

A Study of Constraint-based Routing with MPLS

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Abstract: This paper presents simulation and analysis of constraint-based routing (CR) with MPLS (multiprotocol label switching). MPLS is basically a fast forwarding scheme for the core of the Internet. Constraint-based routing computes routes that are subject to constraints to meet QoS (quality of service) requirements. Constraint-based routing with MPLS greatly enhances network utilization and enables advanced traffic engineering functionality. We review a previously published example, and discuss its advantages and shortcomings. We present a revised example, and demonstrate how to select better packet sizes for the data sources, measured by bandwidth at sink, packet loss rate, average end-to-end delay, delay distribution, and jitter.

1. Introduction

The Internet [1] [2], as originally conceived, offers only best-effort (BE) data delivery service, but this method alone is no longer able to serve the rapid growth of network applications with diverse QoS requirements. The Internet Engineering Task Force (IETF) has proposed some useful schemes, for instance, IntServ/RVSP, DiffServ, and MPLS to improve on BE and provide QoS.

Neither IntServ nor DiffServ alone can solve the problem of network congestion caused by uneven distribution of data traffic. Hence traffic engineering, as a very important and urgent topic for IP networks, has become a focus for research. Constraint-based routing is adopted to avoid congestion as far as possible. MPLS, an advanced routing and forwarding scheme, is used to deliver traffic engineering capacity and support differentiated services with absolute end-to-end QoS. MPLS transmits IP data packets by means of a unique label switched path (LSP). The CR-LDP (constraint-based label distribution protocol) [3] implements CR-LSPs to achieve advanced traffic engineering functionality.

An example of using CR-LDP is introduced in [4]. This uses the CR capacity of the MPLS model MNS 2.0 [5] in ns-2 [6] to simulate a range of traffic needs. This example demonstrates the importance of the CR-LSP setup order, and shows it has a significant impact on the average delay of all data sources. But it neither tells whether the bandwidth required by a source is satisfied, nor shows the jitter of data traffic. Furthermore, it is important to know the delay distribution, rather than just the average delay. By calculating these values we can show how to optimise packet sizes for a certain constraint-based routing implemented MPLS network.

In this paper, we provide a simulation study of constraint-based routing with MPLS. In Section 2 & 3, we describe traffic engineering and constraint-based routing as MPLS applications, respectively. In Section 4, we go over an existing instructive simulation. In Section 5, we modify the simulation, in order to improve the network utilisation. Finally, we present our conclusions and discuss future work in Section 6.

2. MPLS Traffic Engineering

MPLS [7] is an advanced forwarding scheme. It extends routing with respect to packet forwarding and path controlling, and it is very useful for traffic engineering. MPLS uses a short, fixed length label inserted into the packet header to forward packets. An MPLS-capable router, termed the label-switching router (LSR), uses the label as an index to find the next hop and a corresponding new label. The path that the packet traverses through a MPLS domain is called LSP, which can be completely predetermined by the label assigned by the ingress LSR.

The term traffic engineering [1] - an iterative process of network planning and network optimization - refers to the ability to control where traffic flows in a network, with the goal of reducing congestion and getting the most use of the available facilities. Implemented using MPLS, explicitly routed paths can be used as a more flexible and straightforward way of addressing the congestion problem and enabling traffic engineering functionality.

MPLS, unlike the basic IP mechanism, is aware of not only individual packets, but also flows of packets that have different QoS requirements. With MPLS, it is possible to set up routes on the basis of these individual flows, and flows of same source and destination routers may be allocated different paths. When congestion or link failure threatens, knowing the traffic demands of each flow and the network QoS parameters, MPLS paths can be rerouted intelligently and fast on a flow-by-flow basis. Network capacity can be greatly increased by MPLS traffic engineering.

3. Constraint-based routing with MPLS

Constraint-based routing [1] computes paths that are subject to constraints, like bandwidth and administrative policy to meet QoS requirements. Because CR considers more than network topology in computing routes, it may find a longer but lightly loaded path better than the heavily loaded shortest path. Thereby traffic is distributed more evenly and network resources are utilized more efficiently.

The statistics resulting from the setup of LSP can assist CR in determining traffic flows between MPLS ingress/egress pairs. From an ISP's point of view, the network administrator configures the LSP based on individual constraints and then the network - using CR - determines the optimal path for the collection of all LSPs given these constraints. CR-LDP is a very powerful tool for implementing traffic engineering.

4. An Existing Instructive Example

An instructive simulation of constraint-based routing in MPLS is described in [4]. It applies four traffic types: SBT (simple BE traffic), HBT (high priority BE traffic), RT1 (real-time traffic 1) and RT2 (real-time traffic 2). They have the same packet and buffer sizes, but increasing required bandwidths and priorities (or importance). This example provides a Perl script to filter the statistics data from the simulation trace files. The author concludes that, if the setup order of CR-LSPs is the same as the order of decreasing traffic priorities, the average packet delays and packet loss rates of RT flows (of higher importance) are greatly improved.

Low or zero packet loss rates are required by all users. However, an average packet delay cannot tell us more than an overall expectation. We need to know the delay distribution. Moreover, such criterions as bandwidth, level of delay, and jitter are important parameters which determine the overall QoS. Packet size will also affect the traffic QoS. We examine different packet sizes to find a better size combination for a certain MPLS network.

5. Simulation and Analysis

5.1 Revision of Script

The new network topology is shown in Figure 1. All the sources are CBR. The delays of all links are 10ms. For the purpose of trials of different packet sizes, the original bandwidths of link are increased to more realistic levels.

In the TCL script, we add a function of calculating traffic bandwidths at sink, and we draw a graph of bandwidths from the calculated data. A bandwidth measured at sink is $B = (b / t) \times 8$ (1), where t is a constant time period for continuous calculation, and b is the number of bytes received by sink during t . We modify the constraint-based-routing function so that applied traffic bandwidths, packet sizes and buffer sizes can be varied more easily and flexibly. The bandwidth requirement is: 300 kbps for SBT, 600 kbps for HBT, 1200 kbps for RT1, and 1600 kbps for RT2. To view the traffic behaviour, a NAM trace file was produced, but note that ns-2.1b9 is unable to display the colour of packets carried along CR-LSPs. So different packet sizes help identify traffic types. We let all the four CR-LSPs start to be established at the beginning of simulated time. The simulated time is extended from 3 to 9 seconds to collect more statistical data.

Other than average delays, the Perl script in [4] creates files storing individual packet delays of all flows. These files can be used to draw graphs of delay distribution for each traffic type. Having these delays in hand, we are also able to calculate the jitter. According to [8], the jitter is the mean deviation of the difference in packet spacing at the receiver. We let S_i = the RTP timestamp for packet i , and R_i = the arrival time of packet i . We define $D_{i,j} = (R_j - S_j) - (R_i - S_i)$, and we have the jitter of packet i calculated continuously $J_i = J_{i-1} + (|D_{i-1,i}| - J_{i-1})/16$ ($J_0 = 0, i = 1, 2, \dots$) (2). Now we can draw graphs of delays and jitters of all flows.

5.2 Simulation Results and Analysis

According to the conclusion of [4], for all simulation trials we set the setup order of CR-LSPs: RT2, RT1, HBT and SBT. Ten scenarios with various combinations of packet size are tried. Because the LSP of RT1 is 1_2_3_8_9_10 and the LSP of RT2 is 1_4_7_10, we stipulate a requirement of average end-to-end delay: not more than 80ms for RT1 and not more than 60ms for RT2. Scenarios with any packet loss rate of more than 0.80% are disregarded. Thus among the ten scenarios, we selected four for further study, whose data is shown in Table 1, 2, 3 & 4 and Figure 2, 3, 4 & 5, respectively.

We choose the best scenario on the basis of providing RT users the best QoS. As for both bandwidth and packet loss rate, obviously Scenario 3 & 4 are better than Scenario 1 & 2. Moreover, considering BE traffic, Scenario 1 & 2 have higher header overhead but similar amounts of payload as Scenario 3 & 4. We draw graphs of delay (ms) vs. packet number for RT traffic, and find that the RT curves of Scenario 3 & 4 are more like the density function of a normal distribution, and the curve section near the peak is steeper than that of Scenario 1 & 2. Scenario 3 & 4 have higher percentages of packet number around the peak. Next we compare RT levels of delay

(or confidence level). According to the requirement of RT average end-to-end delay, we compute the percentages of delays that are not more than the two values, respectively. Scenario 1: RT1 66.1%, RT2 67.5%. Scenario 2: RT1 70.3%, RT2 75.9%. Scenario 3: RT1 77.2%, RT2 97.5%. Scenario 4: RT1 82.0%, RT2 92.7%. So far we see that Scenario 3 & 4 are better than Scenario 1 & 2 as for such RT application QoS: bandwidth at sink, packet loss rate, average delay, delay distribution, and confidence level. Scenario 4 offers RT1 better QoS than Scenario 3, but the latter provides finer service to RT2.

We present graphs of jitter for all traffic and the RT curves are shown in Figure 6, 7, 8, 9, 10, 11, 12 & 13. For BE traffic, the jitter curves all drop to values of approximately 0.5. For RT traffic, we see that the curves of Scenario 3 are the best as a whole, especially for RT2. Now we can say that Scenario 3 is the best one.

6. Conclusion and Future Work

In this paper, we present a simulation study of constraint-based routing with MPLS. From [4] we learn that the setup order of CR-LSPs can have great impact on end-to-end packet delays and packet loss rate. We improve the simulation and find a combination of packet sizes which make better use of the resource of a certain MPLS network, examined by comparing packet loss rate, average end-to-end delay, bandwidth at sink, delay distribution, level of delay, and jitter. Future work is needed as we simulate only RT and BE traffic types and have not yet done statistical analysis on jitters. Simulated time should be longer if BE traffic needs detailed and deep study, since during the 9 seconds relatively small numbers of BE packets are transmitted.

References

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Appendix of Figures and Tables

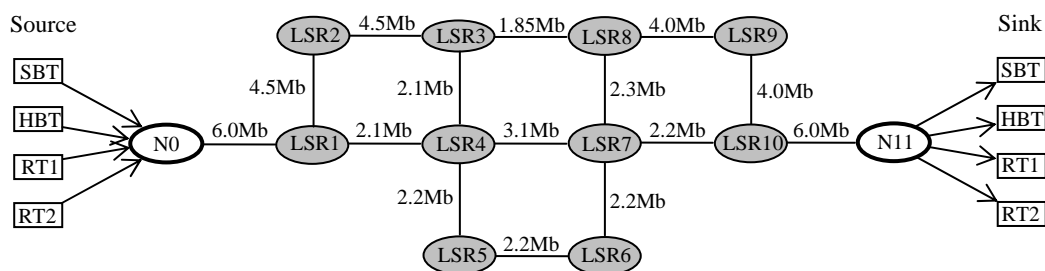


Figure 1 Simulation Network Topology

Traffic Type	Packet Size (Byte)	Packet Sent	Packet Loss Rate	Average Delay (ms)
SBT	300	137	0	119.4
HBT	400	923	0	100.1
RT1	400	3336	0.18%	79.1
RT2	400	4456	0.52%	59.3

Table 1 Scenario 1

Traffic Type	Packet Size (Byte)	Packet Sent	Packet Loss Rate	Average Delay (ms)
SBT	400	63	0	121.6
HBT	400	860	0	99.5
RT1	400	3336	0.03%	78.9
RT2	400	4456	0.47%	59.5

Table 2 Scenario 2

Traffic Type	Packet Size (Byte)	Packet Sent	Packet Loss Rate	Average Delay (ms)
SBT	600	78	0	127.7
HBT	600	621	0	102.5
RT1	400	3336	0.06%	78.8
RT2	400	4456	0.20%	58.5

Table 3 Scenario 3

Traffic Type	Packet Size (Byte)	Packet Sent	Packet Loss Rate	Average Delay (ms)
SBT	700	169	0	130.3
HBT	600	344	0	102.9
RT1	400	3336	0.03%	78.5
RT2	400	4456	0.45%	59.0

Table 4 Scenario 4

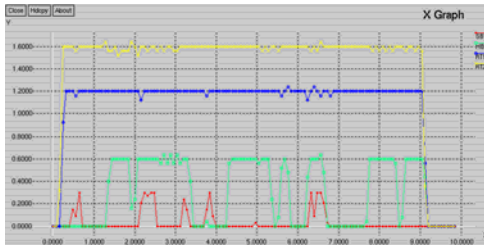


Figure 2 Bandwidths of Scenario 1 Measured at Sink

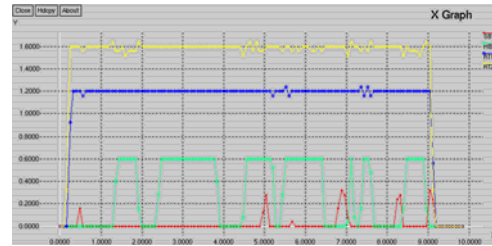


Figure 3 Bandwidths of Scenario 2 Measured at Sink

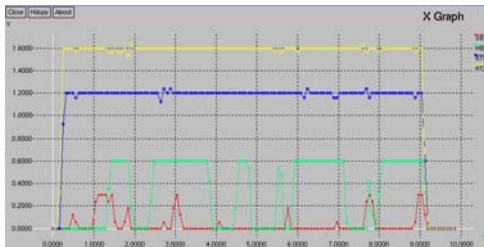


Figure 4 Bandwidths of Scenario 3 Measured at Sink



Figure 5 Bandwidths of Scenario 4 Measured at Sink

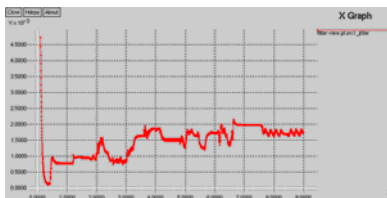


Figure 6 RT1 Jitter of Scenario 1

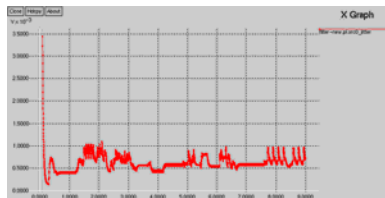


Figure 7 RT2 Jitter of Scenario 1

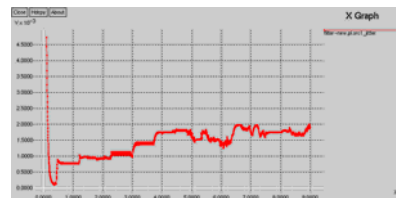


Figure 8 RT1 Jitter of Scenario 2

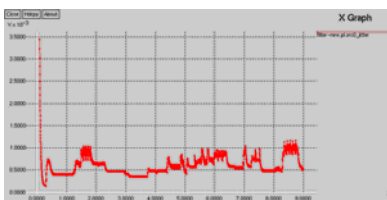


Figure 9 RT2 Jitter of Scenario 2



Figure 10 RT1 Jitter of Scenario 3

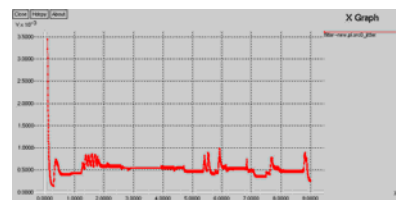


Figure 11 RT2 Jitter of Scenario 3

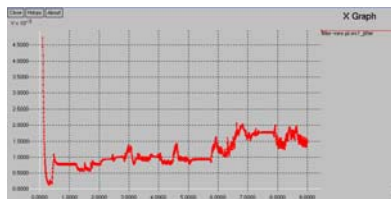


Figure 12 RT1 Jitter of Scenario 4

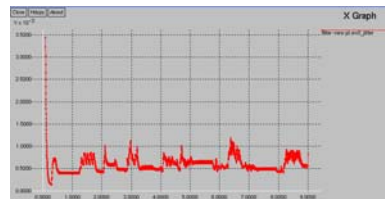


Figure 13 RT2 Jitter of Scenario 4