A STUDY ON ADVANCED ROUTING AND TRAFFIC ENGINEERING IN MULTIPROTOCOL LABEL SWITCHING NETWORKS

Author Thanh Nguyen Hoang * and Author Hung Tran Cong **
* Dept of Information Technology, Posts & Telecom Institute of Technology (PTIT), HCMC, Vietnam
Tel : +84-8-829-9605 Fax : +84-8-829-5258 E-mail: thanhnh@ptithcm.edu.vn
** Dept of Information Technology
Posts & Telecom Institute of Technology (PTIT), Hochiminh, Vietnam
Tel : +84-8-829-9605 Fax : +84-8-829-5258 E-mail: conghung@ptithcm.edu.vn

Abstract:

Internet is developing so far with a variety of value-added services to ensure security and quality of service. In recent years, telecommunication industry is looking up for a new switching technique that can associate the strong points of IP (routing) and ATM (switching). MultiProtocol Label Switching (MPLS) is an optimal solution. It associates the strengths of both ATM and IP: fast switching in the core, efficient routing at the edge, ensuring the quality of service, provisioning and optimizing network resources.

We will talk about the basic definitions and operations in MPLS. Traditional IP routing does not solve completely the problem of traffic engineering and resource provisioning. With best effort, network resource in IP network is not ultilized. Some parts are overloaded while the others are under-ultilized. Consequently, we must extend the existing routing and signaling protocols for assured quality traffic stream and making the best use of network resources. We discuss main routing issues in MPLS networks like constraint-based routing, explicit routing, traffic engineering and fast reroute. Based on simulation in NS, I can illustrate that advanced routing in MPLS can make the best use of network resources. Moreover, I involve to attempt a new approach to MPLS in unprofitable organization like university enviroment in Vietnam, that is Linux MPLS.

Key words: explicit routing, constraint-based routing, fast reroute, traffic engineering, MNS (MPLS Network Simulation), Linux MPLS.

1. INTRODUCTION

Most of WANs in Vietnam are based on traditional IP routing which has a lot of weak points. Every node in IP network has to process two works: routing and forwarding. And the routing table is very big with hundreds of millions entries for the router to find the longest matching prefix address. That makes router work in slow performance when the traffic is overloaded. It leads to connection losing and traffic losing.

A model that has been considered is IP over ATM. This overlay approach enable IP and ATM to cooperate without changing its protocol. However, this approach is not scalable and flexible due to the fact that both end systems must maintain ATM and IP addressing.

2. ROUTING AND TRAFFIC ENGINEERING IN MPLS

MPLS can associate the strong points and overcome the weak points. Because of using shim header, MPLS has the capability of fast switching in the core and efficient routing at the edge. It also makes the best of network resources, support multicast and traffic engineering. In addition, the cost to deploy an MPLS network from existing networks is inexpensive.

First, we will make some MPLS basic definitions clear. Then, we will discuss the problem of traditional IP routing and how to expand the existing routing protocols to support traffic engineering. And last, we talk about MPLS simulation and implementation.

A label identifies the path a packet should traverse. A label is carried or encapsulated in a Layer-2 header or between Layer-2 and Layer-3 header. The receiving router examines the packet for its label content to determine the next hop. Once a packet has been labeled, the rest of the journey of the packet through the backbone is based on label switching [26].

LIB (Label Information Base) is the database of all labels that an LSR creates and receives from MPLS neighbors for a certain prefix address. LFIB (Label Forwarding Information Base) is only a subset of LIB. It contains necessary information to forward a packet to the next hop. LSP (Label Switch Path) is a sequence of routers, <R1, R2… Rn>. Edge router analyzes the IP header to decide which LSP to use. It adds a corresponding Label Switched Path Identifier and then forwards the packet to the next hop. Core routers just swap label based on its LFIB established before [1], [3], [11], [16].

Because the label distribution operation associates closely with routing operation, it is necessary to grasp the knowledge of IP routing protocols and Internet routing architecture ([6], [7], [8], [9], [10], [15]). But traditional IP routing did not solve completely the problem of traffic engineering: some network parts are underutilized while the others are overloaded.

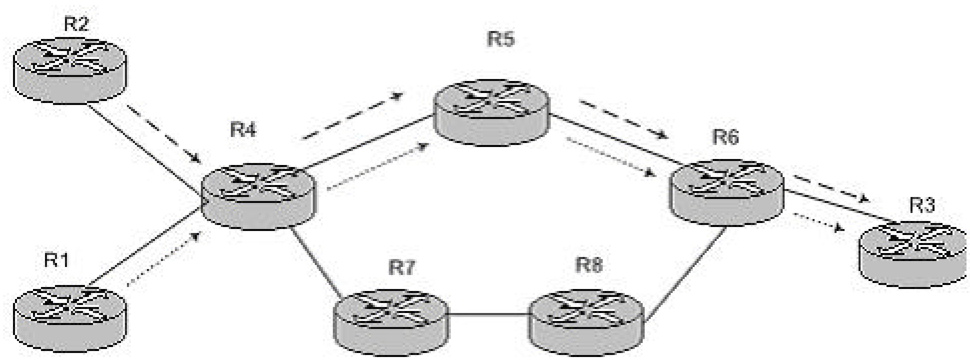

Figure 1: IP routing based on destination and lowest cost

Path from R2 to R3

Path from R1 to R3

Bandwidth of link (R4,R5), (R5,R6) is 100M, bandwidth of link (R4,R7), (R7,R8), (R8,R6) is 150M. Supposing that routing is based on hop count, traffic from R1 to R3 will follow the path (R4, R5, R6). Links along this path will be congested because bandwidth of each link is 100M while total bandwidth of R1 and R2 is 100 + 100 = 200M. At that time, all links along the path (R4, R7, R8, R6) is underutilized. Routing based on bandwidth also leads to the same fact that resource is underutilized along the path (R4, R5, R6) while load in path (R4, R7, R8, R6) is heavy because bandwidth of each link is 150M.

We observe that to support traffic engineering, besides the capability of optimal path finding based on a scalar metric, we must take account of current bandwidth of all links. IP routing just meets the first condition.

Path choosing in MPLS depends on IP routing operation. But as we said before, IP routing did not utilize network resources. To solve this problem, we have to extend existing routing and signaling protocols, for example extend existing Label Distribution to support constraint-based routing (Constraint based Label Distribution Protocol), or extend existing Resource Reservation to distribute label (Resource Reservation for Traffic Engineering) or extend existing routing protocol Open Shortest Path First to advertise labels and calculate paths that meet all constraints (Open Shortest Path First for Traffic Engineering) …

One of the most requirements of traffic engineering is the capability to force a traffic trunk go through a particular path which is pre-calculated by constraint-based routing and established by label distribution protocol. It is a part of **advanced routing**. The key ideals of MPLS advanced routing are constraint base routing, explicit routing, signaling protocol and fast reroute. The term constraint implies a set of constraints that a node or a link must be satisfied like minimum bandwidth or security. Hence, each MPLS node has to maintain a specific Traffic Engineering Database. MPLS use Type-Length-Value (TLV) format in exchanging messages to build this TE database. For example Link TLV includes Link ID, Link Type, Local interface IP Address, Remote interface IP Address, Traffic engineering Metric, Maximum bandwidth, Maximum preserved bandwidth, Resource class/color.

We must modify the existing algorithm Shortest Path First into Constraint Shortest Path First to find out the path that meets all the constraints. Ingress router (IR) collects information of network state. When there is a request for provisioning resources, IR uses CSPF to calculate the path that meets these constraints. Constraint-based routing must combine with explicit routing. It uses CR-LDP (a extension of signaling protocol LDP) to request an explicit Label Switching Path.

Explicit routing is the capability to allow a particular packet stream to follow a pre-determined path rather than a path computed by traditional routing (destination based). Explicit routing is integral to constraint-based routing. This route is set up at the edge of the network. Explicit routing in MPLS ensures QoS, load sharing and does not entail additional packet header overhead. Explicit routing is established and done by signaling protocol. MPLS uses CR-LDP to establish LSP. CR-LDP uses messages Request and Mapping to establish the MPLS tunnel. The constraint-based route, which is calculated by constraint-based routing, is encoded as a series of hops contained in CR-LDP Request Message.

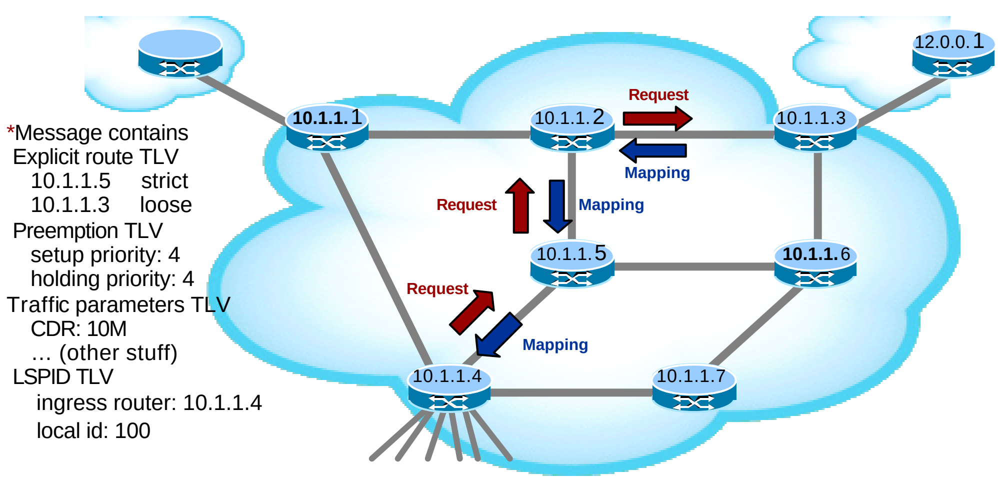

Figure 2: MPLS Request and Mapping Message to establish LSP

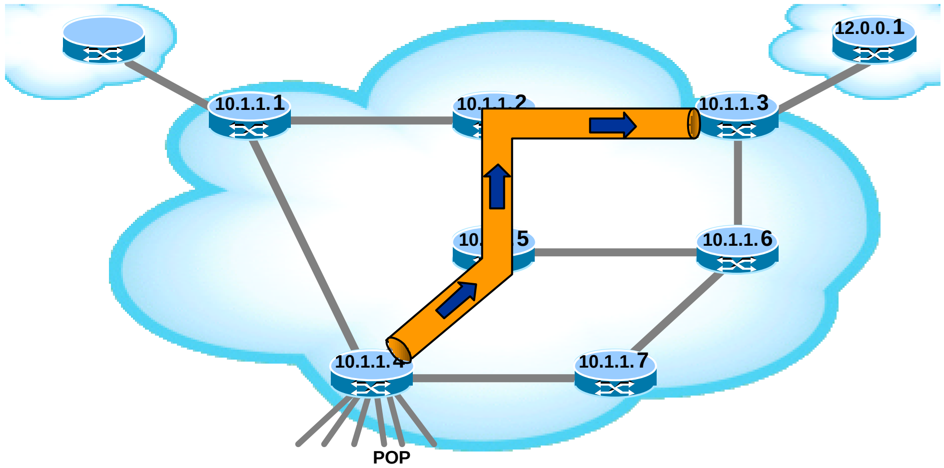

Figure 3: LSP tunnel has been created

Therefore, it can't be denied that constraint based and explicit routing are mechanisms that support MPLS traffic engineering. In the figure below, it forces the first traffic stream to go through LSP1 and second through LSP2.

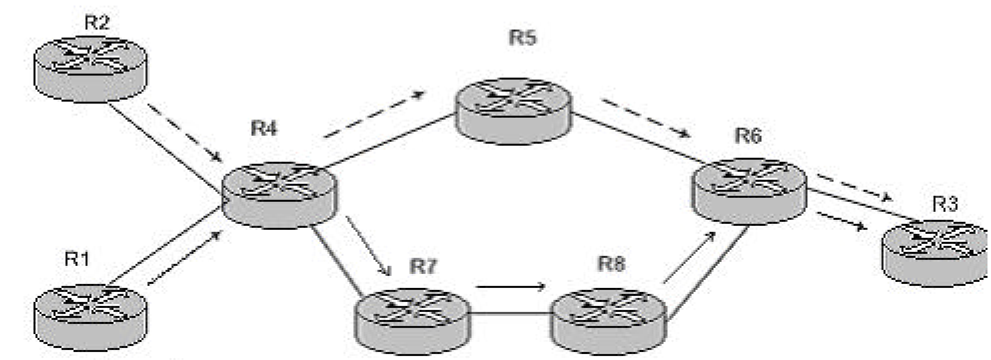

Figure 4: MPLS Traffic engineering based on constraint-based and explicit routing

3. REROUTING

Fast reroute is a useful tool to support traffic engineering. MPLS operates like connection-oriented. Hence, it takes much time to establish new tunnel, especially when the current path is corrupt. MPLS has an efficient way to fast switch the corrupt path to a new one by switching to a pre-route LSP which has been established before. MPLS uses label stack when a node or a link is down. [1]

We should modify the CSPF algorithm to find out K shortest paths first. In this way, we have prepared K entire paths. But if this path fails, MPLS will switch to an entirely new path.

But in some cases, we don't have to rebuild the entire ones, we just rebuild one part. When link from B to D is down, B pushes label 67 to its stack before sending packets to C, C swaps label 67 to 13, E removes label 13 and forwards packets to D. So when D receives packets labeled 67, D thinks that those packets were sent by B normally. D does not have to rebuild its LFIB.

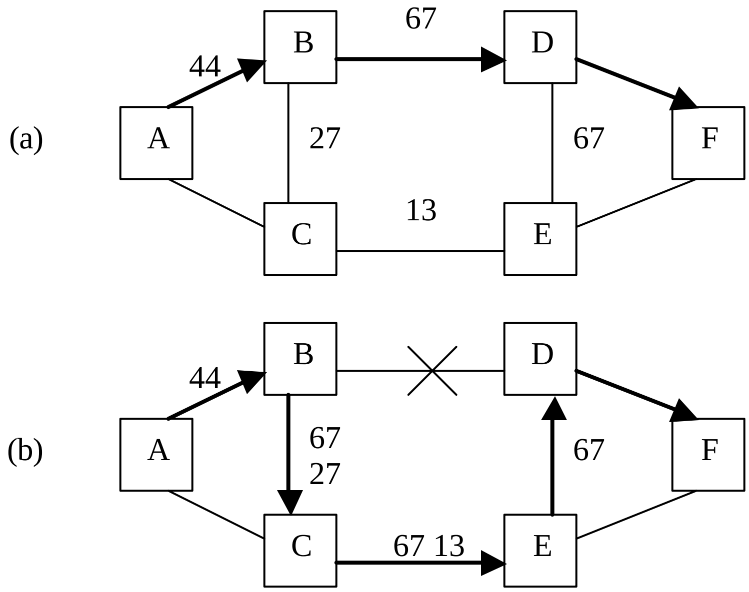

Figure 5: Label stack and switching protection

Another routing issue is dynamic routing. It ensures the bandwidth requirement of tunnels in the future. The main idea of dynamic routing algorithms is that new tunnel should not infer too much to paths that will have a big burden in the future.

TRAFFIC ENGINEERING

Advance routing associates strongly with and expand to traffic engineering.

First, we will go through the definition of Traffic Engineering (TE). TE is to optimize the network performance; it includes traffic oriented and resource oriented. Traffic oriented enhances the QoS of traffic streams (minimization of packet loss). Resource oriented pertains to the optimization of resource utilization (efficient management of bandwidth, minimizing congestion) ([40], [17], [20], [21]).

Second, we talk about traffic and resource control. The traffic engineer acts as the controller in an adaptive feedback control system which includes a set of interconnected network elements (a network performance monitoring and measurement system, network configuration management tools). The traffic engineer observes the network state, characterizes the traffic and applies the control actions to the controller.

A famous TE scheme is MATE (Multiple Adaptive Traffic Engineering) [40]. MATE avoids network congestion by balancing the load among multiple paths based on measurement and analysis of path congestion. The goal of ingress node is to distribute the traffic across LSPs so that loads are balanced and congestion is minimized. Ingress node includes these following components: Filtering and distribution, TE (monitoring phase and load balancing phase), Measurement and analysis (ingress node transmit probe packets periodically to egress node). The most important component of Traffic Engineering is **TE database**. [4]

4. SIMULATION

With new technology, we should use simulator to illuminate behavior of algorithms and test the network performance in different environments and different kinds of topology, traffic model, different priority levels of traffic (best-effort, more than Best-effort, signaling traffic, real time traffic), network parameters (type of queue, length of queue, bandwidth, delay time). Moreover, we can monitor packet receiving, total received packets, number of out-of-order packets and graph, evaluate some statistics.

NS is an open source simulation software on Linux, written in C++ and OTck. Information Science Institute in California has developed it. NS simulates IP networks including routing protocols and queue management. MNS has been implemented by extending NS. It is very useful for us to simulate various MPLS applications without constructing a real MPLS network. This is the conceptual model, architecture of MPLS node and the way MPLS nodes process traffic to ensure QoS request. [26], [27], [28]

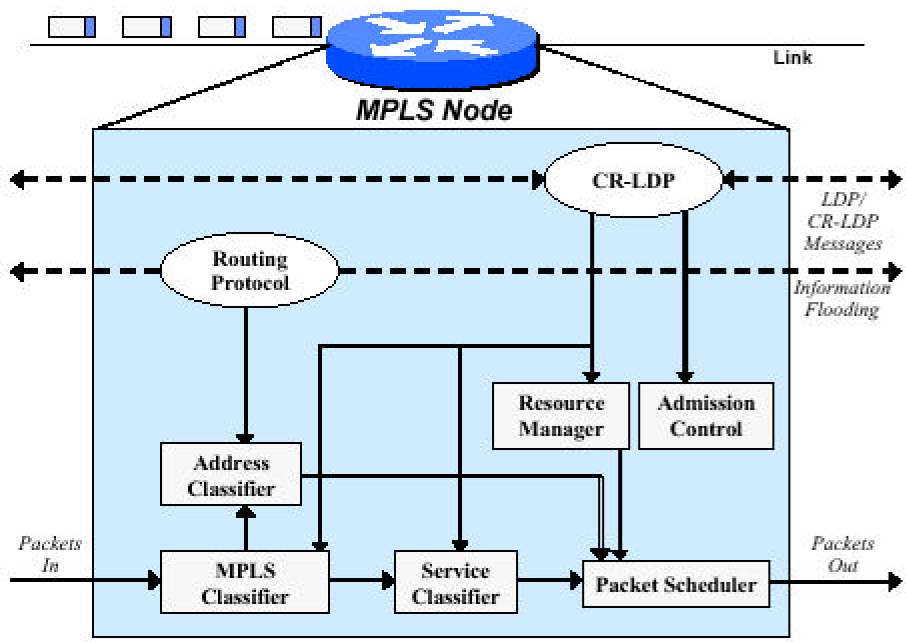

Figure 6: Conceptual model of MNS

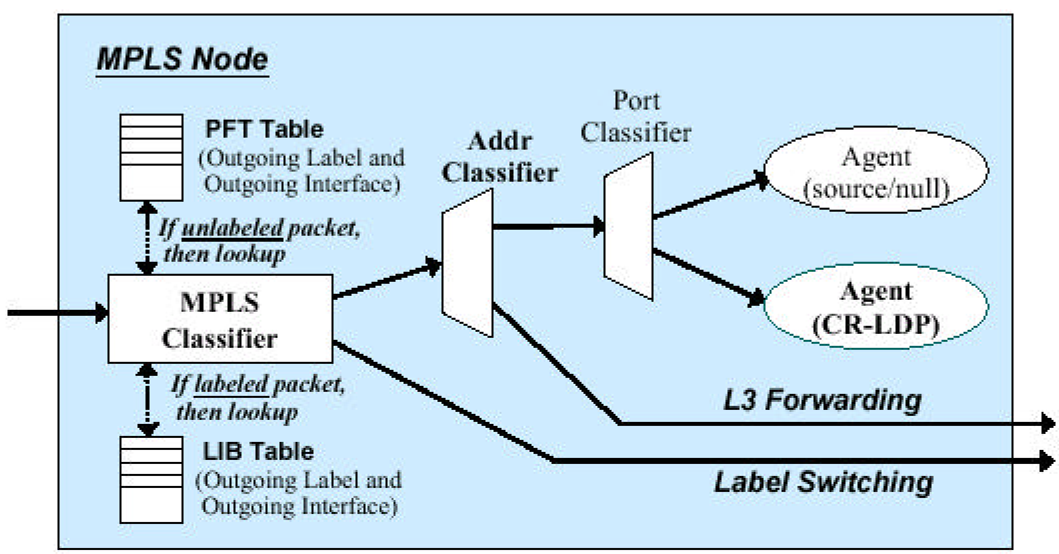

Figure 7: Architecture of MPLS node for label switching

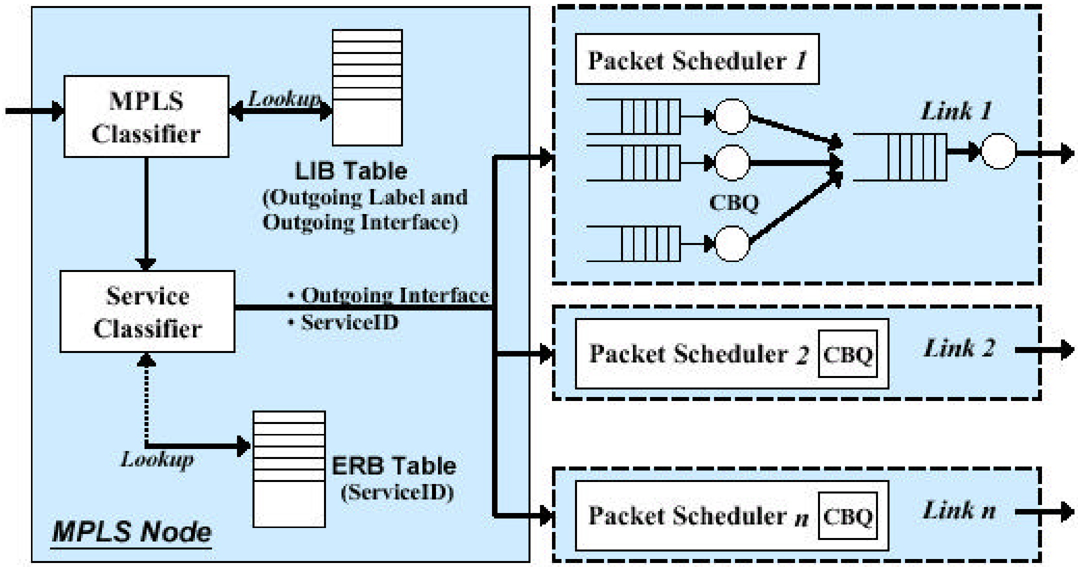

Figure 8: Traffic processing of MPLS node and link

ERB (Explicit Route information Table)

CBQ (Class Based Queuing)

To build a test-bed, we write a simulation program in Tcl and have to follow these steps. First, we have to create network topology including nodes, links, and queues at every node. Second, we create transport agent (TCP or UDP), bind it to corresponding node, and then connect them. Next, create application entity like FTP, CBR… Last, we write a script to schedule all the events [29], [32]. This is a simple script.

```
$ns at 1.2 "$LSRmpls4 setup-erlsp        8 4_5_6_8          3500"
$ns at 1.4 "$LSRmpls2 setup-erlsp        7 2_3_4_L3500_7    3600"
$ns at 1.6 "$LSRmpls2 bind-flow-erlsp    9 -1               3600"
$ns at 1.7 "$LSRmpls2 erb-dump"
$ns at 1.7 "$LSRmpls2 lib-dump"
$ns at 2.0 "$LSRmpls7 send-crldp-withdraw-msg  3600"
$ns at 2.0 "$LSRmpls8 send-crldp-withdraw-msg  3500"
```

We can monitor the LIB table at each node.

```
      --)At 1.7 seconds:

      --) ___ERB dump___ [node: 2] (--
-----------------------------------------------------------------------
FEC   LSPid   LIBptr  SLIBptr  QoSid  aPATHptr iLabel iIface FailNext
7     3600      8       -1       -1      -1      -1      -1       *

      ___LIB dump___ [node: 2]
---------------------------------------------
     #      iIface     iLabel    oIface   oLabel    LIBptr   Linkerror?
     0:       -1         1         3        0         -1         -1
     1:       -1         2         5        0         -1         -1
     2:       -1         3         3        2         -1         -1
     3:       -1         4         5        3         -1         -1
     4:       -1         5         5        7         -1         -1
     5:       -1         6         3        6         -1         -1
```

6:	-1	7	3	7	-1	-1
7:	-1	8	5	10	-1	-1
8:	-1	-1	3	11	-1	-1

We observe that with traditional IP routing based on hop counts, network resource is not utilized; some of them are overload while the others are underutilized. Network is congested, lead to packet loss in links along the path (1_3_5_7_9). The result has shown in figure 10.

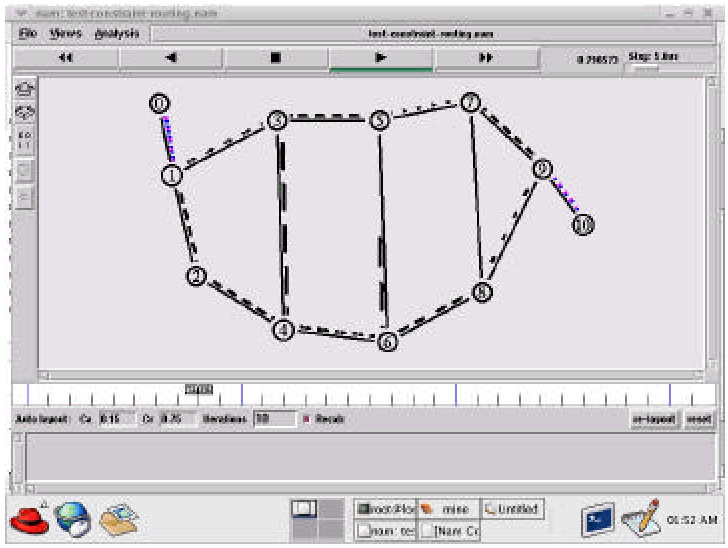

Figure 9: MPLS networks with constraint-based routing utilize network resource

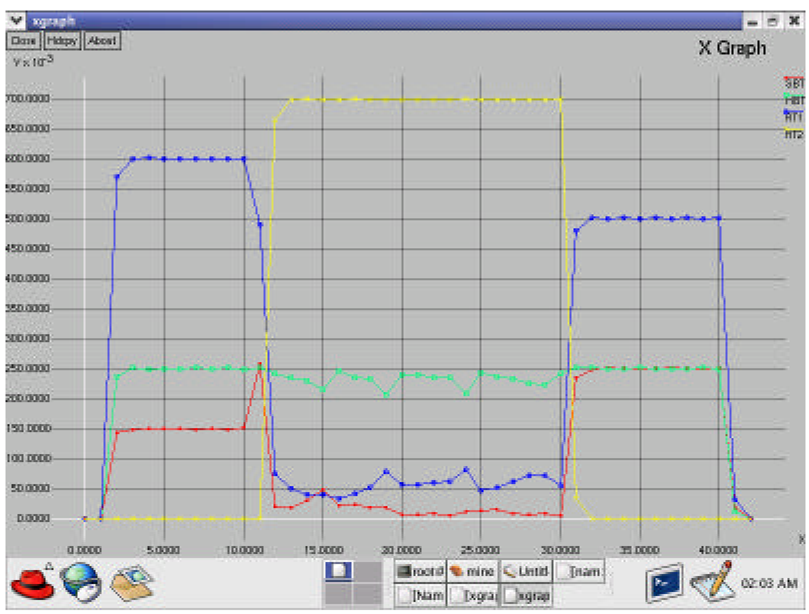

Figure 10: Network congestion lead to traffic lost in IP network

MPLS support constraint-based routing to find out the optimal path that meets the requirement and utilize networks resources. We use XGraph to illustrate bandwidth of each resource. Those graphs prove that MPLS advanced routing (constraint-based and explicit routing) can make the best use of network resources. The traffic load is distributed. Network performance is increased.

This is the initial parameter of our MPLS network which topology is in Figure 9. Bandwidth of links between nodes 0-3, 1-3, 9-10 is 3Mb, between 5-7, 4-6, 8-9 is 2Mb and the others is 1Mb.

```
$ns duplex-link $node0 $LSR1  3Mb  10ms DropTail
$ns duplex-link $LSR1  $LSR3  3Mb  10ms CBQ
$ns duplex-link $LSR3  $LSR5  1Mb  10ms CBQ
$ns duplex-link $LSR5  $LSR7  2Mb  10ms CBQ
$ns duplex-link $LSR7  $LSR9  1Mb  10ms CBQ
$ns duplex-link $LSR1  $LSR2  1Mb  10ms CBQ
$ns duplex-link $LSR2  $LSR4  1Mb  10ms CBQ
$ns duplex-link $LSR4  $LSR6  2Mb  10ms CBQ
$ns duplex-link $LSR6  $LSR8  1Mb  10ms CBQ
$ns duplex-link $LSR8  $LSR9  2Mb  10ms CBQ
$ns duplex-link $LSR3  $LSR4  1Mb  10ms CBQ
$ns duplex-link $LSR5  $LSR6  1Mb  10ms CBQ
$ns duplex-link $LSR7  $LSR8  1Mb  10ms CBQ
$ns duplex-link $LSR9  $node10  3Mb  10ms DropTail
```

There are four streams, the first stream request 1200kb, three streams requests 700kb. In this network, there is no path with bandwidth at least 1200kb in all links. So that it could not allocate for the first stream 1200kb. At 0.2, 0.4 and 0.6 second, there are three stream request 700kb, The first stream is allocated the LSP along the path 1-3-5-7-9-10, the second stream followed 1-2-4-6-8-9-10 and the last stream is distributed to path 1-3-4-6-5-7-8-9-10. In figure 11, the horizontal axist is time and the vertical axist is bandwidth of each stream. The first is Red, the three next are Green, Blue and Yellow. Each stream has bandwidth approximately 700kb. It mean that we can distribute the network load and ultilize the network resources.

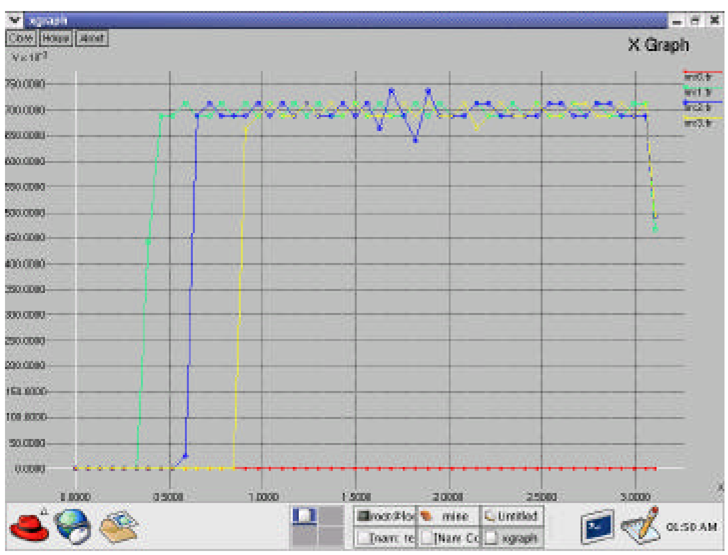

Figure 11: Flows with satisfied bandwidth in constraint-based routing in MPLS

5. IMPLEMENTATION OF LINUX MPLS

Linux is one of the best networking operating systems and can operate as a router. It not only reduces hardware invention cost but also makes your network run stability. There is a variety of open source software on Linux like Zebra, Linux router project supporting multi routing protocols like RIP, OSPF, BGP … For a MPLS network, we must have some specific MPLS Cisco routers (platform at least 3500, IOS 12.3 or above). With Linux, after applying MPLS patch and changing network options, we just recompile the kernel, install MPLS Linux Project or RSVP-TE, which are supporting MPLS and integrated well with Zebra, IPsuite… It is really a useful tool for students to approach and research MPLS in case there is a lack of specific equipments. Moreover, there is a large community using MPLS Linux and willing to share their experience.

MPLS for Linux is distributed widely at [30]. It implements a forwarding plane and a set of signaling protocols for MPLS (RFC 3063) [19], including two main packets: mpls-linux and ldp-portable. It defines data structure ILM (Incoming Label Mapping) which contains label, opcode, FEC… to interpret incoming MPLS label. First, it extracts label from the top shim header, looks up label in ILM and applies different processing based on its different opcode like POP_AND_LOOKUP, POP_AND_FORWARD, NO_POP_AND_FORWARD, SEND_TO_RP…

6. CONCLUSION

In short, MPLS is a hybrid technology. It combines the best of IP and ATM. MPLS solves the problem of traffic engineering by combining constraint-based routing and explicit routing. Moreover, it can cooperate with and easy-to-upgrade from existing ATM networks. MPLS ensures the quality of service and utilizes network resources but the cost to deploy is inexpensive. MPLS is really a promising solution to apply for backbone network in Vietnam.

We have analyzed the main routing issues in MPLS networks including constraint-based routing, explicit routing, traffic engineering and fast reroute. MPLS is hard to approach because of specific infrastructure and network devices. Based on simulation in NS, I can illustrate that advanced routing in MPLS can make the best use of network resources. Through network simulation, we can illustrate all the theory without a big invention to build a real MPLS network. On the other hand, we ourselves can implement a simple MPLS networks base on MPLS Linux. I think this solution is a new promising way and suitable to approach MPLS in unprofitable oganizations like university environment in Vietnam.

References:

[1]. UYLESS BLACK, *MPLS Label Switching Network*, *PRENTICE HALL*, 2002

[2]. VIVEK ALWAYN, *Advanced MPLS Design and Implementation*, *Cisco Press*, 2002

[3]. SEAN HARNEDY, *MPLS Primer*, *PRENTICE HALL*, 2002

[4]. BRUCE DAVIE, YAKOV REKHTER, *MPLS Technology and Application*, Academic Press, 2000

[5]. JAMES REAGAN, *CCIP MPLS Study Guide*, *CIBEX*, 2002

[6]. STEPHEN THOMAS, *IP Routing Essential and Architecture*, *WILEY*, 2002

[7]. Bassam Halabi , *Internet Routing Architecture*, *Cisco Press*, 1997

[8]. ROBERT N. MYHRE, *CCNP 2.0 routing*, *PRENTICE HALL*, 2001

[9]. JEFF DOYLE, *TCP/IP Routing Vol I*, *Cisco Press*, 1998

[10]. *Cisco Network Academy Program*, *Cisco Press*, 2001

[11]. Christopher Y.Metz, *IP Switching*, *McGraw-Hill*, 1999

[12]. Peter Tomsu, *MPLS-based VPN*, *PRENTICE HALL*, 2002

[13]. Andrew S. Tanenmaum, *Computer Networks*, *PRENTICE HALL*, 1996

[14]. Douglas E. Comer, *Internetworking with TCP/IP: Principles, Protocols and Architecture*, *PRENTICE HALL*, 2000

[15]. Thomas M. Thomas II, *Cisco Internetwork Design, MacGraw-Hill, Technical Expert*, 2001
[16]. "Multiprotocol Label Switching Architecture", RFC 3031.
[17]. "Requirements for Traffic Engineering Over MPLS", RFC 2702.
[18]. "Constraint-based LSP setup using LDP", RFC 3212.
[19]. "MPLS Loop Prevention Mechanism", RFC 3063.
[20]. "RSVP-TE: Extensions to RSVP for LSP Tunnels", RFC 3209
[21]. "Constraint-Based LSP Setup using LDP", RFC 3212
[22]. "A Framework for QoS-based Routing in the Internet", RFC 2386.
[23]. "An Architecture for Differentiated Services", RFC 2475.
[24]. "MPLS Support of Differentiated Services", RFC 3270.
[25]. "A provider Architecture for Differentiated Services and Traffic Engineering", RFC2430.
[26]. http://www.iec.org/online/tutorials/mpls/index.html
[27]. http://www.isi.edu/nsnam/ns/
[28]. http://perform.wpi.edu/NS/
[29]. http://flower.ce.cnu.ac.kr/~fog1/mns/mns2.0/source/mns_v2.0.tar
[30]. http://mpls-linux.sourceforge.net/
[31]. http://www.lathspell.de/linux/uml/
[32]. http://charlie.it.uts.edu.au/~tkaphan/xtn/capstone/
[33]. http://www.mplsrc.com
[34]. http://www.cisco.com/warp/public/104/
[35]. http://www.convergedigest.com/tutorials/
[36]. http://cell-relay.indiana.edu/mhonarc/mpls/
[37]. http://www.juniper.net/techpubs/
[38]. http://ww.ietf.org
[39]. http://www.nanog.org/mtg-0402/soricelli.html
[40]. http://web.mit.edu/6.263/www/EJLW01.pdf
[41]. http://flower.ce.cnu.ac.kr/~fog1/mns/mns2.0/doc/MNS_v2.0_arch.pdf

Author's Profile

NGUYEN HOANG THANH was born in VietNam in 1981

She was the First in the Entrance Examination Posts and Telecommunications Institute of Technology and received the B.E in Information Technology from PTIT, 2003 with graduation thesis entitled "Advanced Routing in Multiprotocol Label Switching Networks".

-Consolation Award of Students' Science Research Movement given by Minister of Education and Training, 2003, First Prize in Students' Science Research Movement, Posts and Telecommunications Institute of Technology, 2002. Science Research project: Managing Network Devices remotely based on Java Agent Technology, Voice portal using VXML (or Accessing internet by telephone), 2003, Implementation a Local Exchange of 4 subscribers, 2001.

Currently, she is a teaching assistant of Faculty of Information Technology II and in section Network & Data Transmission in Post and Telecom Institute of Technology (PTIT), in HOCHIMINH City, VietNam.

Author's Profile

TRAN CONG HUNG was born in VietNam in 1961

He received the B.E in electronic and Telecommunication engineering with first class honors from HOCHIMINH university of technology in VietNam, 1987.

He received the B.E in informatics and computer engineering from HOCHIMINH university of technology in VietNam, 1995.
He received the master of engineering degree in telecommunications engineering course from postgraduate department HaNoi university of technology in VietNam, 1998.
He has recently finished his Ph.D at HaNoi university of technology in VietNam, 2004.
His main reseach areas are B – ISDN performance parameters and measuring methods.
Currenthy, he is a lecturer, deputy head of Faculty of Information Technology II and head of section Network & Data Transmission in Post and Telecom Institute of Technology (PTIT), in HOCHIMINH City, VietNam.
He was the author of some papers in ICACT' 99 and ICACT' 2000:

1. "B – ISDN per formance parameters and measuring methods".
   Paper No.: P0069 (in ICACT' 99), Korea.
2. "An overview of ATM technology". Paper No.: P0068
   (in ICACT' 99), Korea.
3. "Traffic control and measuring methods in ATM Networks".
   Paper No.: TF – 009 (in ICACT' 2000), Korea.
4. "ATM – Network management Architectures" Paper No.: TF - 008
   (in ICACT' 2000), Korea.
5. "Simulating ATM Technology on High-speed Networks to support the training at PTIT". (Report on conference of ETRI,Korea), July 2000, Korea.
6. "Fault Management and Measuring Methods in ATM Networks".
   (Report on conference of ETRI,Korea), July 2000, Korea.
7. "Testing Policing in ATM Networks",2nd scientific conference in Post & Telecommunications Institute of Tecnology, Sep 15,2000, VietNam.
8. "InterNetworking Frame Relay and ATM", scientific conference in HaNoi university of technology, Oct 15,2001, VietNam.
9. "Illustration of The Traffic Conformance in ATM" (Report on conference of ETRI,Korea), Jule 2002, Korea.
10. "The Traffic Conformance in ATM Network", paper code No.47, 28th AIC (Asian Info-communications Council), Nov 11-15, 2002, Manila, Philippine.
11. "Performance parameters for cell transfer variations and cell transfer timing in ATM Network", paper code No.48, 28th AIC (Asian Info-communications Council), Nov 11-15, 2002, Manila, Philippine.
12. "ATM Network's delay parameter measurement using simulation method",
    Paper code.: 107001 (in ICACT' 2003), Jan, 2003, Korea.