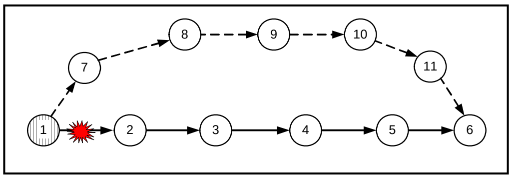
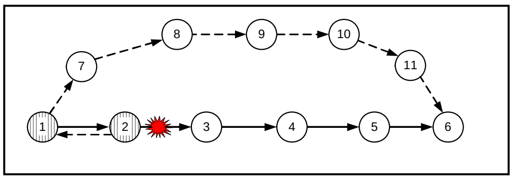
Hybrid Switching

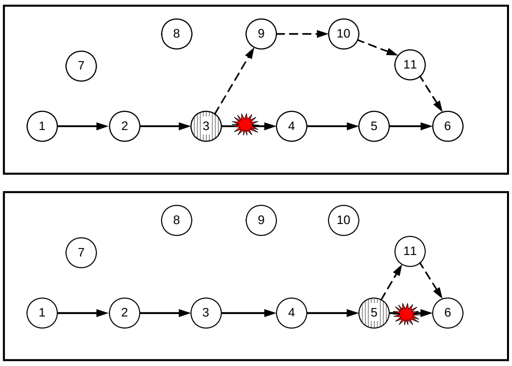
According to hybrid backup mechanism, the HB model has four switching types which are global, global reverse, local and local reverse switching (see Figure 6). If a failure is detected at adjacent downstream link/node to the ingress node, global switching is activated (see Figure 6 (a)). If a failure is identified at adjacent downstream link/node to the PSL node that is the most upstream to the first branch point, global reverse switching is started (see Figure 6 (b)). If a failure is discovered at adjacent downstream link/node to the branch point, local switching is operated (see Figure 6 (c)). Lastly, if a failure is occurred at adjacent downstream link/node to the downstream PSL node from branch point, local reverse switching is activated. (see Figure 6 (d)). Note that, PSL/PML nodes are activated according to different switching types.



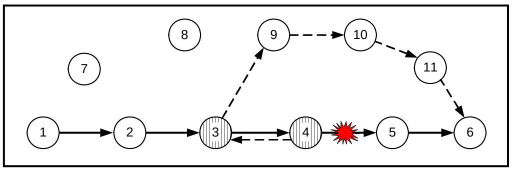
(a) Global Switching for a Link Failure at Link 1-2



(b) Global Reverse Switching for a Link Failure at Link 2-3



(c) Local Switching for a Link Failure at Link 3-4 and 4-5



(d) Local Reverse Switching for a Link Failure at Link 5-6

Figure 6. Examples for four Hybrid Switching Types of HB model

Routing and Recovering Procedures

Here, details of the HB procedures are shown. The procedures could be divided into two phases: *Routing* and *Recovering phase*. We define *G(N,L,B)* as an input network graph composed of sets of node N, link L, and residual bandwidth B. N_I and N_E are denoted to an ingress node and egress nodes, respectively. According to routing phase (see Figure 7), a working, global backup, branch backup and reverse backup paths are defined. Also, PSL and PML functions are activated at corresponding nodes. We assume that there is only single element failure occurred in the mean time. Then in recovering phase (see Figure 8), traffic is switched based on four switching types described in the previous sub section. Note that, for simplicity, the routing phase is based on 1:1 dedicated restoration allocation. Then, the routing performance can further be improved for the shared restoration allocation. This is one of our research topics.

Performance Metrics

Performance metrics we considered are cost effectiveness, level of QoS protection based on the Diff-Serv model, and network performances which are described in following sub-sections.

```
Procedure HB_Routing_Phase
  Inputs: A network graph $G(N,L,B)$, an ingress $N_I$ and an egress $N_E$ nodes, QoS routing algorithm $A_{RT}$ , request bandwidth $B_R$ , branch_point$_1$, …, branch_point$_n$ and number_of_branch_point
  Outputs: Sets of working $P_{WK}$, global backup $P_{GB}$, branch backup $P_{BP}$ and reverse backup $P_{RB}$ paths.
  Procedures: {
  1. Remove links that $B<B_R$
  2. Route for a $P_{WK}$ from $N_I$ to $N_E$ based on $A_{RT}$.
  3. Set PSL+PML functions at $N_I$. Set PML function at $N_E$.  Set PSL function at all $N \in P_{WK}$ except $N_I$ and $N_E$.
  4. Remove $P_{WK}$ from $G(N,L,B)$.
  5. Route for a disjoint $P_{GB}$ from $N_I$ to $N_E$ based on $A_{RT}$.
  6. Run GA_Branch_Point_Optimization
  7. Route for branch backup $P_{BP}$ and reverse backup $P_{RB}$ paths based on $A_{RT}$.
  8. Establish $P_{WK}$, $P_{GB}$, $P_{BP}$ and $P_{RB}$
  }
```

Figure 7. Routing Phase of HB Model

```
Procedure HB_Recovering_Phase
  Input: A failure of node $N_F$ or link $L_F$
  Output: Recovery operation
  Procedures: {
  1. If the failure is identified by an $N_I$
       Global switching: switch traffic over $P_{GB}$
  2. If the failure is identified by a $N_{PSL}$ downstream to $N_I$ and upstream to the first branch point ($N_{PML}$)
       Global reverse switching: switch traffic upstream to $N_I$ and then $P_{GB}$
  3. If the failure is identified by a $N_{PML}$
       Local switching: switch traffic over $P_{BP}$ and subset of $P_{GB}$
  4. If the failure is identified by a $N_{PSL}$ downstream to the branch point
       Local reverse switching: switch traffic over upstream $N_{PML}$ and then subset of $P_{GB}$
  }
```

Figure 8. Recovering Phase of HB Model

Cost Effectiveness

According to cost effectiveness, there are four performance metrics related to the working path *w*: number of PSL nodes (n^w_{PSL}), PML nodes (n^w_{PML}), backup paths (or flows) (n^w_{BKP}), and labels used (n^w_{LBU}). Firstly, the higher number of n^w_{PSL} and n^w_{PML} brings higher implementation costs and complexity and also affects longer recovery operation time (T_{RO}) according to switching over and merging processes. Secondly, the higher number of backup paths, n^w_{BKP}, directly increases size of routing table and label matching space of particular nodes belonging to the working path *w* and the backup path *b*. Thirdly, because of limitation of label space related to type of switching infrastructure, number of labels used for traffic swapping over backup paths must be taken into consideration. Then, the minimal number of label used is preferred. Therefore, establishment of backup paths must take into account those four metrics, in order to minimizing cost of the backup model. Finally, n^w_{PSL}, n^w_{PML}, n^w_{BKP} and n^w_{LBU} could be simply obtained by Equation (2) ~ (5), respectively.

$$n^w_{PSL} = \sum N_i, \qquad i \in \{N^w_{PSL}\} \tag{2}$$

$$n^w_{PML} = \sum N_i, \qquad i \in \{N^w_{PML}\} \tag{3}$$

$$n^w_{BKP} = \sum P_i, \qquad i \in \{P^w_{BKP}\} \tag{4}$$

$$n^w_{LBU} = \sum L_i, \qquad i \in \{P^w_{BKP}\} \tag{5}$$

Where $\{N^w_{PSL}\}$ is denoted to set of PSL nodes used along the working path *w*. $\{N^w_{PML}\}$ is referred to set of PML nodes along the working path *w*. $\{P^w_{BKP}\}$ is designated to set of backup paths reserved for the working path *w*. And R^w_{TX} is denoted to the requested transmission rate of the working path *w* (bps)

Quality of Service Protection (QoSP) Level

When a failure is detected over the working path *w*, the Quality of Service Protection metric of the path ($QoSP_w$) is evaluated to signify guarantee level of each backup models. In Equation (6), $QoSP_w$ is function of *Packet Loss* (E^w_{PK}), *Restoration Time* (T^w_{RS}) and *Bandwidth (or Resource) Consumption* (B^w_C) measured during recovery operation. The α,

β, and λ (see Table 1) are weighted values defined based on the *Differentiated Services* (Diff-Serv) traffic characteristics [12]. For example, in the expedited forwarding (EF) traffic class, guaranteed QoS traffic strictly requires very low packet loss and delay time. Then, weighted value of packet loss (α), restoration time (β) and bandwidth consumption (λ) are set to 50%, 45% and 5%, respectively. According to performance comparison between difference models, corresponding normalized values of E_{PK}^{w}, T_{RS}^{w} and B_{C}^{w} should be obtained by dividing with their reference values ($E_{PK}^{w,REF}$, $T_{RS}^{w,REF}$ and $B_{C}^{w,REF}$). These reference values are determined by the maximum worst-case performance among all considered backup models (see Equation (7) ~ (9)). H_w is denoted to number of hop along the working path *w*. From Equation (5), the higher value of *QoSP* demonstrates better QoS protection (or guaranteed) level of backup model. Hence, the *QoSP* ranges from 0 (worst *QoSP* case) to 1 (best *QoSP* case).

$$\begin{aligned} QoSP_w &= f\left(E_{PK}^{w}, T_{RS}^{w}, B_{C}^{w}\right) \\ &= 1 - \left\{ \alpha \times \left(\frac{E_{PK}^{w}}{E_{PK}^{w,REF}} \right)^{H_w} + \beta \times \left(\frac{T_{RS}^{w}}{T_{RS}^{w,REF}} \right)^{H_w} \right. \\ &\quad \left. + \lambda \times \left(\frac{B_{C}^{w}}{B_{C}^{w,REF}} \right)^{H_w} \right\} \end{aligned} \tag{6}$$

$$\begin{aligned} E_{PK}^{w,REF} &= \max\left(E_{PK}^{w,ALL}\right) \\ &= \max\left(E_{PK}^{w,GB}, E_{PK}^{w,RB}, E_{PK}^{w,LLB}, E_{PK}^{w,ELB}, E_{PK}^{w,BHB}\right) \end{aligned} \tag{7}$$

$$\begin{aligned} T_{RS}^{w,REF} &= \max\left(T_{RS}^{w,ALL}\right) \\ &= \max\left(T_{RS}^{w,GB}, T_{RS}^{w,RB}, T_{RS}^{w,LLB}, T_{RS}^{w,ELB}, T_{RS}^{w,BHB}\right) \end{aligned} \tag{8}$$

$$\begin{aligned} B_{C}^{w,REF} &= \max\left(B_{C}^{w,ALL}\right) \\ &= \max\left(B_{C}^{w,GB}, B_{C}^{w,RB}, B_{C}^{w,LLB}, B_{C}^{w,ELB}, B_{C}^{w,BHB}\right) \end{aligned} \tag{9}$$

Table 1: Diff-Serv QoS Protection Requirements and Assignments of α, β, and λ values.

Traffic Class	QoS Requirements	α	β	λ
Expedited Forwarding (EF)	Very Low Packet Loss and Restoration Time	0.5	0.45	0.05
Assured Forwarding 1 (AF1)	Very Low Packet Loss	0.5	0.3	0.2
Assured Forwarding 2 (AF2)	Low Packet Loss	0.33	0.33	0.33
Best Effort (BE)	No requirements	0.05	0.05	0.9

Generally, the packet loss can be defined by numbers of discarded packet during the time before recovery process starts (the time during fault detection (T_{FD}), fault hold-off (T_{FH}) and fault notification time (T_{FN})). It is a product of transmission rate (R_{TX}) multiply by the time ahead of recovery process starts (T_{FD}+T_{FH}+T_{FN}) and then divided by the packet size (S_{PK}) (see Equation (10)). Therefore, longer duration of fault detection and notification brings higher numbers of lost packets.

$$E_{PK} = \frac{R_{TX} \times (T_{FD} + T_{FH} + T_{FN})}{S_{PK}} \tag{10}$$

$$T_{RS}^{w} = T_{FD}^{w} + T_{FH}^{w} + T_{FN}^{w} + T_{RO}^{w} + T_{TR}^{w} \tag{11}$$

$$T_{FD}^{w} = [0, T_{LMI}] \tag{12}$$

$$T_{FH}^{w} = T_{LLD} \tag{13}$$

$$T_{FN}^{w} = \sum T_{D}^{p}\ , \quad p \in \{P_{FIS}\} \tag{14}$$

$$T_{RO}^{w} = \left(T_{SWO} \times n_{PSL}^{w}\right) + \left(T_{MGO} \times n_{PML}^{w}\right) \tag{15}$$

$$T_{TR}^{w} = \sum T_{D}^{p}\ , \quad p \in \{P_{RCO}\} \tag{16}$$

$$B_{C}^{w} = R_{TX}^{w} \times T_{TR}^{w} \tag{17}$$

The second term of Equation (6), restoration time, is defined as total delay during the MPLS recovery cycle. Therefore, from the section 2.3, restoration time is a total time between T_{FD}, T_{FH}, T_{FN}, T_{RO} and T_{TR} (see Equation (11)). The fault detection time, T_{FD}, ranges from 0 to Liveness Message (LM) interarrival time (T_{LMI}) which is at least 2 times of the propagation delay over detected adjacent node (see Equation (12)). The fault hold-off time, T_{HO}, could be set to delay of the lower layer protocol (T_{LLD}) before activation data transmission provided by the higher layer protocol, see Equation (13). This value can be neglected because of its small value comparing to other duration. The fault notification time (T_{FN}) depends on propagation time of an FIS to upstream PSL node (see Equation (14)). The recovery operation time, T_{RO}, is time during switchover and merging operation of PSL and PML nodes currently activated by the recovery operation (see Equation (15)). The traffic recovery time, T_{TR}, is duration of transmitting recovered traffic transmitted until it reaches the egress node once again (see Equation (16)). Other analysis of the restoration time could be obtained in [12], [13], and [14]. Finally, the bandwidth consumption (B_C) is evaluated by amount of bandwidth utilized over the activated recovery path (see Equation (17)).

Overall Network Performances

Here, three network performance metrics are evaluated which are bandwidth reserved (B_{RSV}), rejection probability (ρ_{REJ}), and total throughput (B_{TH}). Bandwidth reserved is evaluated by summation of transmission rate of backup path multiply by total number of links of the backup paths (see Equation (18)). In Equation (19), rejection probability is calculated by total number of call rejected divided by total number of call requested. Lastly, from Equation (20), total throughput is determined by summation of transmission rate of all successful established working paths.

$$B_{RSV} = \sum \left(R_{TX}^{b} \times \sum L_{b} \right) \quad , \; b \in \left\{ P_{BKP} \right\} \qquad (18)$$

$$\rho_{REJ} = \frac{\sum Call_{REJ}}{\sum Call_{REQ}} \qquad (19)$$

$$B_{TH} = \sum R_{TX}^{w} \quad , \; w \in \left\{ P_{WK} \right\} \qquad (20)$$

Numerical Models and Results

We have developed extensive MATLAB 7.0 simulator [18] in order to evaluating performance of the HB model. Moreover, for scalability issue, we also repeat performance evaluation over two experimental networks.

Numerical Models

Two experimental networks are chosen for performance evaluation described in previous sub-sections. The first network is shown in Figure 9. It composes of 15 nodes and 28 links. It has ten edge nodes which are node 1, 2, 4, 5, 8, 9, 12, 13, 14 and 15. The second network composes of 30 nodes and 56 links (see Figure 10). It also has ten edge nodes which are node 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10. Although, both networks are different in size, but they have the same link characteristics and traffic parameters. According to link characteristics, all links are bi-directional. Capacity of links are 100 Mbps. Distance of all links is 100 km. Then, propagation delay of all links is 500 μs (100 km × 5 μs/km which is propagation velocity over single mode fiber). Average size of packets is set to 1024 bits. Fault detection or Liveness Message interarrival time is set to round-trip propagation time of link or 1000 μs (500 μs × 2). Lastly, fault hold-off time, switchover and merging delay are equally set to 1 μs. Size of traffic requests are 1-5 Mbps varied by uniformly distribution. For more accuracy, we use the same orders of traffic requests to test on different backup models including the HB model. Ingress and egress nodes (or source-destination node pairs) of each traffic request are also populated by uniformly distribution. QoS Routing algorithm A_{RT} is Widest Shortest Path (WSP) [16], which select a shortest path with the highest residual bandwidth. Note that, other exist QoS routing algorithms related to Diff-Serv model could be used to improve the routing performance. With GA parameters, we set GAOPTIMSET: ‘generations' = 100, 'PopulationSize' = 20 and 'StallGenLimit' = 50. And we left other parameters at default value. Finally, maximum number of branch point is set to 2.

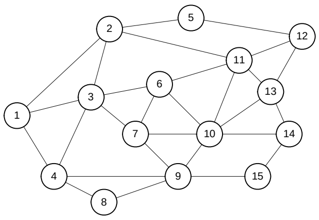


Figure 9. Example Experimental Network with 15 Nodes

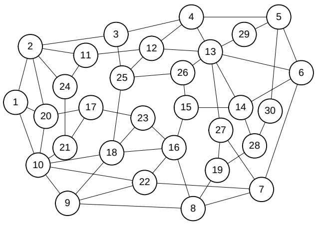


Figure 10. Example Experimental Network with 30 Nodes

Table 2: **Comparison of Cost Effectiveness Parameters.**

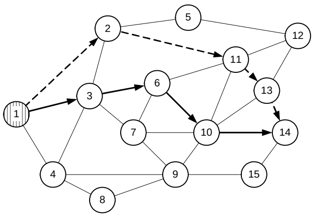
	n_{PSL}^{w}	n_{PML}^{w}	n_{BKP}^{w}	Backup Path List	n_{LBU}^{w}
GB	1	1	1	{1-2-11-13-14}	4
RB	4	2	2	{1-2-11-13-14}, {10-6-3-1}	7
LLB	4	4	4	{1-2-3}, {3-7-6}, {6-11-10}, {10-13-14}	8
ELB	4	3	4	{1-2-11-6}, {3-2-11-10}, {6-11-13-14}, {10-13-14}	11
HB	4	2	4	{1-2-11-13-14}, {3-1}, {6-11}, {10-6}	7

Numerical Results

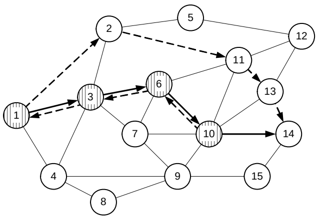
CASE 1: Cost Effectiveness

Evaluating cost effectiveness, we choose node 1 and 14 to be ingress (source) and egress (destination) nodes, respectively.

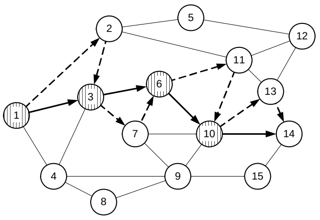
Figure13 shows results of working and backup path based on five backup models: GB, RB, LLB, ELB and HB. According to the same routing algorithm, all backup models have a same working path {1-3-6-10-14}. However, backup paths of each backup model are different. Further, cost effective parameters are determined and shown in



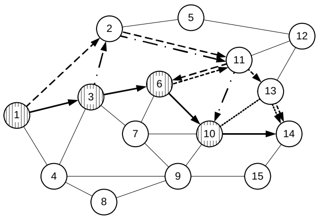
(a) Global Backup (GB)



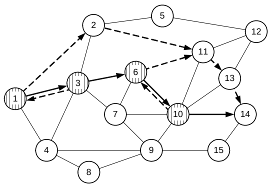
(b) Reverse Backup (RB)



(c) Local Backup with Single Link Failure Protection (LLB)



(d) Local Backup with Single Element Failure Protection (ELB)



(e) Hybrid Backup (HB)

Figure 11. Example for Working and Backup Paths with N_I=1 and N_E=14

From the table, GB has the minimum cost of only one PSL, one PML, one backup path and four label used for backup path. Note that, label is determined by total hop of the backup path. Although, GB is the cheapest model, it suffers from high level of packet losses and restoration delay. This disadvantage will be discussed later in next experimental case. Further, both LB models have the highest cost. Because LLB has the highest number of PSL, PML and backup path, and ELB has the highest number of label used. In RB model, the cost effectiveness is considered in medium level.

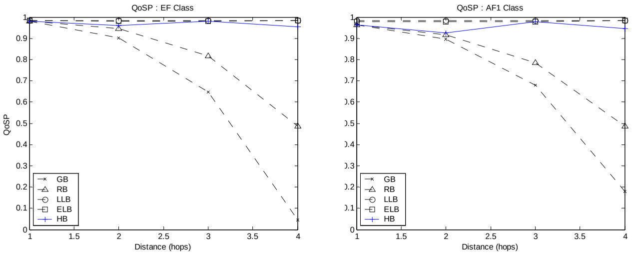
Comparing to both LB models, HB can reduce cost of number PML and label used. This implies that HB model can reduces implementation cost, while it still maintains level of QoS protection in case of fast restoration and low packet losses.

CASE 2: QoSP vs Point of Failure Detection

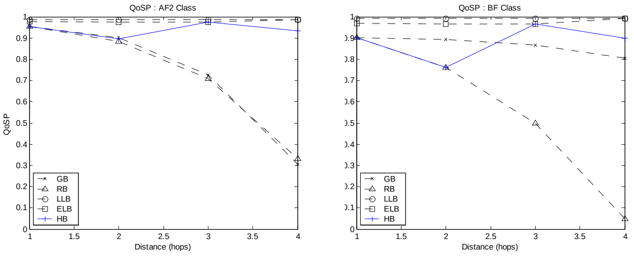
Based on CASE 1, QoSP value is determined by varying of point of failure detection from the 1st node (node 1) to the 4th node (node 10) of the working path. Transmission rate is set to 1 Mbps.

Figure12 illustrates QoSP of four Diff-Serv traffic classes related toα,β and λ values. As mention in the Section 5, high QoSP value is required. Because of FIS transmission delay, the longer point of failure detection highly increases restoration time and then degrades QOSP level of GB and RB (see Figure12 (a)-(c)).

While, point of failure detection rarely impacts on QoSP of both LLB and ELB, the result shows that with HB, QoSP is a little lower than LLB and ELB. This shows that the HB model has almost high QoS guaranteed level as equal as both LLB and ELB model. In Figure12 (d), because of best effort class, restoration time and packet losses are less important. Therefore, the RB model has the worst QoSP, because of high bandwidth consumption.



(a) EF Class (b) AF1 Class

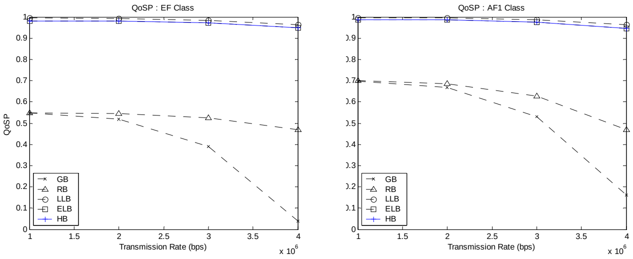


(c) AF2 Class (d) BE Class

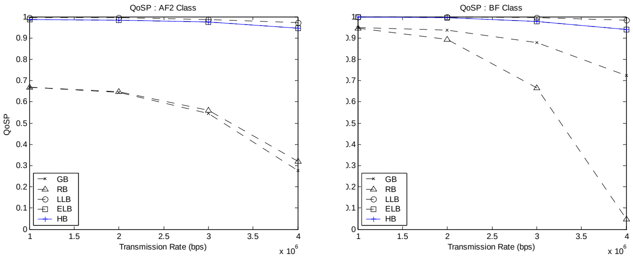
Figure 12. QoSP vs Point of Failure Detection

CASE 3: QoSP vs Transmission Rate

Also, based on CASE 1, QoSP value is reevaluated by varying of input transmission rate from 1 to 4 Mbps. Point of Failure is fixed to the 3rd node (node 6) of the working path. Again, From Figure13, the HB model has high QoSP level and a little lower than LLB and ELB models. Further, because of high restoration delay of GB and RB models, QoSP level of GB and RB models are obviously lower than LLB, ELB and HB models (see Figure 13 (a)-(c)). Lastly, from Figure 13 (d), the RB model again has the lowest QoSP level because it consumes the maximum bandwidth due to the failure.



(a) EF Class (b) AF1 Class



(c) AF2 Class **(d) BE Class**

Figure 13. QoSP vs Transmission Rate

CASE 4: Network Performances of 15-Nodes Network

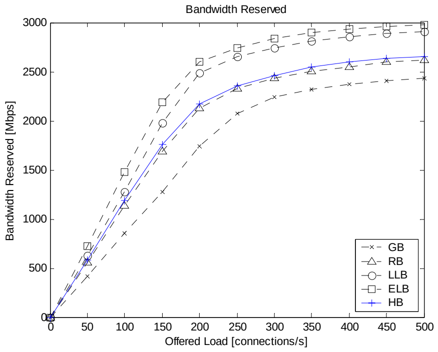
Here, overall network performances of the15-nodes network are evaluated by simulation. Input traffic is varied from 0 to 500 connections per second. As mention in sub-section 6.1, size of traffic requests are 1-5 Mbps varied by uniformly distribution. For more precise result, we repeat ten time simulation and show the averaged result. Figure 14(a) shows that the GB model reserves the minimum bandwidth. The RB and HB reserve the medium bandwidth, and the LLB and ELB reserve the highest bandwidth. The more bandwidth reserved brings the more chances for a future traffic to be rejected. Then, in Figure 14 (b), the GB model is the best model in case of rejection probability and the ELB model is the worst. Furthermore, the less rejection probability leads to high total throughput. Then, in Figure 14 (c), the GB model is again the best model in case of total throughput.

Although the GB model is the best backup model in case of the lowest bandwidth reserved, the lowest blocking chance, and the highest total throughput. It is still considered to be not suitable for QoS guaranteed traffic since this model has low QoSP level according to high packet losses and restoration time.

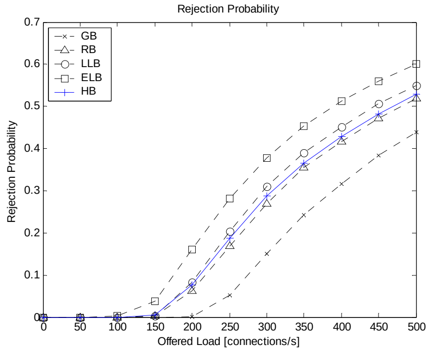
With RB model, all three network performances are in the medium level. However, because of its high restoration time, the RB model is only suite for the QoS traffic that guarantees only low packet losses such as AF1, AF2 and BE classes.

In LLB model, the model achieves high QoSP level and suites to apply to EF traffic. However, bandwidth reserved is high. This is resulted in high rejection probability and low total throughput. Moreover, it has high cost and can be used to protect only link failure type.

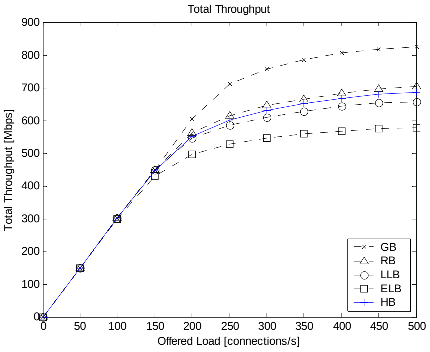
Also, the ELB model reaches high QoSP level as same as the LLB model. This model can be applied to both link and element failure protections. However, it has the highest cost and the lowest network performances.



(a) Bandwidth Reserved



(b) Rejection Probability



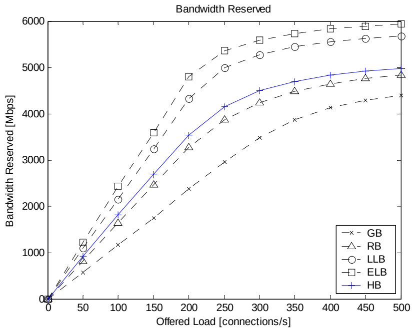
(c) Total Throughput

Figure 14. Network Performances of 15-Nodes Network

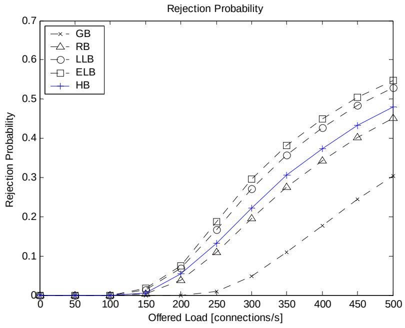
Clearly, HB model has high QoSP level as same as the LLB and ELB models. Then, it is suite for EF traffic. Besides, both link and element failures can be protected by the backup model. In case of cost and overall performance, the model is in the medium level. So, the HB model is the best choice for time-critical traffics.

CASE 5: Network Performances of 30-Nodes Network

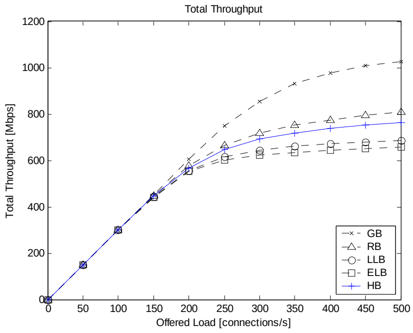
According to scalability issue, overall network performances are retested by the 30-nodes network. From Figure 15., the HB can maintain the medium level. In addition, network performances of the LLB model become more a few worse than in the 15-nodes network.



(a) Bandwidth Reserved



(b) Rejection Probability



(c) Total Throughput

Figure 15. Network Performances of 30-Nodes Network

Conclusions

In this paper, we present an approach for enhancing current MPLS resilience, called Hybrid Backup model (HB). Currently, there are three exist MPLS backup models: global, reverse and local backup models. Firstly, the global backup model is the cheapest model but it suffers from high packet losses and long restoration time. Secondly, the reverse backup improves the packet loss problem; however, the delay problem is still remaining. Thirdly, the local backup method is seemed to be the best choice in case of the minimum restoration time and packet losses, nevertheless, it has high cost in terms of number of path switch label switching router (PSL), path merge label switching router (PML), label usage, and bandwidth reserved. Therefore, we proposed a new approach based on hybrid of four switching types which are global, global reverse, local and local reverse switching types. Furthermore, branch point optimization based on Genetic algorithm is proposed. The proposed model can reduce the cost of the local backup model, while it still maintains fast restoration and low packet losses. Furthermore, it can improve some significant network performances such as bandwidth reserved, rejection probability, and total throughput. According to performance comparison between all backup models, numerical and simulation results are presented to support the proposed model.

Further research interests focus among other optimization model and improvement of routing algorithm for shared resource allocation model.

References

[1] E. Rosen, A. Viswanathan, and R. Callon, *Multiprotocol Label Switching Architecture,* RFC Multiprotocol Label Switching Architecture, January 2001.

[2] E. Mannie, ed., *Generalized Multi-Protocol Label Switching (GMPLS) Architecture*, RFC 3945, October 2004.

[3] M. Kodialam, and T.V. Lakshman, "Dynamic routing of locally restorable bandwidth guaranteed tunnels using aggregated link usage information," In: *Proceedings IEEE INFOCOM 2001: The Conference on Computers Communications-20th Annual Joint Conference of the IEEE Computer and Communications Society*, 2001.

[4] V. Shama, and F. Hellstrand, *Framework for Multiprotocol Label Switching (MPLS)-based Recovery*, RFC3469, February 2003.

[5] F. Le Facheur, ed., *Requirements for Support of Differentiated Services-aware MPLS Traffic Engineering*, RFC3564, July 2003.

[6] O. Banimelhem, J. W. Atwood, and A. Agawal, "Resiliency issues in MPLS networks," In: *CCECE 2003-Canadian Conference on Electrical and Computer Engineering: Toward a Caring and Humane Technology*, Vol. 2, pp. 1039-1042, 2003.

[7] T.M. Chen, and T.H. Oh, "Reliable services in MPLS," *IEEE Communication Magazine*, Vol. 37, No. 12, December 1999.

[8] J.L. Marzo, E. Calle, C. Scoglio, and T. Anjaili, "QoS online routing and MPLS multilevel protection: A survey," *IEEE Communication Magazines*, Vol. 41, October 2003

[9] A. Agarwal, and R. Deshmukh, "Ingress failure recovery mechanisms in MPLS network," In: *MILCOM 2002 Proceddings*, Vol. 2, pp. 1039-1042, 2002.

[10] M. Yu, and B. Xie, "An analytical availability model for MPLS networks with end-to-end IP resilience," In: *2003 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM2003),* Vol. 2, pp. 820-823, 2003.

[11] E. Calle, T. Jove, P. Vila, and L. Marzo, "A dynamic multilevel MPLS protection domain," *Third International Workshop on Design of Reliable Communication Networks*, DRCN, Budapest, Hungary, 2001.

[12] J.L. Marzo, E. Calle, C. Scoglio, and T. Anjaili, "Adding QoS protection in order to enhancing MPLS QoS routing," In: *IEEE International Conference on Communications 2003* (*ICC'2003)*, Vol. 3, pp. 1973-1977, 2003.

[13] A. Autenrieth, "Recovery time analysis of differentated resilience in MPLS," *Fourth International Workshop on Design of Reliable Communication Networks'2003* (DRCN'2003), October 2003.

[14] E. Calle, J. L. Marzo, A. Urra, and P. Vila, "Enhancing MPLS QoS routing algorithms by using the network protection degree paradigm," In: *Global Telecommunications Conference 2003*, Vol. 6, pp. 3053-3057, 2003.

[15] W. Sa-Ngiamsak, and R. Varakulsiripunth, "Local reverse backup and resiliency buffer approaches for MPLS-based recovery," *IEEE Region 10 Conference TENCON 2004*, Vol. 2, pp. 3053-3057, 2004.

[16] R. Guerin, D. Williams, and A. Orda,"QoS Routing Mechanisms and OSPF Extensions," In: *IEEE Global Telecommunications Conference-Globecom'97*, Vol. 3, pp. 1903-1908, 1997.

[17] P. Lacommea, C. Prinsb, and M. Sevauxc, "A genetic algorithm for a bi-objective capacitated arc routing problem," *Computers & Operations Research*, Vol. 33, No. 12, pp. 3473-3493, 2005.

[18] "*Mathtools.net: MATLAB/Genetic algorithms*" (n.d.) [Online]. Avaliable: http://www.mathtools.net/MATLAB/Genetic_algorithm [Accessed: January, 2011]