Implementation of QoS Routing in Pre-configured GMPLS-based Optical Networks

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Abstract: This paper presents a review of QoS (Quality of Service) Routing algorithms and proposes the implementation of QoS Routing in pre-configured Generalized Multi-Protocol Label Switching (GMPLS) based optical networks. Simulation results show that the proposed algorithm performs better than previous ones in terms of connection establishment time whilst maintaining near-optimal blocking probability performance under light network traffic loads.

I. Introduction

In the context of dynamic service requests, GMPLS is one deployment strategy for the control plane in intelligent optical networks to facilitate the automatic establishment and teardown of Label Switched Paths (LSPs) based on the network conditions (resources and topology). Thus, a dynamically changing virtual topology is built up based on the physical topology. The two topologies have distinctive differences: the former represents the services distribution among different nodes while the latter depicts the actual connection relationships (i.e. the optical fibre links) among the nodes in the optical networks. Upon a connection request between a specific pair of nodes, it is mapped onto the physical topology by the RWA (Routing and Wavelength Assignment) algorithms and a lightpath is set up using signalling protocols such as RSVP-TE (ReSource reserVation Protocol-Traffic Engineering) or CR-LDP (ConstRaint-based Label Distribution Protocol) according to the calculated route [1, 2].

Most of the research in this area is either focused on optimal design of the physical resource [3, 4] or improving the related protocols to obtain better network performance [5, 6, 7]. As the previous work [8] states, the concept of a pre-configured topology is proposed for two reasons: (1) the poor match between the virtual and physical topologies, and (2) the complexity and difficulty in optimizing routing and path establishment process. The simulation results given in [8] show that routing based on a pre-configured network topology has the advantage of a large reduction in the average hops as compared with the one based only on the physical topology. Thus, it can reduce the connection establishment time. However, the performance improvement is gained at the cost of higher blocking probability, which has negative effect on the performance of the intelligent optical networks. In this paper, we propose a novel pre-configured based routing algorithm by incorporating a QoS Routing method in the pre-configured

GMPLS-based optical networks and simulations are carried out based on the proposed algorithm to verify its effectiveness in shortening the average service connection hops whilst maintaining near optimal blocking probability at the same time.

The structure of this paper is as follows. A review of QoS Routing algorithms is presented in Section II; the idea of network topology configuration is explained briefly in Section III; then, based on the work of Section II and III, a novel QoS routing algorithm based on Pre-Configured GMPLS-based optical networks (PC-QRA) is described in detail in Section IV; Section V provides simulation results and analysis. Finally, conclusions and future work are given in Section VI.

II. Review of QoS Routing Schemes

QoS Routing is introduced to provide the network with the routing algorithms that are able to identify QoS-satisfied paths so as to accept as many service requests as possible whilst meeting specified QoS constraint(s). Metrics such as link bandwidth, delay and packet loss are examples of QoS constraints. Usually, bandwidth is considered as the main requirement in QoS Routing algorithm exploration and other metrics can be converted into bandwidth requirements if necessary [9]. There are many QoS Routing algorithms proposed till now and most of them are proposed to be deployed in MPLS (Multi-Protocol label Switching) networks. MPLS QoS Routing algorithms distinguish themselves from other QoS Routing algorithms such as WSP (Widest Shortest Path protocol) and SWP (Shortest Widest Path protocol) in the aspect of taking into consideration the ingress-egress pairs [9].

QoS Routing can be classified into two categories according to whether it supports restoration: QoS Routing without protection (QSR-NP) and with protection (QSR-P). QSR-NP mainly focuses on online QoS Routing algorithms without restoration schemes and it will be reviewed in this paper.

SWP and WSP are two well-known QoS Routing algorithms possessing dual-objectives with different priorities: minimizing resource usage (Shortest) and balancing load (Widest). SWP gives higher preference to the second target whilst WSP tries to use the least amount of network resource.

The second type of QoS Routing algorithm is primarily aimed at minimizing the blocking probability of the service requests in MPLS networks. One typical example is the QoS algorithm called MI-based (Minimum Interference) Routing, which was first proposed by M. Kodialam [9]. The main idea of this algorithm is to route the path that interferes as little as possible with those paths that may meet the requirements of future service connection demands, thus it can achieve a lower request rejection ratio. There are several variants based on Kodialam’s algorithms, which are classified into the same category. E. Calle *et al* [10, 11] give a survey of MI-based routing algorithms, which is recommended reading for a detailed description and comparison. Recently, another QoS Routing algorithm called the WSS (Widest Shortest path Switching) algorithm [12] is proposed, which calculates the potential path after adding a weight to each link according to the number of paths that might be routed over it. Besides achieving lower blocking probability, WSS has lower computation complexity in contrast to MI-based routing algorithms [12].

Last but not least, the authors in [13] propose QoS Routing algorithms that are based on k-WSP and NPD (Network Protection Degree) in MPLS networks and verified using performance parameters such as NLP (Number of Links to be Protected) etc. Although no protection methods are implemented, the proposed algorithms indicate that QoS Routing considering network protection parameters can decrease the complexity of protection implementation with the penalty of a slightly higher call blocking probability.

A summary of QoS Routing algorithms is given in Table I.

Table 1 Summary of the QSR-NP algorithms

Scheme	Objective(s)	Complexity	Info. Needed	Computation Process
SWP (1997)	1st: balancing load; 2nd: minimizing cost	Low	Residual Bandwidth (RBW)	upon each request, run as follows: 1st stage: getting the network graph with insufficient links pruned; 2nd stage: finding all possible paths with equal maximum residual bandwidth(MRBW); 3rd stage: finding the one with minimum hops.
WSP (1997)	1st: minimizing cost 2nd: balancing load	Low	RBW	upon each request, run as follows: 1st stage: getting the network graph with insufficient links pruned; 2nd stage: finding all possible paths that have equal minimum hops; 3rd stage: finding the one with MRBW.
MI-based family(1) (2000-2006)	Minimizing the blocking probability	High	RBW; Ingress-egress node pairs information;	upon each request , run as follows: 1st stage: determining the link weight using Maximum Network Flow theory; 2nd stage: assigning weights to the links according to their criticalities; 3rd stage: selecting the path using Dijkstra algorithm based on the weighted graph.
WSS (2008)	Minimizing the blocking probability	Medium	RBW; Ingress-egress node pairs information;	1st stage: Link Weight Calculation; 2nd stage: upon each request, selecting the path using Dijkstra algorithm based on the weighted graph.
NPD-based (2003)	Protection-related criteria(2)	Medium	RBW; Ingress-egress node pairs information;	1st stage: NPD parameters and K-WSP calculation; 2nd stage: upon each request, selecting the path using the proposed algorithms based on the pre-computed K-WSP paths.

(1) The MI-based family shares the same objective, but other performances are different, MIRA [8] is used as representative for this category in this paper;

(2) e.g., NLP and Number of backup paths needed if the protection mechanism is introduced in the network scenarios.

III. Introduction to the Pre-configuration Schemes

The assumptions for the pre-configured mechanisms in GMPLS-based optical networks are listed as below:

1. No knowledge of ingress-egress pairs information is considered; thus, it is assumed that every node pair can be a (src, dest) pair candidate for each dynamic connection request;
2. In the routing process, traffic engineering is incorporated, and it is assumed that the RBW information is distributed across the network either through routing-based or signalling-based methods in GMPLS-based networks;
3. Only a path with two hops will be pre-configured to balance the extra cost that the pre-configuration schemes introduce and the connection establishing time;
4. The weight of link is inversely proportionally to the residual bandwidth and is defined as: W_{mn} = C (Capacity) / RBW;
5. It is assumed that all nodes in the network have Wavelength Conversion (WC) capabilities.

The principle of the pre-configuration schemes is that with the help of pre-establishing certain amount of paths, the physical topology will be shaped (i.e. to form a virtual topology) to adapt the dynamically coming connection request. Specifically speaking, if the amount of resource on certain two-hop segment that is consumed to set up paths for connection requests goes across the limit (i.e. Tpc that will be explained later in this section) within a short period of time, then the 2-hop paths will be pre-established and proper amount of resource will be allocated. Thus, the virtual topology is built up and will be used during the path set-up process upon each connection requests. Detailed explanations about the three pre-configuration schemes are given in [8].

The Pre-Configuration Algorithms (PCA) are depicted in Figure 1 and the explanation of the notations used in the figure is given as below.

- Q = Max(q_{mn}), it is the maximum number of lightpaths routed in the network while q_{mn} is the number of lightpaths between the (m, n) node pair;
- $F_{ij}(k) = t_{ij}(k)/Q$, it is the distribution factor used to decide the percentage of pre-configuration resource; while $t_{ij}(k)$ represents the number of lightpaths on the node pair (i, j) that goes through node k;
- Tpc is the threshold defined to decide whether one two-hop path should be pre-configured or not. If one two-hop path meets the criteria, namely its distribution factor is bigger than Tpc, then Fij(k)*C resource will be preconfigured.

IV. Design of PC-based QoS Routing Algorithm (PC-QRA)

A novel algorithm is proposed for deployment in pre-configured optical networks by incorporating QoS Routing. As the main objective for the pre-configured routing schemes are to reduce the average number of hops, exploiting pre-established two-hop paths whilst maintaining a low blocking probability, the WSP algorithm listed in Table I is suitable for this application and deployed in the routing stage. A QoS constraint (we only use the bandwidth requirement as the metric.) is included in the process of the path selection process and the algorithm is explained in Figure 2.

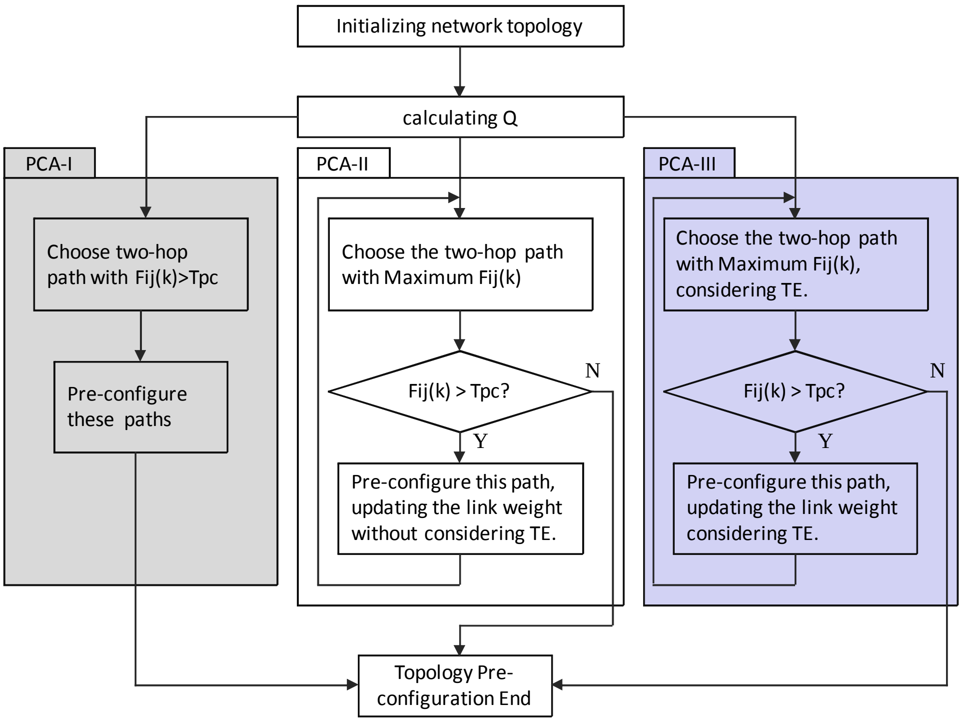

Figure 1 Flow chart of the Pre-Configuration Algorithms (PCA)

V. Simulation Results and Analysis

In this section, the proposed QoS Routing Algorithm based on Pre-Configuration schemes (PC-QRA) is evaluated using the same topology as presented in [8]. The traffic is distributed equally among all nodes pairs and arrives according to a Poisson distribution. For comparison purposes, the following two schemes are included:

(1) The scheme with the optimal performance proposed in [8] (i.e. PCT-DRA-I over PCA-I);

(2) WSP routing algorithm based on physical topology (QRA on physical topology);

Figure 3 depicts the QRA routing algorithm with different PCA approaches, which again verifies the effectiveness of pre-configuration in lowering average number of hops. Moreover, QRA with the first PCA scheme (PC-QRA for short) is optimal in regard to both blocking probability and average number of hops, which is selected for comparison with PCT-DRA-I over the PCA-I scheme (PCT-I for short).

As shown in Figure 4, the PC-QSRA scheme is superior to the PCT-I scheme, as it can reduce the average number of hops whilst maintaining near optimal blocking probability performance. However, as the traffic load becomes heavy, the average hop number with PC-QRA will be slightly higher than that of the PCT-I scheme, but still smaller than that obtained without the pre-configuration strategy. However, the average hop performance of PCT-I is lower at higher traffic loads because its blocking probability is as high as 10%. Whereas, the PC-QRA scheme has blocking probability lower than 1% under the same traffic conditions. Thus, overall, the performance of the proposed scheme is better than the previous one.

Pre-Configuration based QoS Routing Algorithm (PC-QRA)

Step I: Inherit the weights updated by PCA;

Step II: When a service request arrives, execute the following steps;
when a service terminates, execute **Step VI**;

Step III: Prune the links that do not have sufficient bandwidth for the request, and run Dijkstra algorithm in the pre-configured topology;

Step IV: find the routes with minimum hops;

Step V: choose the route with MRBW;

Step VI: Allocate network resources, and go to **Step II**;

Step VII: Release network resources, and go to **Step II**;

Figure 2 PC-based QoS Routing Algorithm

VI. Conclusion and Future Work

In this paper, a review of the QoS Routing algorithms is given and then a novel QoS Routing algorithm based on pre-configured GMPLS-based optical networks (PC-QRA) is presented. Simulation results show that the performance of the proposed algorithm is better than the previous ones as it can obtain lower average number of hops whilst still keeping near optimal blocking probability.

Ongoing work is now considering other QoS Routing algorithms and the deployment of pre-configuration schemes in MPLS scenarios where ingress-egress node pair information is known.

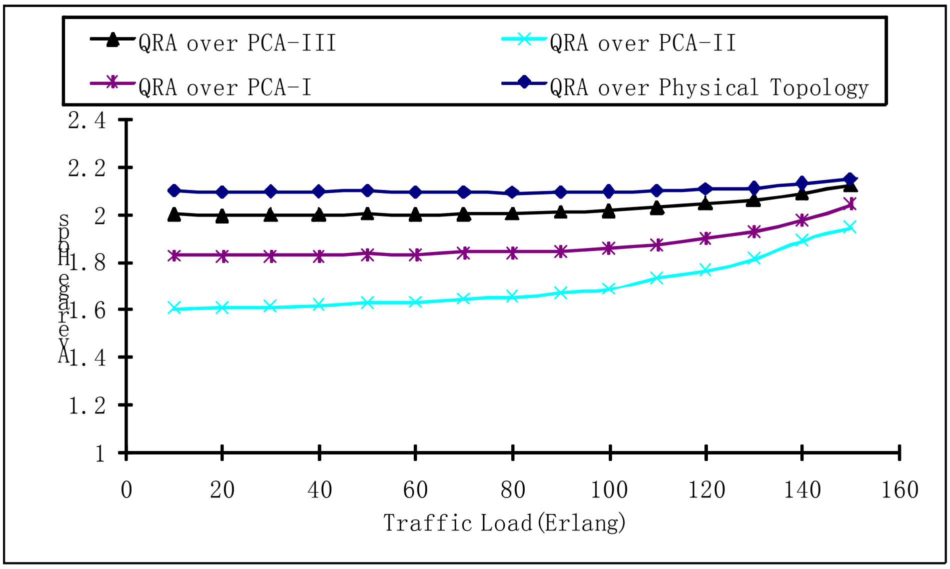

Fig.3 (a) Average Hops

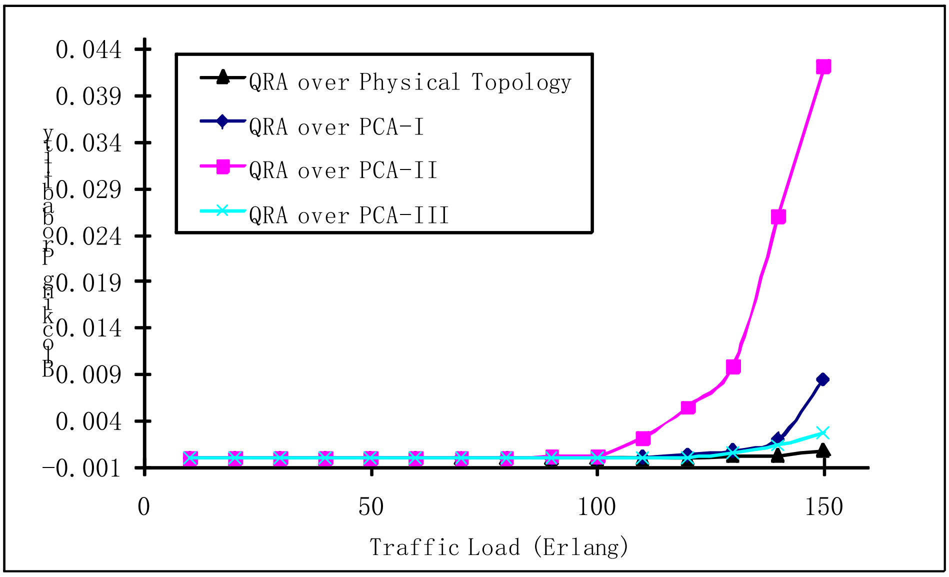

Fig. 3 (b) Blocking Probability

Figure 3 PC-QRA with different pre-configuration schemes

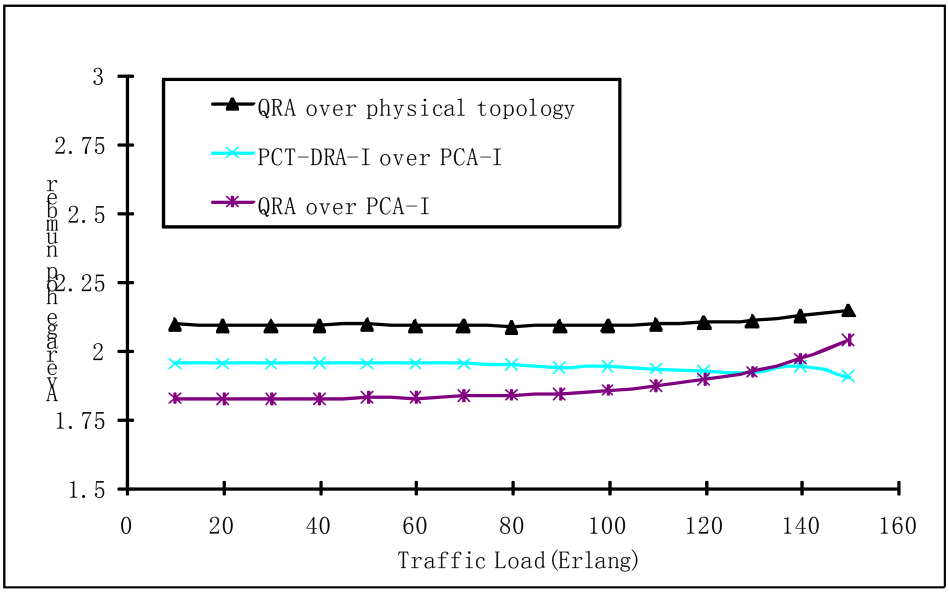

Fig. 4 (a) Average Hops

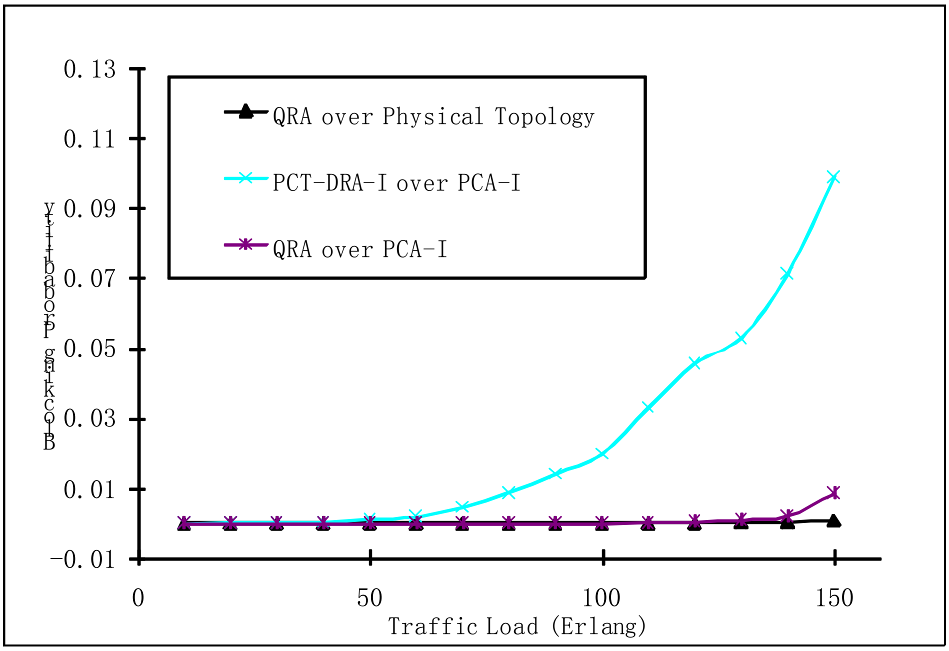

Fig. 4 (b) Blocking Probability

Figure 4 PC-QRA compared with PCT-DRA-I over PCA-I schemes

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