Constraint–Based Routing with Maximize Residual Bandwidth and Link Capacity – Minimize Total Flows Routing Algorithm for MPLS Networks

Piyaporn Krachodnok
School of Telecommunication Engineering,
Suranaree University of Technology,
Nakhon Ratchasima 30000, Thailand.
Email: priam@ccs.sut.ac.th

Abstract—**This research proposes an on-line routing algorithm for bandwidth-based guaranteed tunnels in the Multi-Protocol Label Switching (MPLS) networks, called the Maximize Residual bandwidth and link Capacity – Minimize total Flows (MaxRC-MinF) routing algorithm. The proposed algorithm can be categorized into link-constrained and path-constrained routing problems. It is based on three objectives: minimizing the interference level among ingress-egress pairs, balancing the traffic load over under-utilized paths, and trying to reserve bandwidth for future request. Finally, we have compared the performance of the MaxRC-MinF algorithm with other previously proposed algorithms. We found that the MaxRC-MinF algorithm achieves lower rejection probability and higher total throughput, maximum and average link utilization. However, because of its computational complexity, the proposed algorithm has a few higher CPU calculation time.**

Keywords—**Routing algorithm, Constraint-Based Routing, QoS Routing, Bandwidth-based Guaranteed Tunnels, Traffic Management and MPLS network.**

I. Introduction

Firstly, the Multi-Protocol Label Switching (MPLS) network [1]-[3], proposed by the Internet Engineering Task Force (IETF), has been developed in order to overcome complexity and scalability problems of mapping the IP network over the Asynchronous Transfer Mode (ATM) backbone. The MPLS technology uses IP router software and label swapping paradigm as control and forwarding plane, respectively (see Fig. 1). The MPLS network uses Label Distribution Protocol (LDP) for the control plane which is able to establish explicit route, called Label Switched Path (LSP), from an ingress Label Switching Router (LSR) node to an egress LSR node (called source-destination node pair) and to assign label into different Forward Equivalent Classes (FECs). With label swapping, packets with the same label coming from the same ingress LSR are swapped and transmitted along the same LSP. The label switching technology allows administrators simply manages their own networks for new technologies such as Traffic Engineering (TE), Constraint-Based Routing (CBR), Quality-of-Service (QoS) routing, and Virtual Private Networks (VPNs).

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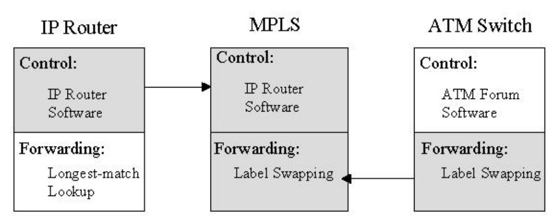

Figure 1. MPLS Architecture

The bandwidth-based guaranteed tunnels (or LSPs) routing problem over the MPLS network is the main topic of this research. This may call on-line routing problems since the LSP establishing requests arrive one-by-one and future demands are unknown. The only dynamic information available for the routing algorithm is residual capacities of links provided by Link-state protocols such as OSPF. Static information is ingress-egress node pairs, link capacity and network topology. Furthermore, the routing algorithm is aimed to achieve following performances:

- Low level of rejection probability
- High level of network total throughput
- High level of network utilization
- Low level algorithm complexity

To obtain above performances, we introduce a MPLS routing algorithm called Maximize Residual bandwidth and link Capacity – Minimize total Flows (MaxRC-MinF) routing algorithm. It tries to select an LSP with maximum residual bandwidth and link capacity in order to increase load balancing and network utilization over under-utilized path. Also, the selected LSP must have minimum traffic or flow in order to reduce interference level among source-destination node pairs and reserve bandwidth for future demand.

The remainder of the paper is organized as follows: Section II presents related works for bandwidth based guaranteed LSP routing. Section III describes the proposed routing algorithm and its details. Simulation results are shown in Section IV. Finally, Section V concludes the paper.

II. Related Works

Various solutions for bandwidth guaranteed LSP for MPLS network have been approached [4]-[12]. Those algorithms search for a LSP to hold up the requested bandwidth of an incoming traffic (or flow). The requested bandwidth must be guaranteed throughout the transmission period. Here, there are 5 previously proposed algorithms chosen for performance comparison. Brief details of those algorithms are reviewed as follows.

The Min Hop algorithm (MHA) [9] is the simplest and most popular algorithm to route both on-line and off-line traffic demands. It always utilizes links belonging to shortest path which satisfies the demand bandwidth. The algorithm has the lowest calculation complexity and consumes least network resources. However, it may use up some shortest paths, while other longer paths may be under-utilized.

The Widest Shortest Path (WSP) algorithm [9] is an improvement to MHA routing, where the shortest path with the largest available bandwidth (or residual bandwidth) is chosen. This will enable load balancing between the equal hop count paths for different traffic request. However, it still chooses to use up all available capacity on particular shortest paths before longer paths with more capacity. Hence, longer paths are under-utilized.

Dynamic Link Weight (DLW) algorithm [10] takes early precautions to avoid using up the capacity of any congested links when alternative lower loaded paths are available. This algorithm enables efficient load balancing of the network and minimizes demand reject probability. However, DLW does not take into account the interference level (introduced by [2]). Hence, the LSP chosen by DLW algorithm may not meet reservation for future demand.

Wisitsak's routing algorithm (WSS) [11] is proposed based on weight calculation of an amount of possible paths per link in the network. A link with high weight value indicates high probability of traffic traversing over the path. The algorithm aims to avoid those high-weight links, in order to reduce the chance of interference between each other source-destination node pairs. According to the performance of WSS algorithm, it performs well in case of low rejection probability. Moreover, it has a lower complexity than that of the minimum interference routing algorithm (MIRA) in [2]. However, the algorithm does not take into account some dynamic information of links such as residual bandwidth. Therefore, the algorithm performance may be degraded over various dynamic scenarios.

Fabio's Weight Function (WF) [12] takes advantage in dynamic scenarios. Since, it is based on calculation of weight function related to both dynamic and static information (residual bandwidth and link capacity). Consequently, this scheme enables load balancing over under-utilized links belonging to the network. However, the interference level among source-destination node pairs still dose not be taken into consideration.

The next section we would like to present a new MPLS routing algorithm as an improvement to MH, WSP, DLW, WSS and WF algorithms.

III. The Proposed Algorithm

As mention, our proposed algorithm is one of link-constrained and path-constrained routing. It relies on link weight as information for routing calculation. The objectives of the algorithm are as follows.

A. *Designing Objectives*

From section II, we try to develop a routing algorithm to overcome many disadvantages of those previous works. Then, we can conclude than the objectives of MPLS routing are:

- Minimizing interference level among source-destination node pairs, in order to reserve more resource for future bandwidth demands.
- Balancing traffic loads through under-utilized paths other than a shortest path, in order to reduce network congestion.
- Taking into account both static and dynamic information of link states, in order to improve performance of routing algorithm over dynamic condition.

To satisfy above objectives, we apply link state information which is residual bandwidth, link capacity, and total flow to be involved in our proposed algorithm.

Firstly, links with high number of total flow could indicate high interference level on those links. Therefore, we try to select LSP with minimal number of total flow in order to avoid link with high interference level. This could satisfy the first objective. Further, total flows over link are a dynamic link state information. This could also satisfy the third objective.

Secondly, new incoming traffic should be traversed onto under-utilized paths having high residual bandwidth (or available bandwidth). Then, we try to select LSP with high amount of residual bandwidth. Since, the residual bandwidth is a dynamic link state information. Therefore, this approach could satisfy both the second and the third objectives.

Lastly, link capacity is also a static information which could be used for load balancing purpose. Thus, we try to choose LSP with high link capacity in order to share traffic load over the network. Similarly, residual bandwidth, this method can satisfy with both the second and the third objectives.

According to those three objectives, the proposed algorithm is therefore named Maximize Residual bandwidth and link Capacity – Minimize total Flows (MaxRC-MinF) routing algorithm. Details of link weight calculation are explained in the next subsection.

B. Calculation of Link Weight

Let us first define some parameters involved in the calculation of link weight.

G(N,L)	: a network graph
N	: set of nodes
L	: set of links
S	: a source node, S∈N
D	: a destination node, D∈N
{S,D}	: set of source-destination node pairs
F_j	: total flows over link j, j∈L
R_j	: residual bandwidth of link j, j∈L
C_j	: capacity of link j, j∈L
w_j	: weight of link j, j∈L
$W_{\{S,D\}}$	: weight of path belonging to source-destination node pair {S,D}

Here, weight of link j could be determined by (1).

$$w_j = \frac{F_j}{R_j C_j} \qquad (1)$$

From "(1)", the higher link weight value (w_j) indicates the higher total flows and the lower residual bandwidth and link capacity. On the other hand, the lower link weight value signifies the lower total flows and the higher residual bandwidth and link capacity. So, MaxRC-MinF algorithm intends to choose a LSP cooperating with those low weight links.

C. Path Selection

The weight of path belonging to source-destination node pair {S,D} ($W_{\{S,D\}}$) could be obtained by (2).

$$W_{\{s,d\}} = \sum_{j \in L_{(S,D)}} w_j \qquad (2)$$

This path weight ($W_{\{S,D\}}$) is a key for MaxRC-MinF algorithm to route LSP from ingress node S to egress node D. The constraint of path selection could be expressed in (3).

$$\min\left(W_{\{s,d\}}\right) \qquad (3)$$

However, if there are many result paths with the same minimum path weight, the algorithm would pick a shortest path (or minimum hop path) between those result paths in order to reserve network bandwidth.

D. Algorithm Steps

The algorithm steps are shown in Fig. 2.

```
Procedure MaxRC-MinF_Routing {
  1. Reduce network graph by eliminate all links that have residual bandwidth less than request bandwidth.
  2. Calculate link weight (wj).
  3. Use Dijkstra routing algorithm to obtain shortest path with minimum path weight (W{S,D} ).
  4. Establish the result path found in Step 3.
  5. If no path is selected, the algorithm fails.
}
```

Figure 2. MaxRC-MinF_Routing Procedure

IV. Simulation Test

For simulation study, we develop extensive routing simulation program on MATLAB 6.5 software. Flowchart of the simulation program could be shown in Fig. 3. The simulation program was run over Microsoft Windows XP SP1 platform with 1.5 GHz Pentium4 Processor and 256 MB RAM. This specification is used as reference of speed of central processing unit (CPU) of the platform.

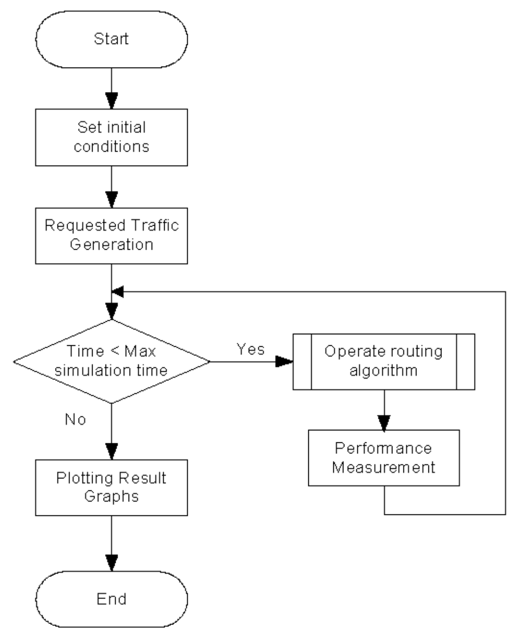

Figure 3. Flowchart of Simulation Program

A. Evaluated Parameters

From the simulation program, there are 5 measured parameters to test performance of algorithms, i.e., rejection probability, total throughput, maximum link utilization, average link utilization, and CPU calculation time. Those parameters can be obtained by (4) - (8). MPLS routing algorithm should have low rejection probability, high total throughput, high maximum link utilization, high average link utilization and low CPU calculation time.

$$RejectionProbaility = \frac{Succesful\,Requested\,Traffic}{Total\,Requested\,Traffic} \qquad (4)$$

$$TotalThroughput = \sum Successful\,Requested\,Bandwidth \qquad (5)$$

$$MaximumLinkUtilization = Max(Link\,BanwidthUsage) \qquad (6)$$

$$AverageLinkUtilization = \frac{\sum(BanwidthUsage\,of\,Link)}{Total\,Number\,of\,Links} \qquad (7)$$

$$CalculationTime = \frac{Total\ SimulationTime}{Total\ Number\ of\ RequestedTraffic} \quad (8)$$

B. Simulation Model

We use the network topology [2] shown in Fig. 4 for performance studies. All links are bi-directional. The thin links have capacity of 120 units (represented for OC-12 link). The thick links have capacity of 480 units (represented for OC-48 link). The size of request guaranteed bandwidth is 1 to 3 units generated by uniformly distribution. The offered load is varied from 0 to 1,600 connections per second. There are 5 source-destination node pairs to transmit through the network. For more precisely results, ingress and egress nodes of those pairs are 5-times randomized. Then random pairs are [1-6, 5-1, 5-8, 8-3 and 10-3], [1-10, 2-9, 3-8, 4-7 and 5-6], [2-1, 2-10, 8-9, 9-3 and 10-5], [2-6, 3-4, 5-3, 5-6 and 9-1] and [3-6, 5-1, 6-4, 9-7 and 9-8]. Finally, results from those 5 scenarios are averaged.

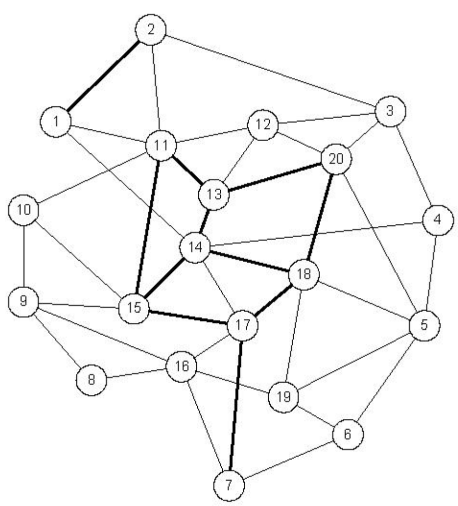

Figure 4. Network Topology

C. Results

Due to space limitations of this paper, we could not show all results from 5 simulation scenarios. However, the average versions are given in Fig. 5 to Fig. 9.

From Fig. 5, all algorithms have the same performance in a low traffic load condition (offered load 0-300 connections/s). The MaxRC-MinF algorithm has the highest performance. It has the lowest rejection probability during offered load 300 – 1,600 connections/s. However, the MHA algorithm suffers from high rejection probability.

Fig. 6 shows that MaxRC-MinF algorithm again gives the best performance in case of total throughput. Differently, the MHA gives the worst result.

Results of both Fig. 7 and Fig. 8 demonstrate that the MaxRC-MinF algorithm could utilize the highest amount of link resources. These results satisfy the second objective in the section III. The proposed algorithm could enable load balancing which reduces chance of rejection and congestion.

However, in Fig. 9, result of the average CPU calculation time per connection shows disadvantage of the MaxRC-MinF algorithm. It consumes the highest amount of calculation time, because of the complexity of the algorithm.

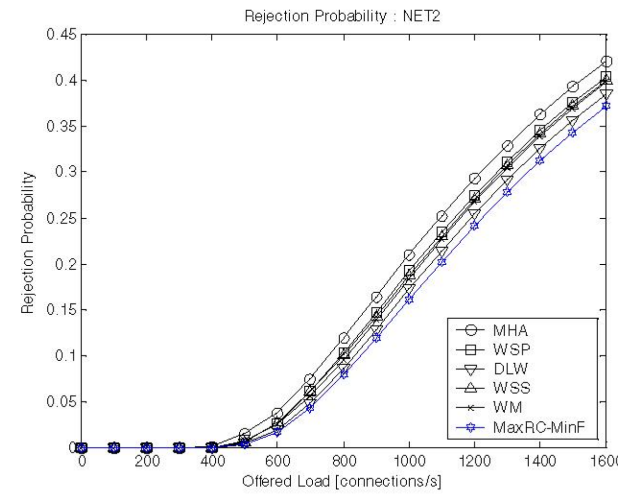

Figure 5. Rejection Probability vs. Offered Load

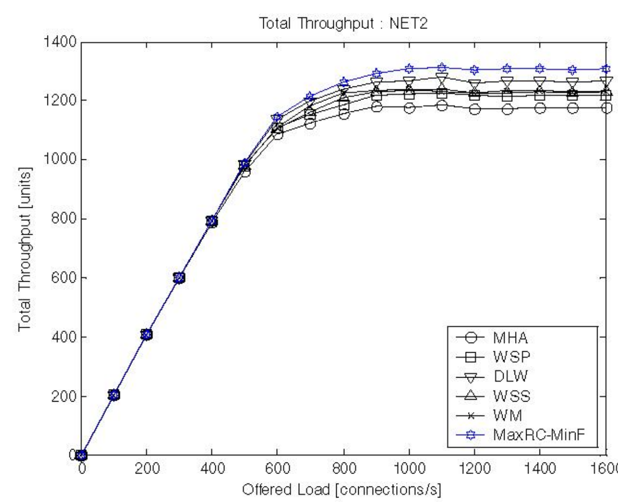

Figure 6.Total Throughput vs. Offered Load

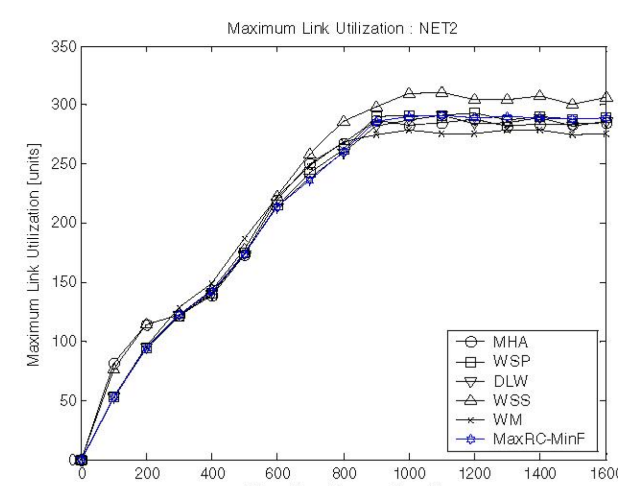

Figure 7. Maximum Link Utilization vs. Offered Load

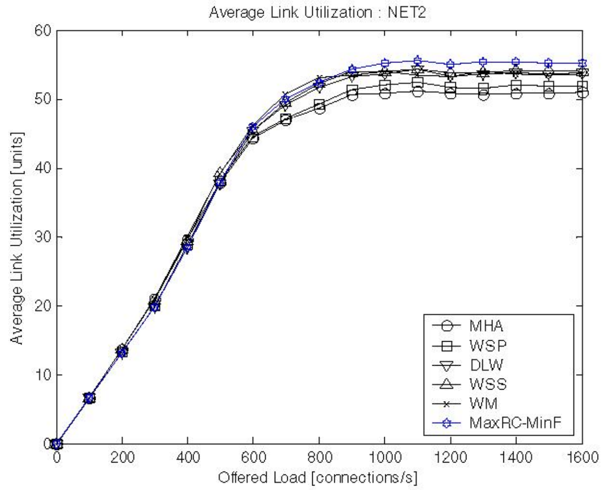

Figure 8. Average Link Utilization vs. Offered Load

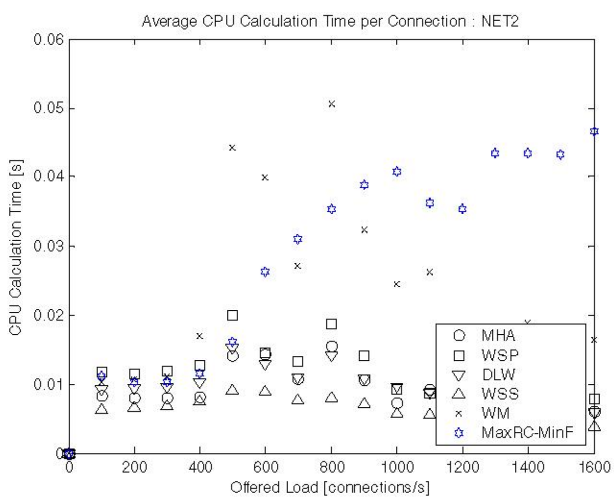

Figure 9. Average CPU Calculation Time vs. Offered Load

V. Conclusions

In this paper, we have proposed a new bandwidth based guaranteed LSP routing algorithm for MPLS networks, called Maximize Residual bandwidth and link Capacity – Minimize total Flows (MaxRC-MinF) routing algorithm. It is one of link-constrained and path-constrained routing problem which relies on calculation of link weight. It uses 3 link state parameters: residual bandwidth, link capacity and total flows to accomplish the 3 objectives: minimizing the interference level among ingress-egress pairs, balancing the traffic load over under-utilized paths, and trying to reserve bandwidth for future request. From the simulation test, the MaxRC-MinF algorithm performs well, since it achieves lower rejection probability, higher throughput and higher link utilization that the previous works. Nevertheless, the proposed algorithm suffers with its computational complexity.Finally, future works are pointed out through simulation tests on critical network topologies and scenarios and the problems about integration of other new guaranteed Quality of Service parameters such as delay.

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