure 6. Figure 6 (a) implies that the convergence time is much less than the no hierarchical network and the performance is better in terms of OSPF response. Figure 6 (b) shows the package lost phenomenon is greatly improved that based on the PING command and the delay of PING is significant cut down. That means the network performance using the improved algorithm is much better than the previous one. The bandwidth utilization is improved, from Figure 6 (c) which shows that the bandwidth utilization reaches 30Kbit/s. Comparing with the network without hierarchy, the improvement is 40% that the bandwidth utilization increased from 18Kbit/s to 30 Kbit/s. The hierarchical network outperforms the one without layers.



(a) Convergence of Hierarchical Network (c) Bandwidth Utilization of Hierarchical Network

Figure 6. Experiments of the Hierarchical Network

5. Summary

This paper introduces an improved OSPF routing algorithm which uses the quotient and granularity space theory. Firstly, the traditional shortest path algorithms are discussed with the mathematical description of two balanced factors. Secondly, the QoS-based routing algorithm is discussed with the basic concept to consider the QoS in a network. Thirdly, the improved OSPF routing algorithm is proposed by giving some definitions in the network which is divided into several hierarchies. Fourthly, experiments from simulations are demonstrated to compare the network without hierarchy in terms of convergence time, reliability, transmission delay, and bandwidth utilization.

Future research direction is carried out from the following aspects. In the first place, since the routing information is kept in each layer, how to reduce the SPF calculation frequency so that the algorithm complexity could be improved could be investigated. Secondly, using the granularity of network, the network information is confined in a layer so that it is very importance to reduce the routing tables when carrying out the router's selection because it costs a lot when calculating the routing tables in a very large network even it is divided into sub-hierarchies. Finally, a prototype system will be designed and developed for carrying out the experiments.

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