ISSN 1000-9825, CODEN RUXUEW
Journal of Software, Vol.17, No.1, January 2006, pp.167−174
DOI: 10.1360/jos170167

E-mail: jos@iscas.ac.cn
http://www.jos.org.cn
Tel/Fax: +86-10-62562563

GMPLS 网络中多约束 QoS 路由的预计算方法*

华 宇[1+], 吴产乐[1], 王 勇[2]

[1](武汉大学 计算机学院,湖北 武汉 430079)
[2](朗讯科技 贝尔实验室中国基础科学研究院,北京 100080)

Precomputation for Multi-Constrained QoS Routing in GMPLS Networks

HUA Yu[1+], WU Chan-Le[1], WANG Yong[2]

[1](School of Computer, Wuhan University, Wuhan 430079, China)
[2](Lucent Technologies, Bell Laboratory Research China, Beijing 100080, China)
+ Corresponding author: Phn: +86-013545256403, E-mail: yhuastar@hotmail.com

Hua Yu, Wu CL, Wang Y. Precomputation for multi-constrained QoS routing in GMPLS networks. *Journal of Software*, 2006,17(1):167−174. http://www.jos.org.cn/1000-9825/17/167.htm

Abstract: Multi-Constrained QoS routing in GMPLS (generalized multiprotocol label switching) network is to find an optimal path satisfying several constraints, such as bandwidth, cost and delay. The problem has been considered as a NP-Complete problem. Based on SRLG heuristic information, the paper provides a MPAS algorithm (Multi-constrained Precomputation Algorithm with SRLG), which includes the precomputation and searching procedures. The precomputation is able to create and update the routing tables in each node. Then, the searching procedure can select an optimal path satisfying several constraints in the hierarchical architecture. The results of extensive simulation based on the self-similar traffic show that the corresponding methods can achieve satisfactory performance and efficiently solve the problem of multi-constrained QoS routing in GMPLS network.
Key words: QoS routing; precomputation; GMPLS; hierarchical networks; NP-complete

摘 要: GMPLS(generalized multiprotocol label switching)网络中的多约束 QoS 路由问题是要在诸如带宽、代价和延迟的约束条件下找到一条优化的路径.这个问题通常被认为是一个NP-完全问题.在研究共享风险链路组具有的启发信息的基础上,提出了一种具有共享风险链路启发信息的多约束预计算算法.该算法包含预计算和搜索两个部分.预计算主要是能创建和更新每个节点上的路由表.而后,搜索部分则可以在层次化的结构中选择满足约束条件的优化的路径.大量仿真数据表明,相应的方法能够取得满意的结果,可以有效地解决 GMPLS 网络中多约束的 QoS 路由问题.
关键词: QoS 路由;预计算;通用的多协议标记交换;层次化网络;NP 完全
中图法分类号: TP393 文献标识码: A

* Supported by the National High-Tech Research and Development Plan of China under Grant No.2003AA001032 (国家高技术研究发展计划(863)); the National Key Laboratory in Software Engineering of Wuhan University under Grant No.SKLSE03-14 (软件工程国家重点实验室开放基金); the Natural Science Foundation of Hubei Province of China under Grant No.2001B057 (湖北省自然科学基金)
Received 2003-11-25; Accepted 2005-07-08

The traditional routing algorithm may compute the shortest path with only one measure and isn't suitable for the applications with different service classes. In order to solve the problem, the multi-constrained QoS routing can be applied, which may find optimal paths given all kinds of constraints. Generally, routing algorithms can be classified into two types: precomputing and on-demand computing. The main advantages of precomputation include: 1) precomputation is independent of requests from arriving packets. The precomputation would be executed if no other paths may be used or after certain periods. 2) precomputation may find more end-to-end paths and selection of the paths can be more flexible in order to avoid network congestion and achieve load balancing. However, common precomputation methods need lots of computing and storage resources. In particular, due to the dynamic characters, the state information is variable and outdated information cannot reflect the real network situation in time.

Current network environments are also changing and networks infrastructure needs not only to handle IP-based traffic and realize different levels of QoS, but also to provide a flexible and dynamic utilization of the network resources due to the unpredictability of the network traffic varying with time. Thus, IETF (internet engineering task force) introduced GMPLS (generalized multiprotocol label switching)[1] technique, which extends the previous MPLS (multiprotocol label switching) in order to accommodate all kinds of services and applications. Concretely speaking, GMPLS may control several layers, such as IP-packet, TDM (time division multiplexing), wavelength and fiber layers, in the distributed manner and utilize the unified control plane to manage heterogeneous network elements, such as OXC (optical cross connect) and ATM switches, in order to efficiently and swiftly respond to the network dynamic changes. In GMPLS networks, the elements in the path with the same SRLG (shared risk link group, defined in Ref.[1]) share resources of nodes and links, whose failure would affect the transmission performance. For example, two links are defined as the same SRLG if they use the same fiber through an OXC. Generally, a link may belong to multiple SRLG, and SRLG can be identified by a 32bit number that is unique within an IGP (interior gateway protocol) domain. As the definition in Ref.[1], SRLG in a LSP (label switching path) is the union of the SRLG identifiers in the links. Naturally, SRLG identifiers can be used to evaluate the degree of risks correlation among different network elements. So, the estimate of risk degree can be used as heuristic information in computing optimal end-to-end paths. Then, GMPLS networks can be designed as follows: from the source node to the destination node, SRLG identifiers are specified in ordered manner, increasing or decreasing according to the management policy. The purpose of specifying identifiers is only to distinguish different SRLG identifiers. Therefore, the extra work can't increase complexity largely. In the process of routing, the links with closer SRLG identifiers will have more opportunities to be chosen as the next hop.

Thus, the focus of routing technology can be explicitly described as how to efficiently utilize state information of nodes and links and find optimal end-to-end paths based on constraints. This is the motivation of the paper. Without loss of generality, we assume that the state information of current networks have been stored at each node and may be updated after certain periods. The precomputation scheme can provide the routing tables in advance and QoS requests may look up and select the corresponding paths on demand. In the paper, we shall present GMPLS-based hierarchical network architecture for precomputation and off-line A-star heuristic routing algorithm, called MPAS (multi-constrained precomputation algorithm with SRLG).

1 Related Work

Because Multiple-constrained QoS routing is considered as a NP-complete problem, several heuristic algorithms have been provided and researched. In Ref.[2], Yong Cui, Jianping Wu, Ke Xu and Mingwei Xu presented overviews of QoS routing algorithms. Ariel Orda and Alexander Sprintson in Ref.[3] gave the typical hierarchical structure with topology aggregation and derived a precomputation scheme. As for the routing algorithms with heuristic information, authors in Refs.[4,5] respectively provided a multi-object genetic algorithm and a classified pre-computed QoS routing algorithm. In addition, in the hierarchical structure, it isn't practical to straightly advertise the exact cost between adjacent nodes and methods of B.Awerbuch and Y.Shavitt in Ref.[6] could be bounded by the logarithm of the number of border nodes and the square-root of the asymmetry in the cost of a link. As far as multicast routing protocol is concerned, LI La-Yuan and LI Chun-Lin in Ref.[7] offered MRPMQ (multicast routing protocol with multiple QoS constraints), which could significantly reduce the overhead for constructing a multicast tree. Furthermore, Chih-Jen Tseng and Chyou-Hwa Chen in Ref.[8] brought forward PPMRP (probabilistic precomputation multicast routing protocol) in order to make the balance between the precomputation and on-demand computation. Based on the branch-and-bound technique and tabu-searching strategy, Yang, Wen-Lin in Ref.[9] presented an optimal algorithm and a tabu-search based heuristic algorithm for solving multi-constrained path selection problem.

MPAS is different from the previous work in three aspects. Firstly, MPAS uses heuristic information from SRLG identifiers, and SRLG character is considered as not only a kind of constraint but also the source of the heuristic information for optimal QoS routing. Secondly, in GMPLS networks, labels are main switching carriers and MPAS combines the labels with routing identifiers from domain-based paths. Thus, all kinds of resources, such as computation and storage, may be saved, and the efficiency of end-to-end routing can also be improved. Thirdly, in order to verify the performance and validity, we utilize the self-similar traffic, not the traditional Poisson rates, as the traffic source models in the simulation. The self-similar traffic could simulate the network characteristics in a real and proper manner.

2 Analytical Model

2.1 Problem Formulation

A network can be described as a directed graph, $G(V,E)$. V is the set of nodes and E is the set of links. Each link $e_{i,j}\in E$ between node i,j is associated with K additive weights, $w_k(e_{i,j})$ and $k=1,2,\ldots,K$. According to the additive characteristic, we define $w(e_{i,j})=\sum_{k=1}^{K}\theta_k w_k(e_{i,j})$ and $w_k(e_{i,j})$ is the k th weight of link $e_{i,j}$. Here, the value of $\theta_k\in[0,1]$ is independent of $e_{i,j}$ and $\sum_{k=1}^{K}\theta_k=1$. Thus, the multi-constrained values can be converted into one value. The weight $w(p)$ of a path p may be defined as the sum of weights of its continuous links as follows: $w(p)=\sum_{e_{i,j}\in p}w(e_{i,j})$ and $w(\phi)=0$. Furthermore, the process of searching paths from source node s to destination node d is to find a path that satisfies the constraints $C_k(s,d)$, where $w(p(s,d))=\sum_{e_{i,j}\in p(s,d)}w_k(e_{i,j})\le C_k(s,d)$ .The degree of risk correlation may be looked on as a function: $U(SRLG_\alpha,SRLG_\beta)=1/|SRLG_\alpha-SRLG_\beta|$) based on the SRLG identifiers, $SRLG_\alpha$ and $SRLG_\beta$, and the function can be used to provide the heuristic information in QoS routing.

In GMPLS networks, the labeling may express the hierarchical structure with clustering and policy support. The actual network with graph $G(V,E)$ can be defined as layer-1 topology and partitioned into different peer domains. Then, a peer domain in layer-1 topology can be abstracted and referred as a logical node in layer-2 topology. Thus, the process is iterative and repeated in order that the layer-i network domains are clustered into layer-$(i+1)$ logical nodes. When only a node is produced, the process is completed. The node in the layer-$(i+1)$ topology is defined as the parent node of the corresponding layer-i domain and the nodes in layer-i domain can be viewed as child nodes of the node in the layer-$(i+1)$ topology. Adjacent peer domains in the same layer are connected by the border nodes. The attributes of each node include three parts: location, weights and routing table. The location information is composed of the layer and domain identifiers, by which a node can be found easily. In particular, the identifiers of domains only have local meaning in the respective layer. The different weights of the node in layer-$(i+1)$ topology are related to the weights of different paths in layer-i topology. The routing tables can be used to select the optimal paths from the results of precomputation. Thus, based on hierarchical architecture, each node needs to capture the state information only in its own domain and store the optimal paths between border nodes in separate domain, not the whole network. The source node only needs to know the information of layers and domains.

2.2 Multi-Constrained precomputation algorithm with SRLG

Based on the analysis above, MPAS can be composed of two parts, PRECOMPUTE and SEARCH. PRECOMPUTE procedure is based on the hierarchical A-star routing algorithm. The main purpose of PRECOMPUTE procedure is to realize the precomputation and produce the corresponding routing information for each border node in each layer. Then, SEARCH procedure is used to search and select the optimal path in routing tables. In the PRECOMPUTE procedure, the estimated value, $f(n)=g(n)+h(n)$, consists of $g(n)$,which is the computed value from the source node to current node n, and $h(n)$, which is the heuristic value from the current node n to destination node. Here, $h(n)$ is computed based on SRLG heuristic information with function $U(SRLG_\alpha,SRLG_\beta)$. Conveniently, we specify that SRLG identifiers are assigned and sorted in an ascending order from the source node to destination node. PRECOMPUTE procedure is executed in advance, and when the requests arrive, SEARCH procedure is used to get the proper path from node s to d . Corresponding description can be found in Table 1.

Table 1 Description of PRECOMPUTE procedure

Create OPEN list and CLOSED list to store the candidate and accepted nodes, respectively;
OPEN= $\{s\}$; CLOSED=∅; $g(s,s)$ =0;
While ($OPEN \notin \varnothing$)
    Get a node i with minimum estimate value from OPEN list and remove it from OPEN list;
    If ($i=d$)
        Insert $path(s,i)$ into CLOSED list;
        Prune links that have the same identifiers in accepted path and produce a new graph;
    Else
        Insert node i into CLOSED list;
    For (each child node j of current node i)
        If ($j \notin OPEN$ and $j \notin CLOSED$)
            Compute heuristic value $h(j,d)=U(SRLG_\alpha,SRLG_\beta)*D(j,d)$;
            // $D(j,d)$ is the linear distance between node j and d.
            $g(s,j)=\sum_{e\in path(s,i)}\sum_{k=1}^{K}\theta_k w_k(e)+\sum_{k=1}^{K}\theta_k w_k(e_{i,j})$;
            $f(s,d)=g(s,j)+h(j,d)$;
            Insert node j into OPEN list;
        Else If ($j \in$ OPEN)
            If (estimate value of node j< estimate value in OPEN)
                Update the estimate value in OPEN;
                Else If (estimate value of node j < estimate value in CLOSED)
                    Update the estimate value in CLOSED;
                    Get node from CLOSED, and insert it into OPEN;
        Insert node i into CLOSED list;
        Sort (OPEN); // OPEN is sorted according to the estimate value.
    End for;
End while;
Return CLOSED list.

After the process of precomputation, each node may get a routing table providing optimal paths from current node to other nodes in the specified domain. When a request arrives, the process of searching can provide optimal paths based on constraints. The expression of paths found can be based on identifiers in different layers of GMPLS networks. The process is presented in Table 2. The searching begins from source node and destination node simultaneously.

Table 2 Description of SEARCH procedure

While (node *s* and node *d* are not in the same domain)
    s=*FatherNode*(*s*) and *d*=*FatherNode*(*d*);
End While;
m=the number identifier of current layer;
For $(t=m, t\geq 1, t--)$
        Based on routing tables, search optimal links and each link should satisfy $w_k(e)<c_k(e)$;
        Label the corresponding path using identifier: [*layer*,*domain*,*link*];
        s=*ChildNode*(*s*) and *d*=*ChildNode*(*d*);
End for;
Aggregate identifiers and output *Optimal Path*.

A case in point can be described in Fig.1. Concretely speaking, there are the source node *s* and destination node *d* in layer-1. They want to establish the end-to-end optimal path with several constraints. At first, two nodes need judge whether they are in the same network domain. If not, the father nodes in higher layer would be found. In this example, the domain-1 in layer-1 is related to node-1 in layer-2’s domain-1. The process can be repeated until the checked nodes are in the same domain. The bottom-up searching process is completed and each visited nodes in different layers have been marked. Then, in layer-3, the optimal link between two marked nodes is selected from the respective routing tables and verified according to the constraints. Thus, the selected link between two nodes can be determined as identifier [3,1,1], which means that the selected link is located in domain-1 of layer-3 and viewed as path-1 from the border node’ routing tables. Similarly, in the layer-2, the marked father nodes of source and destination nodes can also select the links. The identifiers, [2,1,1] and [2,3,1], can be determined in layer-2. Finally, similar methods may help the layer-1 nodes select optimal links, [1,2,1] and [1,9,2], respectively in different domains. The whole end-to-end path can be determined to be [1,2,1]→[2,1,1]→[3,1,1]→[2,3,1]→[1,9,2]. The continuous identifiers in the path can be easily mapped and incorporated into labels, which stand for different service classes and types in GMPLS networks. Thus, each node is only responsible for managing the links in its own domain.

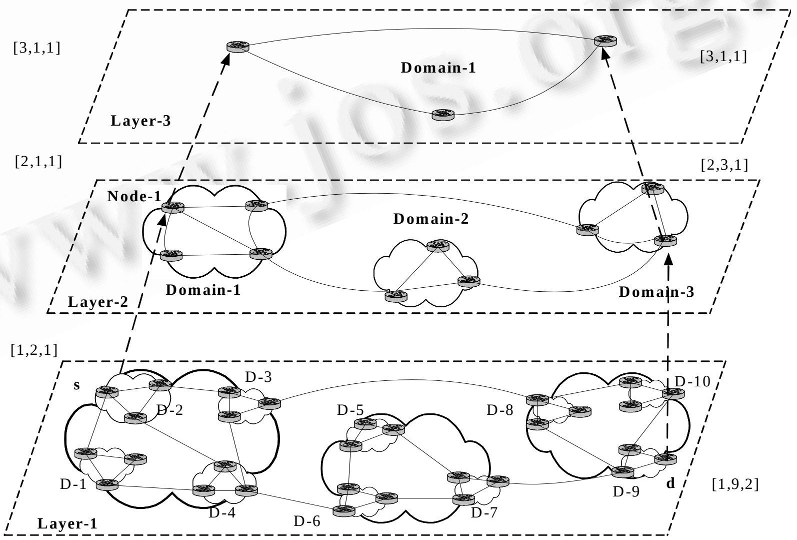

Fig.1 A searching example with identifiers [*layer*,*domain*,*link*] (D is the abbreviation of “Domain”)

3 Performance Study

In order to simulate real traffic, the model of traffic generation is based on self-similar property, not a Poisson connection arrival process with negative exponential holding time. The input traffic is generated by multiplexing many ON/OFF sources with ON and OFF periods independently and identically distributed. In state ON, the data are sent continuously and in state OFF, no data are sent. For an infinite number of sources, the traffic can generate the self-similar process with Hurst parameter $H\in(0.5,1)$. We can control the network traffic by adjusting the number of ON/OFF source models. The 8×8 mesh was chosen as the network topology in Fig.2. The 64 nodes can be viewed as layer-1 and every 4 nodes may be clustered into one domain. Thus, 16 nodes can be seen in layer-2 and similarly, every 4 nodes are considered as one domain. The clustered 4 nodes are in one domain of layer-3 and the whole topology is clustered into hierarchical architecture. Each fiber link can operate with 6 wavelengths transmitting at 4Gbps. Each node contains 4 add/drop ports to ingress/egress traffic. Each output port equips the wavelength converters with the full-range conversion capability. The evaluation of MPAS was based on the success ratio. The success ratio is defined as the ratio of the number of requests satisfied and the total number of requests generated. The criterion is checked under different amounts of ON/OFF source models and constraints. At the same time, the comparison between MPAS and Tabu algorithms could be made at the aspect of cost and blocking probability. Each node can be assumed to have related state information based on the routing protocols, and the marking of SRLG identifiers conforms to the definition in Ref.[1]. The information produced by PRECOMPUTE and SEARCH procedures could be embedded into the labels in GMPLS and used for transmission.

The results shown in Fig.3 presented the success ratio under different constraints with six traffic models. Although the correlation with different H values affected the performance, the average values in three levels are close to 91.4%, 88.2% and 72.5% respectively, which may guarantee the transmission requests of most packets. Furthermore, the results with success ratio versus number of traffic models with four constraints were presented in Fig.4. As the number of traffic models was increased, the whole trends of success ratio would be on the decline. However, the average success ratio could be around 78.4%, 67.5% and 58.9%, respectively, which were lower than those in former scenario. This was because self-similar packets were more sensitive to increased traffic than constraints in this simulation. Furthermore, the average number of paths found in mesh network could be about 935, 784 and 507 in Fig.5. This was the basic guarantee to realize the end-to-end transmission performance.

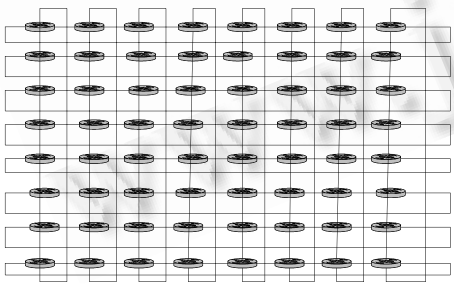

Fig.2 Topology of mesh network

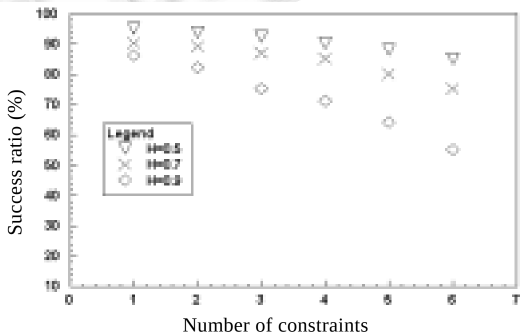

Fig.3 Success ratio in mesh network

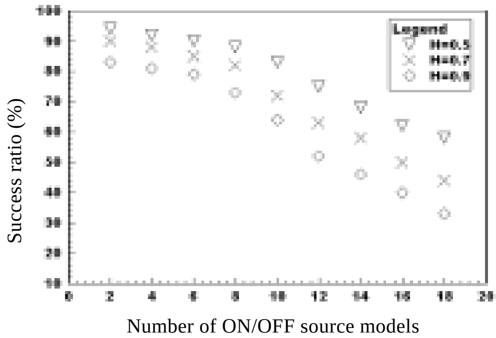

Fig.4 Success ratio in mesh network

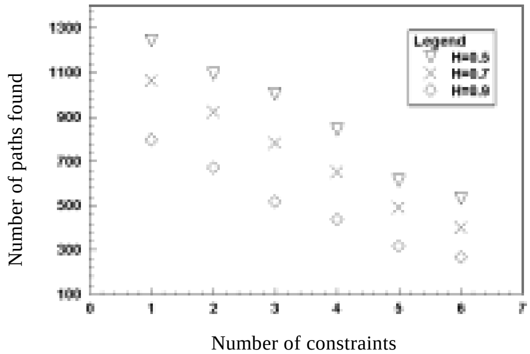

Fig.5 Number of paths found in mesh network

In order to verify the efficiency, the results of the comparison between MPAS and Tabu algorithms are provided in Fig.6 and Fig.7. As shown in Fig.6, the cost would rise with the increased constraints due to computation and searching consumption. However, the average costs of two algorithms are 1657.4 and 1015.7, respectively. The performance of MPAS outperforms that of Tabu as a result of using the label-based method and saving computation and storage cost. At the same time, because more paths could be found and selected flexibly, the better performance of transmission, expressed in blocking probability, could be achieved obviously in Fig.7. Therefore, from the results above, MPAS could obtain better performance of QoS routing.

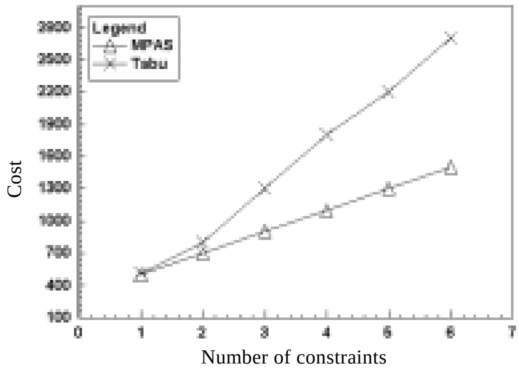

Fig.6 Comparison between two algorithms with cost versus constraints

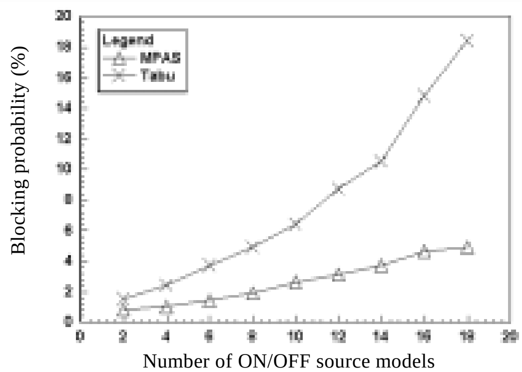

Fig.7 Comparison between two algorithms with blocking probability versus traffic models

4 Conclusion

As for the problem of QoS routing with multiple constraints in GMPLS network, this paper proposes MPAS in order to solve the NP-complete problem. The algorithm is composed of two parts, PRECOMPUTE and SEARCH. In each layer, MPAS can realize the precomputation with SRLG heuristic information. Feasible paths can be found when requests arrive. In addition, we verify the validity and efficiency of MPAS through extensive simulations with self-similar traffic. Finally, the analysis and comparison are also made in detail.

References:

[1] Mannie E, ed. Generalized multi-protocol label switching (GMPLS) architecture. IETF Network Working Group. Request for Comments: 3945 Standards Track October 2004. http://ietf.org/rfc/rfc3945.txt

[2] Cui Y, Wu JP, Xu K, Xu MW. Research on internetwork QoS routing algorithms: A survey. Journal of Software, 2002,13(11): 2065−2075 (in Chinese with English abstract). http://www.jos.org.cn/1000-9825/13/2065.pdf

[3] Orda A, Sprintson A. Precomputation schemes for QoS routing. IEEE/ACM Trans. on Networking, 2003,11(4):578−591.

[4] Yang Y, Xu YH, Li QM, Liu FY. A multi-object genetic algorithm of QoS routing. Journal of China Institute of Communications, 2004,25(1):43−51 (in Chinese with English abstract).

[5] Feng J, Zhou RF, Gu GQ. A classified pre-computed QoS routing algorithm. Journal of Software, 2002,13(4):591−600 (in Chinese with English abstract). http://www.jos.org.cn/1000-9825/13/591.pdf

[6] Awerbuch B, Shavitt Y. Topology aggregation for directed graphs. IEEE/ACM Trans. on Networking, 2001,9(1):82−90.

[7] Li LY, Li CL. A multicast routing protocol with multiple QoS constraints. Journal of Software, 2004,15(2):286−291 (in Chinese with English abstract). http://www.jos.org.cn/1000-9825/15/286.htm

[8] Tseng CJ, Chen CH. Combining precomputation and on-demand routing for multicast QoS routing. Journal of Information Science and Engineering, 2005,21:547−570.

[9] Yang WL. Optimal and heuristic algorithms for quality-of-service routing with multiple constraints. Performance Evaluation, 2004, 57(3):261−278.

附中文参考文献:

[2] 崔勇,吴建平,徐恪,徐明伟.互联网络服务质量路由算法研究综述.软件学报,2002,13(11):2065−2075. http://www.jos.org.cn/1000-9825/13/2065.pdf

[4] 杨云,徐永红,李千目,刘凤玉.一种 QoS 路由多目标遗传算法.通信学报,2004,25(1):43−51.

[5] 冯径,周润芳,顾冠群.一种分类预计算 QoS 路由算法.软件学报,2002,13(4):591−600. http://www.jos.org.cn/1000-9825/13/591.pdf

[7] 李腊元,李春林.多 QoS 约束的多播路由协议.软件学报,2004,15(2):286−291. http://www.jos.org.cn/1000-9825/15/286.htm

HUA Yu was born in 1978. He is a Ph.D. candidate at the School of Computer, Wuhan University. His current research areas are computer network and grid economy.

WU Chan-Le was born in 1945. He is a professor and doctoral supervisor at the School of Computer, Wuhan University. His current research areas are high-performance network and grid computing.

WANG Yong was born in 1973. He is an MTS in Lucent Technologies, Bell Labs Research China. His current research interests include optical networks and QoS routing.