of enterprise flows, higher priority flows receive more bandwidth and better performance and lower priority flows would be delayed to release bandwidth. This mechanism would enhance the performance of an enterprise network and help an enterprise get the urgent and important operation information as soon as possible. With a high performance enterprise network, an enterprise would operate more efficiently and improve its competition capability.

Keywords: differentiated service, expedited forwarding (EF), assured forwarding (AF), best-effort (BE), priority

Abstract

E-commerce makes a relationship closer between enterprises' operation information and enterprise network. A network performance of an enterprise will impact its operation performance. How to efficiently utilize an enterprise network resources and its bandwidth? It is an important issue for an enterprise to enhance its competition capability in an E-business era. This research proposes a differentiated service mechanism to manage traffic flows in an enterprise. With this mechanism, enterprise network traffic flows are divided into three categories by their characteristic: expedited forwarding flow, assured forwarding flow and best effort flow. Basing on these three flows, differentiated services would be provided in an enterprise network. According to their importance and urgency

（B2B）
（B2C）

10%　30%

10%

QoS　　　　　　　　　　　　　　　　　　　　　　　　10%
　　　　　　　　　　　　　　　　　　　30%
　　　　　　　　　　　　　　　　　　　　　　　　30%

Zona Research　　　　1999

362

Service Working Group

[10]

(DiffServ)

Per-Hop Forwarding
Behavior, PHB [10]

Best-Effort Forwarding, BE
Expedited Forwarding, EF
Assured Forwarding, AF

Multiprotocol Label Switching,
MPLS [2]

IETF
Differentiated

Min_Pri

●

Min_Pri

preemption

Voice
over IP, VoIP

●

●

Min_Pri

1.

2

Min_Pri

EF

EF

AF

EF

AF

ns-2[11]

BE

(Mesh Logical Network
Topology)

F1

1-4-2

AF1

2Mbps > 1.2Mbps > 1Mbps

1Mbps

AF

1-3-2

BE1

BE1

AF2

1.0Mbps   1-3-2

EF2

1-3-2

AF1   AF2   1-2

BE1

EF2   1-2

BE1

1-3-2

AF2

1-2

BE1

AF3

0.6Mbps   1-2

BE1

" International Journal of Network Management"

[1] Awduche, D., et. al. (1999), "Requirements for Traffic Engineering Over MPLS," RFC 2702

[2] Callon, R., P. Doolan, N. Feldman, A. Fredette, G. Swallow and A. Viswanathan (1999), "A Framework for Multiprotocol Label Switching," draft-ietf-mpls-framework-05

[3] Jamoussi, B., et. al.(1999), "Constraint-Based LSP Setup using LDP," draft-ietf-mpls-cr-ldp-03.txt

[4] Heinanen, F. Baker, W. Weiss and J. Wroclawski (1999), "Assured Forwarding PHB Group," RFC 2597

[5] K. Nichols and K. Poduri (1999), "An Expedited Forwarding PHB," RFC 2598

[6] Faucheur et. al.(2000), "MPLS Support of Differentiated Services", draft-ietf-mpls-diff-ext-05.txt.

[7] Mohammad Peyravian and Ajay D. Kshemkalyani (1998), "Decentralized network connection preemption algorithms," Computer Networks and ISDN Systems, (30), pp. 1029-1043.

[8] Roch A. Guerin, Ariel Orda and Douglas Williams (1996), " QoS Routing Mechanisms and OSPF Extensions", Internet Draft.

[9] Sally Floyd and Van Jacobson (1995), "Link-sharing and Resource Management Models for Packet Networks," IEEE/ACM Transaction on Networking, 3(4)

[10] S. Blake, D.Black, M.Carlson, E. Davies and W. Weiss (1998), "An Architecture of Differentiated Services," RFC 2475

[11] S. McCanne and Sally Floyd, "ns-Network Simulator," URL http://www-mash.cs.berkeley.edu/ns/

A Research of Enterprise Traffic with a Differentiated Service mechanism

Chyan Yang   Chen-Hua Fu   Yueh-Heng Tu

National Chiao Tung University

Institute of Information Management

Mb307, 1001 Ta Hsueh Rd., Hsin Chu 300 Taiwan

chyan_yang@yahoo.com   u8634804@cc.nctu.edu.tw

Tel:886-3-5712121 ext. 57407, 57417

Fax:886-3-5723792

Abstract

As an enterprise grows, its network bandwidth requirement also increases dramatically. A network performance of an enterprise will impact its operation performance. How to efficiently manage an enterprise network resources and its bandwidth? It is an important issue for an enterprise to enhance its competition capability in an E-business era. This research proposes a differentiated service mechanism to manage traffic flows in an enterprise. This mechanism classifies enterprise network traffic flows by their characteristics. They can be divided into three categories: expedited forwarding traffic flow, assured forwarding traffic flow and best effort traffic flow. Each category of traffic has its own transmission privilege and characteristics. One can categorize enterprise network traffic flows according to their importance and urgency. Higher priority traffic flows receive more bandwidth and faster transmission. Lower priority traffic flows should release bandwidth and delay its transmission. This mechanism would enhance the performance of an enterprise network and help an enterprise efficiently transmits urgent and important operation information. With a high performance enterprise network, the enterprise can then operates more efficiently and improves its competition capability.

1. Introduction

Advances of Internet enable an enterprise in its capability of integrating of applications and services. Over time business activities of enterprises become dependent on its applications of computer network. As an enterprise grows, the bandwidth volume required by network applications also increases dramatically. The original bandwidth of enterprise network no longer satisfies the bandwidth requirement. The business operations therefore become inefficient. To enhance network performance and meet the requirements of internal information system is an important issue faced by many enterprises. Moreover, in an E-business era, either a B2B or a B2C company needs a responsive network to satisfy customers' requirements.

Enterprise networking traffic originates from interior and exterior of an enterprise. However, the content of transmitted data is all-inclusive. It may be important operational information or some junk mails. Regardless the type of traffic, each transmission needs network bandwidth. Without a proper control mechanism, a network overflow often occurs. When an enterprise network becomes congested,

it cannot support timely operations of the enterprise. When resources and bandwidth of a network can be allocated and managed properly, say, through traffic priority one can assure at least important traffic flows get through. The differentiated service mechanism is one of such possible solutions.

Every department of an enterprise has its mission and unique business responsibility. Network traffic flows generated from different departments also have different characteristics such as content, property, sender, receiver, importance and urgency. A differentiated service mechanism will classify enterprise network traffic flows based on their characteristics and allocate appropriate network bandwidth to them. High priority flows receive more bandwidth and better transmission performance; lower priority flows only get leftover bandwidth and secondary transmission performance. With priority flows, an enterprise network could have sufficient bandwidth to transmit important and urgent traffic flows quickly. This would satisfy requirements of an enterprise operation and brings its maximum efficacy to an enterprise.

This research tries to propose and validate a traffic flow classification mechanism for an enterprise network. According to the characteristics of transmission data, traffic flows can be divided into three categories: expedited forwarding, assured forwarding and best effort. Each type of the traffic flows has been assigned a different priority. The higher priority the traffic flows is, the more bandwidth assigned and better transmission performance assured. An efficient enterprise network would assure the operational excellence and efficiency, therefore becomes a core competence of a business in E-business era.

2. Motivation to Differentiated Services

2.1 Necessity of differentiated service for enterprise networks

Applications of Internet are no longer limited to academic researches and pure text transfers. Data flows over the Internet can be of many forms: graph, image, audio, video or animation. The abundant information enriches Internet content and supports many business applications. Convenience provided by the Internet causes the number of global hosts connected to Internet increases explosively. Figure 1 shows this trend [15].
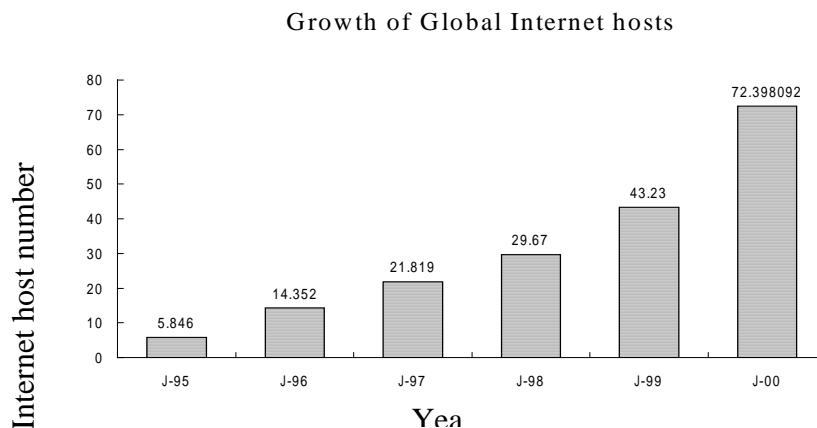
Figure1. Growth of global Internet hosts

Source: Network Wizards (2000/01) & R.O.C. Ministry of economics affairs

10

When the business activities of E-commerce grow, the enterprises' transmission volumes increase accordingly. This growth is exponential and is more dramatic than that of Figure 1. When available bandwidth cannot support timely data flow delivery, most data flows experience congestion. This in turn jeopardizes the operational performance of an enterprise. Moreover, a research report from U.S. Zona Research Corporation in 1999 [2] has pointed out that industries suffer 362 millions of E-commerce revenue losses per month due to slow network performance.

Additionally, another research report [16] shows a relationship between networking users' behaviors and website response time. This research pointed out that a website response time decided how many commercial opportunities it may receive from customers. Longer website response time assures, more disconnected customers are prospective. It is usually the critical one second delay, websites would lose 10% ~ 30% prospective customers. The report also revealed the "8 seconds rules". The critical response time of websites is 7 seconds. If response time of one website is less than 7 seconds, the probability that user disconnects from the website is small. Otherwise, if the response time of one website is longer than 7 seconds, the probability a user disconnects from the website would increase rapidly. This is shown in Figure 2. The key message of this report is that to keep customers stay with a business one needs a responsive network.
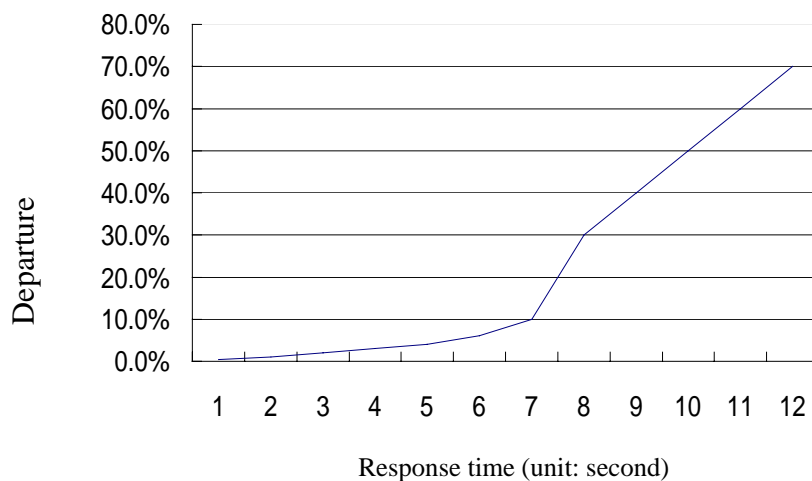
Figure2. A relationship between website response time and customer departure probability
Source: Zona Research

Factors such as types of industry, business operation model, and business scale affect each enterprise that each has its own unique internal structure and computer networking requirement. A common need of an enterprise for its network is to manage its bandwidth utilization effectively. Normally some peak loads or burst traffic concentrate during certain periods. The required bandwidth exceeds that provided by the enterprise network. For the average load, there is sufficient bandwidth to satisfy an enterprise's demand. This imbalance phenomenon can be demonstrated by Figure 3. Figure 3 shows utilization of a leased line that connects to Internet for a real company. The peak traffic load of the leased line concentrates during office hours from Monday to Friday. The maximum traffic load through the leased line reaches 194% of the subscribed bandwidth. But the average traffic load

through the leased line is smaller than 70% of the subscribed bandwidth. For this company, most of network traffic connected to Internet concentrate on specific office hours. The leased line congestion affect enterprise network performance and operations. Therefore, during office hours, the leased line cannot efficiently support responsive requirements of business operations. However, it shows low network utilization during after hours.

	Input		Output	
	max.: 249.2kb/s(194.7%)		max.: 198.0kb/s(154.7%)	
Input	avg.: 68.3kb/s(53.3%)	Output	avg.: 57.1kb/s(44.6%)	
	cur.: 18.7kb/s(14.6%)		cur.: 51.3kb/s(40.1%)	

	max.: 248.7kb/s(194.3%)	max.: 234.6kb/s(183.2%)
Input	avg.: 88.2kb/s(68.9%)	Output avg.: 49.2kb/s(38.5%)
	cur.: 17.6kb/s(13.8%)	cur.: 27.6kb/s(21.6%)
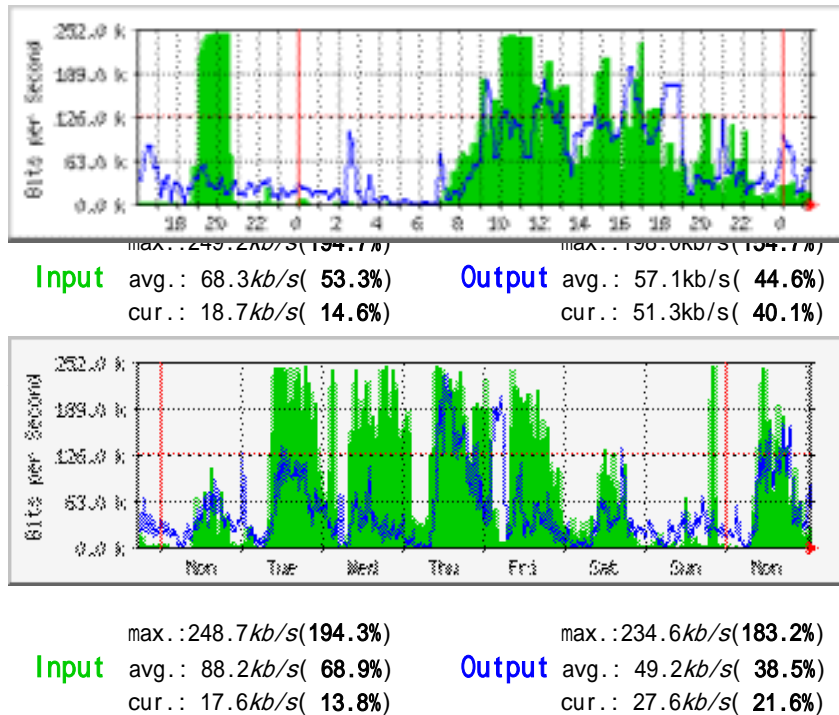
Figure 3. A leased line traffic statistics of a company

When network congestion occurs, an enterprise should adopt a necessary measure to assure some important or urgent information get through. Two alternatives of resolving network congestion are increase investment and regulate usage.

"Increase Investment" means an enterprise continue to invest enterprise network infrastructure and advanced computer equipments to expand enterprise network system's bandwidth and capacity. However, if an enterprise use the peak traffic load as its criterion, it would cost the enterprise a lot of money and manpower. The continuing investment would be a heavy financial burden for the enterprise. If an enterprise adopt average traffic load as its upgrade criterion, then enterprise network cannot satisfy the bandwidth requirement in a peak traffic transmission period. Network congestion still exists. The leased line case in Figure 3 has been used to demonstrate this point. If the enterprise enhances its leased line capacity based on the peak traffic load, it should upgrade its leased line bandwidth to 256Kbps. Consequently, the leased line can satisfy this enterprise's transmission requirement at any time and no congestion exists. But the upgrade expense is expensive.

"Regulate Usage" means that an enterprise does not invest further; instead it assign bandwidth to data flow of urgency or importance. With a proper traffic flow regulation, important and urgent information are quickly transmitted. "Regulate usage" measure allows an enterprise to leverage a

minimum investment and is an economical solution to increase enterprise network efficiency. This strategy is an analogy to a control mechanism of trains' traffic. For instance, Passenger trains and freight trains would run on a railroad. But at the same time, there is only one train could run on a railroad. The train scheduling mechanism can use the following rules:

1. Passenger trains receive higher priorities than that of freight trains. Passenger trains are further classified in to different priorities.

2. Passenger trains are scheduled mainly during daytimes and office hours. Freight trains are treated otherwise.

With such a train schedule, a railroad administration would efficiently utilize a railroad transportation capacity and satisfy most of requirements of passenger and freight transport. Likewise, an enterprise can apply differentiated service over its enterprise network. A differentiated service mechanism allows network administrators or Internet service providers (ISP) to allocate different network bandwidth to different users according to corporate policy or customers' agreements. Network administrators may tune the network traffic by factors such as business properties, procedures, users, time urgency, importance of content and interrelationships. With these characteristics of traffic flows, network administrators may assign different transmission priorities to traffic flows. These important traffic flows for an enterprise might generate from the following business information: executive level's strategy information, orders from important customers, important e-mail, a control information of product manufacture, information of financial operating and internal important information. Such a differentiated service mechanism may let important or urgent traffic flows get better transmission performance and assured timely transmission.

2.2 A classification mechanism of enterprise traffic flow

A classification mechanism is used to assign priority to differentiated services. If the classification results correctly represent importance and urgency of enterprise traffic flows, then an enterprise network differentiated service mechanism could really maximize its effective utilization networking resources. Otherwise, bad classification results may result in poor transmission performance. Figure 4 shows a conceptual classification framework of networking.
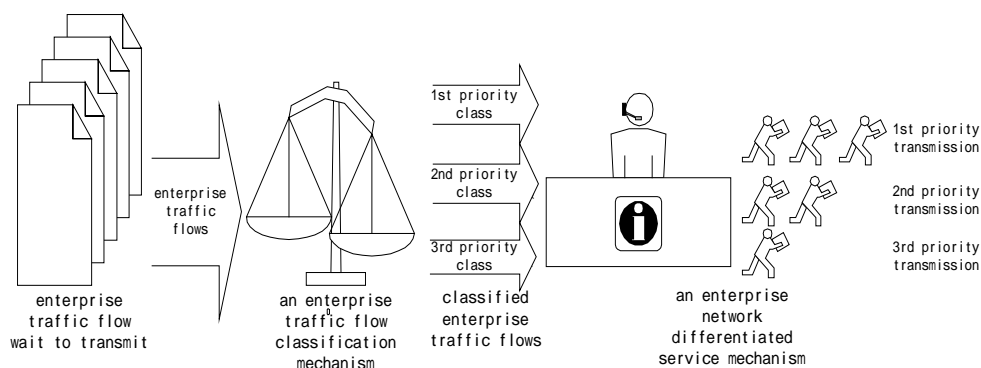
Figure 4. A relationship between an enterprise network differentiated service mechanism and enterprise traffic flow classification mechanism

Differentiated service mechanism would allocate bandwidth leftover from high priority traffic and put them all in the category of best-effort traffic. Therefore, these best-effort traffic flows do not received guaranteed transmission performance.

Each enterprise may have its own the classification criterion. Major factors affecting traffic flow classification mechanism are listed as follows.

1. The managerial rank of sender/receiver:

   In an enterprise, the rank of a sender or a receiver is an important index for an enterprise traffic flow classification mechanism. Generally speaking, the information transmitted by executives or high-level managers is more important and urgent than the information transmitted by low-level managers or employees. With efficient business operation information, key executives may make timely quality decisions managers.

2. The business characteristics of each department:

   The transmission requirements of each department in an enterprise depend on the business properties each department administered. Usually, marketing and customer service departments face customers directly, and need responsive information received and sent. These departments require more bandwidth and resources. Departments of internal affairs that do not directly face customers may not require real time responses over the intranet. These departments may share the bandwidth leftover by the other departments.

3. Time factor:

   Time is another factor might impact the assignment of transmission priority. During office hours of weekdays, marketing departments and customer service departments should receive more network bandwidth and resources to create or maintain more commercial opportunities. During weekends or after hours, marketing departments and customer service departments would no longer face customers. Bandwidth and resources could be transferred to supporting departments such as manufacturing.

4. The features of applications:

   Applications are function-oriented. Workflows run across several departments. Applications of various purposes may require different attentions. Executive information system, for example, should receive priority treatment. On the other hand, the normal bulletin board and discussion groups used by employees are applications that do not require guaranteed bandwidth for timely transmission. Routine functions or regular personal communications can be categorized as best-effort traffic flows.

5. Emergency events or other factors:

   Emergent events definite have serious impact to business operations. For these emergent events, network managers could allocate assured bandwidth and resources temporarily.

To summarize, good classification scheme should consider factors discussed above. These factors should be reflected in the enterprise network management system. A classification mechanism needs to know the properties of traffic flows to assign appropriate priority. Factors affecting the classification

mechanism include the following: (1) Who is the sender or receiver? (2) The corresponding department that sends it or receives it. (3) The application systems at both sides. (4) Timing.

3. An enterprise network differentiated service mechanism

The DiffServ is a mechanism proposed by IETF Differentiated Service Working Group [13]. According to traffic flows' transmission properties or SLA (Service Level Agreement), traffic flows can be assigned to different priority classes by routers or switches that support routing functions. The DiffServ mechanism allocates different ratio of bandwidth or resources to different traffic classes. The DiffServ mechanism does not provide end-to-end QoS (Quality of Service) over networks. It only assigns more bandwidth to higher priority traffic flows than that of lower priority traffic flows in the same period. Therefore, higher priority traffic flows would get better transmission performance than lower priority traffic flows and might get away with network congestions.

The DiffServ mechanism uses the "TOS (Type of Service)" field in IPv4 packets [10] or "traffic class" field in IPv6 packets as a basis of traffic flow classification [4]. These two fields are called DS (Differentiated Service) fields or DSCP (Differentiated Service Code Point) [7]. Each DiffServ domain's border router uses SLA to define a network service requirement of each traffic flow. SLA can be established statically or dynamically. SLA indicates the transmission performance requirements or characteristics of a data flow. Based on SLA, a packet classifier can examine the traffic flow when the packet enters a DiffServ domain. After packets classified, the traffic flow would be metered, marked, shaped, dropped and policed by a traffic conditioner. A classifier works on PHB (Per-Hop Forwarding Behavior)[13] basis. The same PHB traffic flows have the same DiffServ characteristics. There are three types of PHB in the research:

- BE (Best Effort Forwarding):

    BE is the default forwarding transmission. Most of Internet traffic flows use BE. BE packets are transmitted only when network bandwidth is available. The transmission performance of BE traffic flows would depend on available bandwidth over the network. When the network is not congested, BE traffic flows' transmission speed is good. Otherwise, its transmission speed is slow. Therefore, BE transmissions do not guarantee the quality of service.

- EF (Expedited Forwarding) [8]:

    EF is a higher priority transmission than that of BE. A network may reserve some resources and bandwidth for urgent EF traffic flows to transmit data. Other types' traffic flows could not share the bandwidth reserved for EF traffic flows. EF traffic flows are guaranteed for its transmission performance: An EF packet can run at a rate larger than or equal to the subscribed rate. Therefore, each EF flow receives a better service than that of BEs.

- AF (Assured Forwarding) [6]:

AF assures a minimum bandwidth to each AF flow. AF flows can be further divided into several priority classes. With differentiated network resources and a minimum assigned bandwidth allocation, an AF packet is assured for service quality. A conceptual share of network bandwidth by three PHB's is shown in Figure 5.
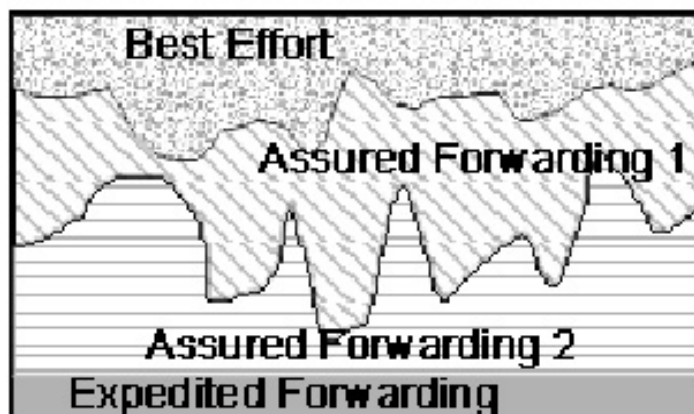
Figure 5. A conceptual shared bandwidth by the three PHB

MPLS (MultiProtocol Label Switch) is a routing mechanism that integrates a label swapping and network layer routing. MPLS has been proven to be the main stream of the next generation networking technology and many vendors are providing devices for enterprise solution. This research uses MPLS [3] to an enterprise network using DiffServ mechanism. In a MPLS domain, there are two kinds of routers exist; edge routers and core router. An edge router locates on the border of a MPLS domain whereas a core router resides in the interior of the MPLS domain. Edge routers examine destinations of all traffic flows that are entering the MPLS domain. An edge router uses a LDP (Label Distribution Protocol) [1] provided by MPLS to establish one or more LSPs (Label Switching Path) for these traffic flows. Note that, most LDP allow each core router to use its own local labels to reduce its size of routing table hence accelerate the routing. This is because labels are short and can be reused instead of directly using unique IP addresses. When a traffic flow enters a MPLS domain, the edge router looks up its routing table, assigns the same labels to every packet of same traffic flow according to its destination, and then selects one of LSPs as its routing path. In each LSP, core routers examine each packet's label, then forward the packet to next hop router or destination according to its label assigned by an edge router. Figure 6 shows the MPLS environment.

The DiffServ mechanism provides differentiated services depending on the content of DSCP field. DSCP field contains 6 bits. These 6 bits in packets would be used by routers to decide which type of PHB would be adopted to transmit packets. Table 1 shows a relationship between DSCP and PHB. MPLS also can use the DSCP field to select a proper LSP.

16
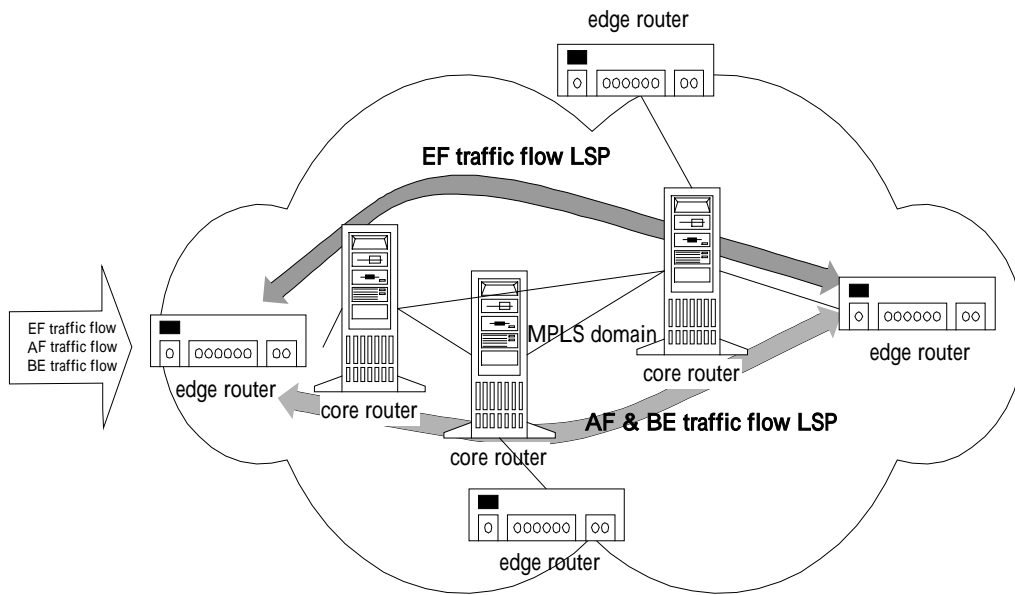
Figure 6. A diagram of MPLS supports an enterprise network differentiated service

Table 1. A mapping table of DSCP and PHB [6,7,8]

DSCP	PHB Drop Precedence	
000000	Best Effort Forwarding	
010000	Assured Forwarding Class 1	Low
010010		Middle
010100		High
011000	Assured Forwarding Class 2	Low
011010		Middle
011100		High
100000	Assured Forwarding Class 3	Low
100010		Middle
100100		High
101000	Assured Forwarding Class 4	Low
101010		Middle
101100		High
101110	Expedited Forwarding	

MPLS can use a CR-LDP (Constraint-base Routed Label Distribution Protocol)[5] to reserve network bandwidth and select transmission paths for classified traffic flows in advance. In this research, we use MPLS and CR-LDP as tools to differentiate traffic flows in an enterprise network.

17

The main reason is that the requirements of DiffServ mechanism can be satisfied by MPLS and CR-LDP. Moreover, MPLS reduces routing cost due to small routing tables. With CR-LDP, each LSP could have different properties, such as: bandwidth limit, duty cycle time and priority, to satisfy different requirements. Figure 7 shows the relationship among DSCP, EF, AF and BE traffic flows and established LSPs. Table 2 is a summary of characteristics of EF, AF and BE traffic flows. It also describes the relationship between MPLS and these three traffic flows.
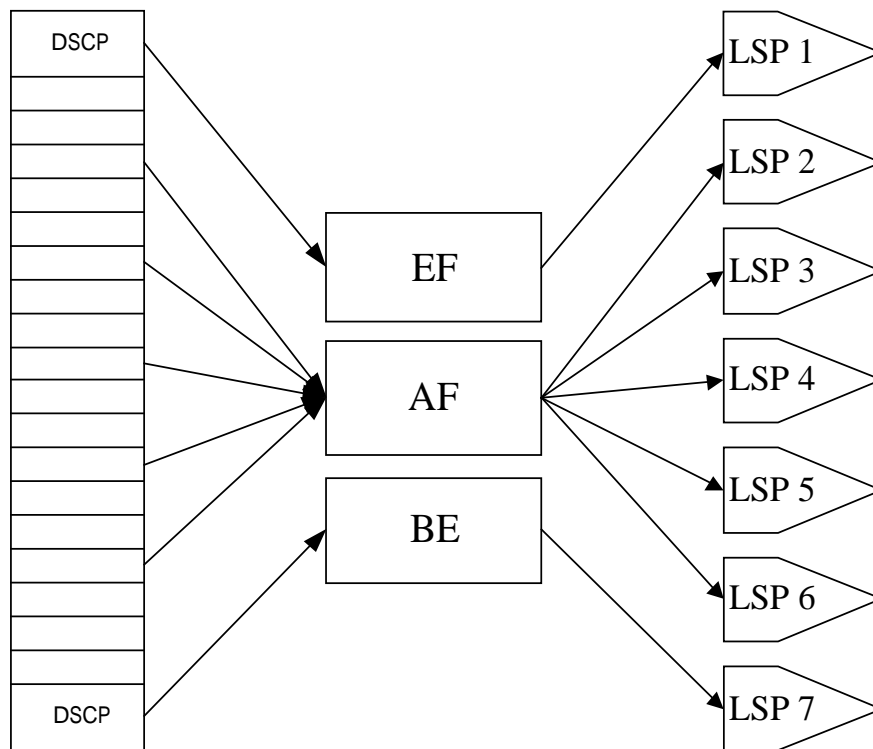
Figure 7. A relationship among DSCP, EF, AF and BE traffic flows and LSPs

Peyravian and Kshemkalyani proposed a path selection algorithm [10] that uses "minimum hop number" as a key parameter to assure fast transmission. When several transmission paths have the same hop number, the algorithm uses the allocated bandwidth or traffic load of a path as weights. The algorithm selects the path with minimum weights. This algorithm, however, cannot guarantee transmission service quality for a traffic flow. In this research, different weighting parameters, such as: a transmission duty cycle time and bandwidth utilization of a transmission path are used to assure transmission quality of service. With these parameters, our algorithm first selects the available transmission path, and then the Minimum Priority algorithm we proposed in this paper would select the best paths described in Figure 8. Therefore, high priority traffic flows obtain better transmission performance and better service qualities than otherwise.

Table 2. A summary of characteristics of EF, AF and BE traffic flows

PHB	Transmission Priority	Priority Level	Preemption Behavior	LSP Property
EF	High	One	1. No preemption behavior allowed among EF traffic flows 2. EF flows preempt AF and BE flows * good for real time applications or urgent data flows	Dedicated LSPs
AF	Middle	Several	1. Preemption behaviors is allowed among AF flows 2. A high priority AF flow preempts a low priority AF flow 3. AF flows could preempt BE flows' bandwidth * good for important customers	Shared LSPs
BE	Low	One	1. No preemption behavior allowed among BE traffic flows 2. Bandwidth might be preempted by EF and AF traffic flows * good for regular data traffic	Shared LSPs

```
/* Minimum Priority algorithm */
Minimum_Priority_Algorithm {
  foreach flow enters the domain {
    LSP_queue(flow_id) = establish_available_LSPs_queue ( ingress, egress )
    min_preempted_priority_LSP = compute_the_min_preempted_priority_of_LSPs
                               ( required_bandwidth,transmission_requirements
                               , LSPs_queue( flow_id ) )
  }
}


/* To search all available LSPs that satisfy the transmission requirements of a traffic
   flow from an ingress router to an egress router */
function establish_available_LSPs_queue ( ingress, egress ) {
    foreach { LSPs exist from ingress to egress } {
                if { this LSP satisfies the transmission requirements } {
                    insert LSP_record into LSPs_queue
                    }
        }
    return LSPs_queue
}
```

```
/* To compute the minimum sum of preempted priority of LSP
function compute_the_min_sum_of_preempted_priority_of_LSPs
        ( required_bandwidth, transmission_requirements, LSPs_queue )
  {
    available_bandwidth = 0
    LSP = the first LSP_record of LSPs_queue

    /* Continue to preempt lower priority flows over the link until the available bandwidth
       satisfies the transmission requirement of a new traffic flow */
    while { LSPs_queue is not empty } {
            if { LSP satisfies the transmission_requirements } {
                sum_of_preempted_priority_of_a_LSP(LSP) =
                sum_of_preempted_priority_of_a_link ( required_bandwidth )
            }
            remove the head LSP_record element from LSPs_queue
            LSP = the first element of current LSPs_queue
    }
    return the minimum sum_of_preempted_priority_of_a_LSP(LSP)
  }


/* To compute the minimum sum of preempted priority over a link
   A link means a line of communication between two routers, switches or related connection
   equipments in an enterprise network. */
procedure sum_of_preempted_priority_of_a_link ( required_bandwidth ) {
    available_bandwidth = 0
    sum_of_preempted_priority = 0

    /* Continue to preempt lower priority flows over the link until the available bandwidth
       satisfies the transmission requirement of a new traffic flow */
    while { available_bandwidth < required_bandwidth } {
            preempt the bandwidth of current lowest priority flow over a link
            available_bandwidth = available_bandwidth + preempted_bandwidth
            sum_of_preempted_priority = sum_of_preempted_priority +
                                        preempted_priority
    }
    return sum_of_preempted_priority
}
```

Figure 8 Minimum Priority algorithm

When establishing a new LSP for a flow entering the MPLS domain, for each congested single link, the algorithm will preempt the lowest priority flow. The preempted flow will find an alternative new link or path, by preemption if needed, to continue its transmission. In other words, the preemption has domain effect until the whole network converges to a stable transmission.

20

4. A simulation analysis

The Network Simulator - ns (version 2 beta release 5) [14] is used for verifying transmission behavior of differentiated services. The ns-2 is implemented on a PC with a pentium-III-500 CPU, 256MBytes RAM running Linux operating system. A simplified enterprise network architecture and two scenarios are simulated. The first scenario's is an enterprise network with differentiated service mechanism operating in a single LSP. The second scenario is a network operating in multiple LSPs.

1. Differentiated services in a single LSP

Figure 9 is the simplified network topology for simulating three PHB differentiated service in a single LSP.
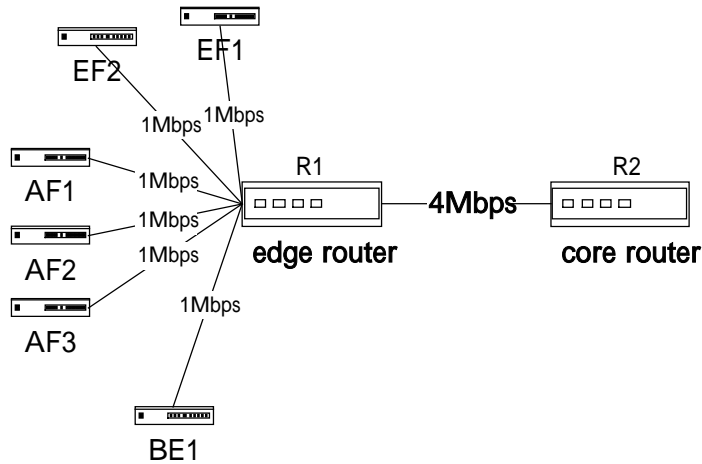
Figure 9. A differentiated service mechanism in simplified enterprise network topology

Figure 9 shows that EF1 and EF2 are classified as EF traffic flows. AF1, AF2 and AF3 are classified as AF traffic flows and BE1 is a BE traffic flow. These six traffic flows have different transmission properties and priorities over the enterprise network. The required bandwidth of each traffic flows is 1 Mbps. These traffic flows would enter the enterprise network from an edge router R1, and then pass through the R1-R2 link. Therefore, the edge router R1 faces 6 Mbps bandwidth. But, the available capacity of R1-R2 link is 4Mbps, and cannot fully satisfy 6Mbps traffic flows. Congestion will occur over the R1-R2 link. Because CBQ (Class Base Queueing) is a mature and proven technique for supporting multiple queues over l single link, a CBQ differentiated service mechanism over the R1-R2 link is used. The starting transmission time of the six traffic flows are specified in Table 3.

Table 3. Start transmission time of the six traffic flows

Start transmission time	1st second	2nd second	3rd second
Traffic flows	EF1, AF1, AF2, BE1	EF2	AF3

Figure 10 shows bandwidth allocations of the LSP (R1-R2 link) by the network administrator. The EF1 receives 30% shares of the LSP. That is, EF1 receives 1.2 Mbps bandwidth from the

R1-R2 link (4Mbps * 30%). Other traffic flows also receive different shares of bandwidth from the R1-R2 link. Note that the proportion of bandwidth assigned to BE1 traffic flow is 0%, i.e. no bandwidth available to BE. Due to the lowest transmission priority of BE traffic flow, BE traffic flow could not receive any bandwidth from the R1-R2 link wherever there is any other flow of a higher priority competing for the bandwidth.
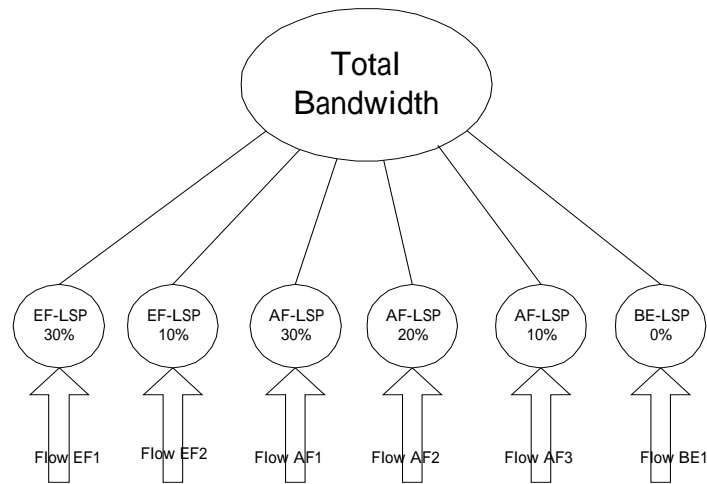
Figure 10. A diagram of bandwidth allocation in a LSP

In this scenario, the DiffServ mechanism is implemented as follows. EF flows receive the guaranteed bandwidth at any time. EF flows are scheduled in FIFO. AF flows receive assured bandwidth after EF flows have been satisfied. AF flows are scheduled according to their transmission priorities. BE flows are allowed to transmit only when bandwidth for EF and AF flows are assigned.
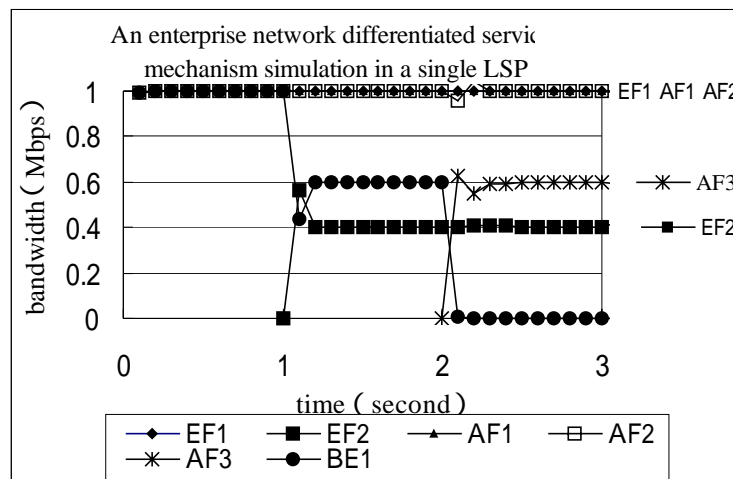
Figure 11. Simulation results of differentiated service in a single LSP

Figure 11 shows simulation results and several observations are summarized as follows.

(1) At time t = 0, the EF1, AF1, AF2 and BE1 flows begin to transmit over the R1-R2 link. Depending on the simulation scenario, EF1 and AF1 flows receive 1.2 (4 (total bandwidth) * 0.3, see Figure 10) Mbps bandwidth though either one of them needs only 1 Mbps. Therefore, each of

22

these four flows receives the needed 1 Mbps bandwidth. No congestion occurs over the R1-R2 link from time t = 0 to time t = 1.

(2) At time t = 1, the EF2 flow begins its transmission and congestion occurs over the R1-R2 link. According to the simulation scenario, the EF2 flow receives 0.4 (4 * 0.1) Mbps guaranteed bandwidth. After satisfying the transmission requirements of EF and AF flows, there is only 0.8 Mbps ($4_{\text{(total bandwidth)}} - 1.0_{\text{(for EF1)}} - 0.4_{\text{(for EF2)}} - 1.0_{\text{(for AF1)}} - 0.8_{\text{(for AF2)}}$) bandwidth available. Since the AF2 flow has higher priority than the BE1 flow, the AF2 flow would receive the extra 0.2 (1.0 – 0.8) Mbps bandwidth that is not the assured bandwidth for the AF2 flow. That is, AF2 takes away 0.2 Mbps from BE1. There are only 0.6 (0.8 – 0.2) Mbps available for BE1 flow. Figure 11 shows BE1 drops to 0.6 Mbps at t = 1.

(3) At time t = 2, the AF3 flow begins its transmission and deteriorates the congestion over the R1-R2 link. The AF3 flow receives 0.4 (4 * 0.1) Mbps assured bandwidth. After all guaranteed and assured bandwidth allocated to EF and AF flows, only 0.4 ($4_{\text{(total bandwidth)}} - 1.0_{\text{(for EF1)}} - 0.4_{\text{(for EF2)}} - 1.0_{\text{(for AF1)}} - 0.8_{\text{(for AF2)}} - 0.4_{\text{(for AF3)}}$) Mbps bandwidth are available for remaining AF and BE flows. Comparing the priorities of AF2, AF3 and BE1 flows, the AF2 priority is the highest and it first gets the 0.2 (1.0 – 0.8) Mbps extra bandwidth, preempts from BE1, that is not the assured bandwidth for the AF2 flow. The AF3 is of the second highest priority; it also gets the available 0.2 (0.4 – 0.2) Mbps extra bandwidth, preempts from BE1, that is not the assured bandwidth for the AF3 flow. Now the AF3 flow uses 0.6 Mbps bandwidth. Since the BE1 flow is of the lowest priority, it receives no bandwidth after time t = 2.

In summary, when a new flow begins its transmission over the R1-R2 link and there is no bandwidth available, the bandwidth reallocations of flows depend on their priority. The EF flows get their required bandwidth. Thereafter, AF flows also get the assured bandwidth. The BE flow receive its bandwidth only when EF and AF flows are satisfied.

Table 4 is a comparison of the EF, AF and BE flows' expected transmission loss and simulation results. It shows that the simulation results approximate the expected transmission loss. This result demonstrates the feasibility and correctness of the enterprise network differentiated service mechanism.

Table 4. A comparison of traffic flows' expected transmission loss and simulation results in a single link

(unit: Mbits)

		0th ~1st second	1st ~ 2nd second	2nd ~ 3rd second
EF	Simulated data loss	0	0.534	0.592
	Expected data loss	0	0.6	0.6
	Total transmission size	1	2	2
AF	Simulated data loss	0	0	0.359
	Expected data loss	0	0	0.4
	Total transmission size	2	2	3
BE	Simulated data loss	0	0.384	0.969
	Expected data loss	0	0.4	1
	Total transmission size	1	1	1

2. Differentiated services in Multiple LSPs

Three PHB traffic flows of differentiated services are simulated in a mesh network topology shown in Figure 12. This is used to simulate a multiple LSPs in an enterprise network. R1 in Figure 12 is the edge router of the enterprise network whereas R2, R3 and R4 are core routers. Three LSPs are available to support differentiated services in the enterprise network. Table 5 describes the simulation parameters: type of traffic flows, the start time of flows, the guaranteed bandwidth of flows, and the delay time limit of flows. Delay time here means the maximum tolerance of the data flow that is delayed.
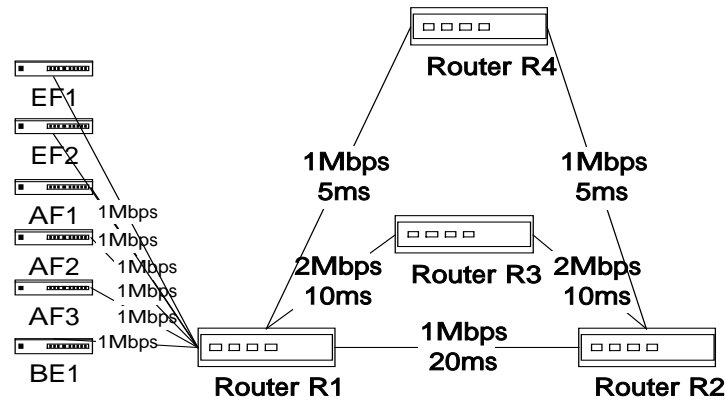
Figure 12. An enterprise network differentiated service mechanism in a multiple LSPs topology

Table 5. Simulation parameters of an enterprise network differentiated service mechanism in a multiple LSPs

Traffic flow	Start time (Second)	Bandwidth (Mbps)	Delay time (ms)
EF1	0	1.0	15
EF2	2	0.4	20
AF1	0	1.2	None
AF2	1	0.8	None
AF3	3	0.4	None
BE1	0	0.0	None

With the network topology of Figure 12 and the simulation parameters of Table 5, simulation results are shown in Figure 13.

Figure 13.A

Figure 13.B

Figure 13.C

Figure 13. Simulation results of differentiated services in multiple LSPs

Several observations are in order.

(1) At time t = 0, the R1-R4-R2 LSP has the minimum transmission delay of 10 ms and is the only choice for the EF1 flow to guarantee its 15 ms delay requirement.

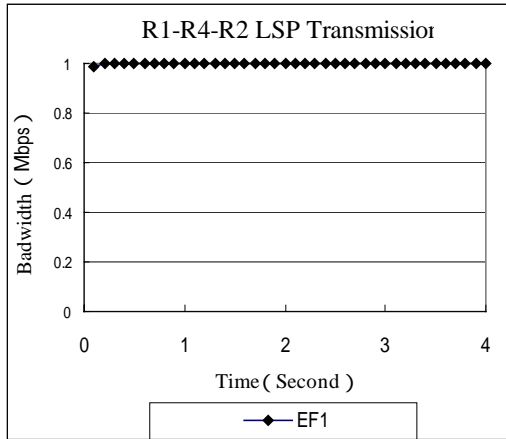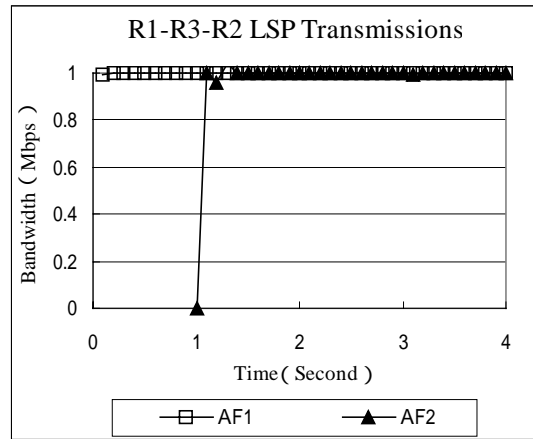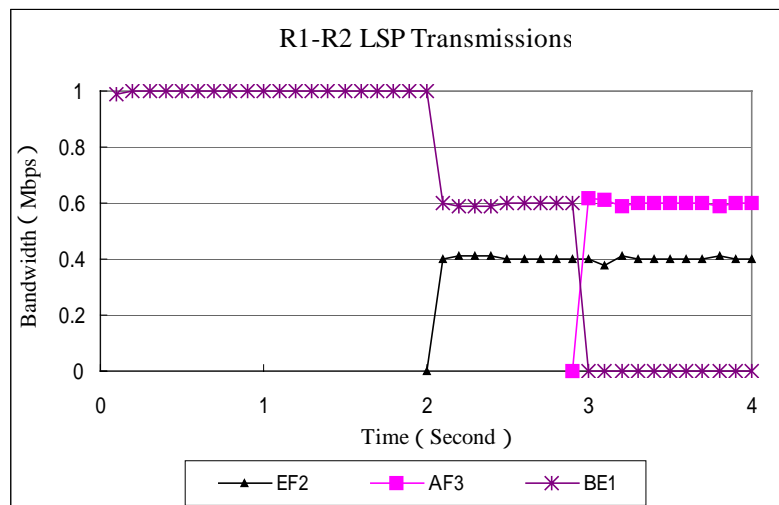(2) At time t = 0, the AF1 only requires 1 Mbps bandwidth. Because of the assured bandwidth of 1.2 Mbps, only the R1-R3-R2 LSP could satisfy. The path of R1-R2 is not chosen because it cannot assure the 1.2Mbps bandwidth that AF1 requires (see Table 5).

(3) At time = 0, having assigned EF1 and AF1, the network can only assign R1-R2 LSP to BE1 since that is the only LSP left. Technically, LSP R1-R3-R2 still has 1 Mbps but the assured bandwidth of AF1 is 1.2 Mbps with 0.8 Mbps left to others. This 0.8 Mbps cannot satisfy 1 Mbps of BE1.

(4) At time t = 1, the AF2 flow begins its transmission. Only the R1-R3-R2 LSP has 1 Mbps idle bandwidth. Therefore, AF2 takes this remaining bandwidth.

(5) At time = 2, all LSPs are allocated to the EF1, AF1, AF2 and BE1 flows. No idle bandwidth is available. Bandwidth preemption would occur to satisfy the transmission requirement of EF2 flow. According to Minimum Priority algorithm, the EF2 flow selects the R1-R2 LSP as its transmission path. EF2 now takes away some bandwidth from BE1. Since the network

administrator only guarantees 0.4 Mbps to EF2 (see Table 5), EF2 must preempt 0.4 Mbps from BE1 where BE1 is now the lowest priority in all flows. Note that BE1 keeps using the remaining 0.6 Mbps bandwidth.

If the EF2 flow selects the R1-R3-R2 LSP as its transmission path, it will cause that the AF2 flow must reselect the R1-R2 LSP and preempt the 0.8 Mbps bandwidth from BE1 flow. This LSP selection of EF2 would reduce the network utilization, the 0.6 Mbps bandwidth are idle in the R1-R3-R2 LSP, and increases the transmission path overhead of AF2.

(6) At time t = 3, the AF3 traffic flow begins its transmission. By using Minimum Priority algorithm, AF3 now can only preempt BE1 since BE1 is now the lowest priority flow. The preempted bandwidth is 0.6 Mbps and is exactly the amount needed to assure AF3.

Table 6 A comparison of traffic flows' expected transmission loss and simulation results in multiple LSPs

(unit: Mbits)

		$0^{th} \sim 1^{st}$ second	$1^{st} \sim 2^{nd}$ second	$2^{nd} \sim 3^{rd}$ second	$3^{rd} \sim 4^{th}$ second
EF	Simulated data loss	0	0	0.598	0.594
	Expected data loss	0	0	0.6	0.6
	Total transmission size	1	1	2	2
AF	Simulated data loss	0	0	0	0.366
	Expected data loss	0	0	0	0.4
	Total transmission size	1	2	2	3
BE	Simulated data loss	0	0	0.964	1
	Expected data loss	0	0	1	1
	Total transmission size	1	1	1	1

Table 6 lists a comparison of EF, AF and BE traffic flows' expected transmission loss and the simulated data losses. It shows the simulated data losses of EF, AF and BE traffic flows are close to the expected transmission losses. This also demonstrates MPLS could support an enterprise network that uses differentiated service mechanism.

5. Conclusion

With advances of Internet applications, enterprises gradually adopt information technologies to enhance their business performance. The prevailing of E-commerce also rests much business burden on a responsive intranet. To survive or to compete in today's competitive business environment, executive managers must make timely business decision. A responsive decision calls for a responsive network.

The enterprise network differentiated service mechanism may solve an insufficient bandwidth issue over an enterprise network. Differentiated service mechanisms depend on the transmission

characteristics of enterprise traffic flows to provide differentiated services among these flows. Traffic flows of enterprise can be classified into three categories: EF traffic flows, AF traffic flows and BE traffic flows. Each of these three traffic flows receives different transmission priority and network bandwidth. An EF traffic flow gets guarantied bandwidth and full transmission service quality at any time. EF traffic flows are good for transmitting urgent information. Minimum assured bandwidth would be allocated to an AF traffic flow. If there is idle bandwidth, an AF traffic flow also could get more bandwidth allocation than its assured bandwidth. AF traffic flows also provide a partial transmission service quality for an enterprise. AF traffic flows are good for delivering important operation information. The transmission priority of a BE traffic flow is the lowest. After satisfying all transmission requirements of EF and AF traffic flows, a BE traffic flow receives bandwidth if there are still available bandwidth. BE traffic flows do not receive transmission service quality. One can use BE to transmit regular messages for an enterprise.

In this research, several simulation scenarios are simulated. The simulation results demonstrate the enterprise network differentiated service mechanism could be a good choice for an enterprise to improve its enterprise network's operation performance with the minimum investment. This would be helpful for an enterprise to enhance its competition capability and expand its business opportunities.

Acknowledge

Reference

1. Andersson, L., et. al.(2000), "LDP Specification," draft-ietf-mpls-ldp-08.txt

2. Awduche, D., et. al. (1999), "Requirements for Traffic Engineering Over MPLS," RFC 2702

3. Callon, R., P. Doolan, N. Feldman, A. Fredette, G. Swallow and A. Viswanathan (1999), "A Framework for Multiprotocol Label Switching," draft-ietf-mpls-framework-05

4. Deering, S. and R. Hinden (1998), "Internet Protocol, Version 6(IPv6) Specification", RFC 2460

5. Jamoussi, B., et. al.(1999), "Constraint-Based LSP Setup using LDP," draft-ietf-mpls-cr-ldp-03.txt

6. J. Heinanen, F. Baker, W. Weiss   and J. Wroclawski (1999), "Assured Forwarding PHB Group," RFC 2597

7. K. Nichols, F. Baker and D. Black (1998), "Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers," RFC 2474

8. K. Nichols and K. Poduri (1999), "An Expedited Forwarding PHB," RFC 2598

9. Le Faucheur et. al.(2000), "MPLS Support of Differentiated Services", draft-ietf-mpls-diff-ext-05.txt.

10. Mohammad Peyravian and Ajay D. Kshemkalyani(1998), "Decentralized network connection preemption algorithms," Computer Networks and ISDN Systems, (30), pp. 1029-1043.

11. Postel, J., Editor (1981), "Internet Protocol", STD 5, RFC 791

12. Sally Floyd and Van Jacobson (1995), "Link-sharing and Resource Management Models for Packet Networks," IEEE/ACM Transaction on Networking, 3(4)

13. S. Blake, D.Black, M. Carlson, E. Davies and W. Weiss (1998), "An Architecture of Differentiated Services," RFC 2475

14. S. McCanne and Sally Floyd, "ns-Network Simulator," URL http://www-mash.cs.berkeley.edu/ns/

15. http://www.find.org.tw/img_howmany\howmany_201.gif
16. http://www.zonaresearch.com/deliverables/white.htm