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Prioritized Traffic Recovery over GMPLS Networks

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Abstract- **This paper proposes the prioritized traffic recovery model for generalized multiprotocol label switching (GMPLS) networks. The network traffics are differentiated into four classes, with the highest prioritized class achieving the dedicated protection, the second prioritized class obtaining the shared restoration, the third prioritized class attaining the on-line restoration, and no recovery for the lowest prioritized class. The QoS performance of such a model is evaluated by extensive simulations. The results show that the delay sensitive traffic receives the service of the fastest recovery, the throughput sensitive traffic with light load takes longer recovery time, and the throughput sensitive traffic with heavy load experiences the lowest recovery service.**

I. INTRODUCTION

With the explosion of Internet traffic and the migration of prioritized traffic, network survivability has become a critical performance issue. There has been a recent interest in provisioning survivability in a common control and measurement plane, i.e., generalized multiprotocol label switching (GMPLS), to reduce traffic recovery redundancy resulted by assigning different recovery mechanisms to different layers [1]. Besides packet switching, GMPLS also supports the switching in the time, wavelength, waveband, and space domains. It combines IP-based control plane techniques with the provisioning capabilities of diverse switches to support enhanced network survivability.

The recovery mechanism of GMPLS provides SONET resiliency features, and thus the IP traffic could be placed directly over the WDM layer [2]. The IP signaling and routing protocols are extended by including the traffic engineering (TE) information [3] to facilitate traffic recovery. This paper proposes a prioritized traffic recovery model for GMPLS networks. The network traffics are differentiated into classes, and a different class is assigned a different recovery scheme to achieve different recovery services. The QoS performance of such a model is analyzed to delineate the tradeoff between the network resource utilization and the network survivability. We show that such a prioritized traffic recovery model is effective in achieving a good traffic recovery service differentiation.

This paper is organized as follows. The prioritized traffic recovery model is presented in Section II, followed by the performance evaluation in Section III, and the conclusions in Section IV.

II. PRIORITIZED TRAFFIC RECOVERY MODEL

The major objective of traffic recovery is to minimize the service interruptions while efficiently utilizing network resources. It is expensive to provide a high degree of recovery for all traffics. Therefore, providing differentiated recovery service is growing in importance [4]. GMPLS networks need to support a variety of service guarantees, in which a different service class obtains its corresponding degree of traffic recovery [2], [5]. Table 1 illustrates our prioritized recovery model. It defines four service classes: gold, silver, bronze, and best effort. The gold class traffic is delay-sensitive, and the network commits to deliver it with the minimum delay. The recovery scheme for the gold class traffic is dedicated path protection (DPP). DPP precomputes a *link-disjoint* backup path for each working path, and one backup path is reserved only for a specific working path, not shared with others. Upon detection of a failure, the traffic on the working path is switched into the backup path to guarantee the fastest recovery.

TABLE 1 PRIORITIZED TRAFFIC RECOVERY MODEL

Service class	Class feature	Recovery scheme
Gold	Delay-sensitive	Dedicated path protection
Silver	Throughput-sensitive (lighter loaded)	Shared path restoration
Bronze	Throughput-sensitive (heavier loaded)	On-line rerouting
Best effort	No service guarantee	None

The silver class traffic is throughput sensitive, and the network commits to deliver it with high probability. The corresponding recovery scheme is shared path restoration (SPR). SPR assigns a disjoint backup path for a working path, while the backup resources can be shared among different backup paths as long as their corresponding working paths are disjoint. Upon detection of a failure, the links along the backup path are allocated on-line. This requires recovery signaling, which is supported by GMPLS signaling protocols.

The bronze class traffic is throughput sensitive with heavier load and lower recovery priority than the silver one. On-line rerouting (OLR) is applied. OLR reroutes the disrupted traffic based on the available spare network resource information.

The best effort traffic has the lowest priority, and does not expect guarantees from the network. It is considered only after the requirement of all other types of traffics is met. Therefore, no scheme is assigned to recover it, and we will not discuss the best effort traffic recovery in this paper.

In the following, we formulate the above recovery schemes. In a network $\boldsymbol{G}(N,E)$, where N is the node set and E is the link set, define (i,j) as the link between nodes i and j; (s,t) represents the incoming traffic requirement from source node s to destination node t; (x,y) stands for the current network traffic, $(x,y)\in T$, where T is the traffic set; and P_{xy} is the working path for traffic requirement (x,y). We also assume link (i,j) supports W_{ij} channels, and an entire channel is allocated to a single traffic requirement. We define the following indicators:

$$O_{ij}^{xy} = \begin{cases} 1, & \text{if } P_{xy} \text{ uses link } (i,j) \\ 0, & \text{otherwise} \end{cases},$$

$$B_{ij}^{xy} = \begin{cases} 1, & \text{if the backup path for } P_{xy} \text{ uses link } (i,j) \\ 0, & \text{otherwise} \end{cases}.$$

Among the TE information, the advertised shared risk link group (SRLG) information is critical for resource sharing [6]. An SRLG is the set of links sharing a common physical resource. When the shared resource fails, all the links in this SRLG are disconnected. Any link in such a set is said to be in this SRLG. A path is in SRLG r if at least one of its intermediate links is in SRLG r. Two paths are *SRLG-disjoint* if neither of them is in the same SRLG. *SRLG-disjoint* paths do not share any risk. The known SRLG information is:

r: SRLG r, $r\in R$, where R is the SRLG set,

$$L_r^{xy} = \begin{cases} 1, & \text{if } P_{xy} \text{ is in SRLG } r \\ 0, & \text{otherwise} \end{cases},$$

$$Z_r^{ij} = \begin{cases} 1, & \text{if link } (i,j) \text{ is in SRLG } r \\ 0, & \text{otherwise} \end{cases}.$$

A. Gold Class Traffic Recovery

DPP is assigned to the gold class traffic. To survive all of the intermediate single failures in the working path and to prevent the working and backup paths from failing at the same time, the backup path must be *SRLG-disjoint* and *link-disjoint* from its corresponding working path. The known parameters in DPP include: network topology $\boldsymbol{G}(N,E)$, current traffic set T, working paths configuration for current traffic O_{ij}^{xy}, and SRLG information L_r^{xy} and Z_r^{ij}. The primary working path for the incoming traffic requirement from s to t, i.e., P_{st}, is determined by the shortest path routing algorithm, and the corresponding path configuration indicator O_{ij}^{st} is known. The problem is to determine the backup path indicator B_{ij}^{st} and minimize the resources employed for the backup path from s to t. That is,

Objective:

$$\text{Minimize} \sum_{(i,j)\in E} B_{ij}^{st} \quad . \tag{1}$$

Such a minimization objective is subjected to several sets of constraints. The flow continuity constraints shown in Eq. (2) guarantee that in the backup path from s to t, source node s only has outgoing flow, destination node t only has incoming flow, and the flow at the intermediate nodes is balanced.

$$\sum_{j\in N} B_{ij}^{st} - \sum_{j\in N} B_{ji}^{st} = \begin{cases} 1, & i=s \\ -1, & i=t \\ 0, & i\neq s,t \end{cases} . \tag{2}$$

The *SRLG-disjoint* constraints in Eq. (3) impose the backup path being *SRLG-disjoint* from its working path. The *link-disjoint* constraints in Eq. (4) guarantee the backup path being *link-disjoint* from its working path. Besides *link-disjoint* from its working path, such a backup path should also be *link-disjoint* from the current working paths as indicated in Eq. (5),

$$B_{ij}^{st} L_r^{st} Z_r^{ij} = 0 \qquad \forall (i,j)\in E \quad \forall r\in R. \tag{3}$$

$$O_{ij}^{st} B_{ij}^{st} = 0 \qquad \forall (i,j)\in E. \tag{4}$$

$$O_{ij}^{xy} B_{ij}^{st} = 0 \qquad \forall (i,j)\in E \quad \forall (x,y)\in T. \tag{5}$$

The link capacity constraints in Eq. (6) ensure the sum of the working and the backup traffic on a link is no more than the link capacity W_{ij}.

$$\sum_{(x,y)\in T} (O_{ij}^{xy} + B_{ij}^{xy} + O_{ij}^{st} + B_{ij}^{st}) \le W_{ij} \qquad \forall (i,j)\in E. \tag{6}$$

B. Silver Class Traffic Recovery

SPR is assigned to the silver class traffic, in which the backup path is not dedicated. Under the assumption that at most one failure occurs at any time, spare resources can be shared among disjoint (both *SRLG-disjoint* and *link-disjoint*) working paths as many as possible to achieve higher efficiency. Here, the known parameters are the same as DPP, and SPR is formulated as

Objective:

$$\text{Maximize} \sum_{(i,j)\in E} \sum_{(x,y)\in T} B_{ij}^{st} B_{ij}^{xy} \quad . \tag{7}$$

Two backup paths share the same link if $B_{ij}^{st} B_{ij}^{xy} = 1$, and maximizing such sharing among the backup path is the objective of SPR. The same flow continuity constraints of Eq. (2) as in DPP apply for SPR. The *SRLG-disjoint* constraints in Eqs. (8) and (9) impose the backup path being *SRLG-disjoint* from its working path. A working path and its corresponding backup path are *SRLG-disjoint iff* $B_{ij}^{st} L_r^{st} Z_r^{ij} = 0$. Two working paths are *SRLG-disjoint* if $\sum_{r\in R} L_r^{st} L_r^{xy} = 0$. The *link-disjoint* constraints in Eq. (10) ensure the backup path being *link-disjoint* from its working path.

$$B_{ij}^{st} L_r^{st} Z_r^{ij} = 0 \quad \forall (i,j)\in E \ \ \forall r \in R. \tag{8}$$

$$\left(\sum_{r\in R} L_r^{st} L_r^{xy}\right) B_{ij}^{st} B_{ij}^{xy} = 0 \quad \forall (x,y)\in T \ \forall (i,j)\in E. \tag{9}$$

$$O_{ij}^{st} B_{ij}^{st} = 0 \quad \forall (i,j)\in E. \tag{10}$$

The link capacity constraints in Eq. (11) ensure that one channel supports at most one working path, while it may support several backup paths if possible. Moreover, the sum of the working and the maximum backup traffic on a link is upper-bounded by the link capacity W_{ij}.

$$\sum_{(x,y)\in T} O_{ij}^{xy} + O_{ij}^{st} + \max_{(x,y)\in T} \{B_{ij}^{xy}, B_{ij}^{st}\} \le W_{ij} \quad \forall (i,j)\in E. \tag{11}$$

C. Bronze Class Traffic recovery

OLR recovers the bronze class traffic after a single link failure has been detected. Network link state information, especially the bandwidth availability, is necessary to reroute. The known parameters include: the network topology ***G***(N,E), the current traffic set T, the working paths configuration for the current network traffic O_{ij}^{xy}, and the SRLG information L_r^{xy} and Z_r^{ij}. The followings about network failure are also known:

$\underline{T}$: the disrupted traffic(s),

$\underline{E}$: the failed link.

OLR aims to employ the least network resources to recover the traffic interruption. To avoid further traffic disruption, the rerouting path is disjoint from the untouched working path. Such a problem is formulated as

Objective:

$$\text{Minimize} \sum_{(i,j)\in E-\underline{E}} \ \sum_{(s,t)\in \underline{T}} B_{ij}^{st}. \tag{12}$$

In the rerouting path, the same flow continuity constraints in Eq. (2) are applied. The *SRLG-disjoint* constraints in Eq. (13) impose the rerouting path being *SRLG-disjoint* from all of the working paths. The link capacity constraints in Eq. (14) ensure that the sum of the working traffic and the rerouting traffic in a link is upper bounded by the link capacity.

$$B_{ij}^{st} L_r^{xy} Z_r^{ij} = 0 \quad \forall (s,t)\in \underline{T} \ \forall (x,y)\in T-\underline{T} \ \forall (i,j)\in E-\underline{E} \ \forall r\in R. \tag{13}$$

$$\sum_{(x,y)\in T-\underline{T}} O_{ij}^{xy} + \sum_{(s,t)\in \underline{T}} B_{ij}^{st} \le W_{ij} \quad \forall (i,j)\in E. \tag{14}$$

III. Results and Discussions

Simulations are conducted in the NSFNET with 14 nodes and 21 bidirectional links. Each link contains 8 channels. 6 SRLGs are placed in the network with each SRLG containing 2 links in the network, and the corresponding SRLG information is advertised among the control plane. Dynamic traffics are accommodated with each traffic possibly terminating after a certain duration. The source and destination nodes are evenly distributed among all nodes, and each traffic occupies one channel bandwidth. Among all traffics, the probabilities of the gold, silver, bronze and best effort class traffic are 10%, 20%, 30%, and 40%, respectively. The backup paths for the gold class traffic is preconfigured to ensure the shortest routing and the disjoint constraints. The backup path for the silver class traffic is predecided while on-line configured. The recovery path for the bronze class traffic is computed after a failure has been detected.

The major parameter of QoS performance investigated is the *recovery time*. *Recovery time* is the time between the failure occurrence and the time that the disrupted traffic is recovered. Such an interval is indicative of the potential data and revenue loss, and depends on the failure location, the recovery scheme, and the propagation delay along the backup path. *Recovery time* of different traffic is collected by initiating single link failures on all links one by one. We assume failure detection time D and failure notification time C are both randomly distributed from 0.1 to 0.2*ms*. Traffic switching time S indicates the time duration that the traffic is successfully switched from the disconnected path to the backup path, and varies in the range from 1 to 2*ms*. The bronze traffic takes on-line processing time K to decide the rerouting path, and K ranges from 100 to 300*ms* in our simulation. Intermediate link reservation is necessary when recovering the silver and bronze traffic. We assume the time of reserving a link is exponentially distributed with mean β.

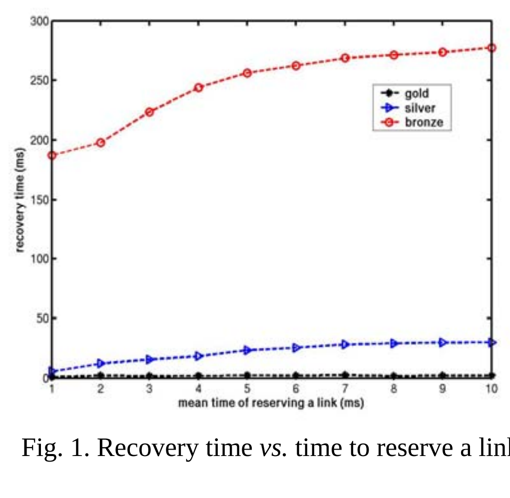

Fig. 1. Recovery time *vs.* time to reserve a link.

As shown in Fig. 1, the *recovery time* for the silver and bronze class traffic increases as the mean time of reserving a link, i.e., β, is longer. The service of *recovery time* for different traffic is classified as: the gold class obtains stable and the fastest recovery, the silver class achieves the medium class recovery which depends on the average link reservation time, and the bronze class takes the longest *recovery time*. The reason is that all the intermediate switches are preconfigured in the recovery path of the gold class traffic, and thus the *recovery time* is independent of the link reservation time. The other two classes take more time for traffic recovery, for they need to reserve the links on the recovery path after a failure occurs. The *recovery time* of the bronze class traffic is the longest one, and most of the time is spent on the recovery path computation.

IV. Conclusions

The prioritized traffic recovery model has been proposed to provide service differentiation over GMPLS networks. The delay sensitive traffic is assigned as the gold class traffic, and the network commits DPP to recover it. The throughput sensitive traffic is classified into silver and bronze classes. For the silver one that has lighter load, SPR is employed to restore the disconnected traffic; for the heavily loaded bronze class traffic, OLR is adopted. There is no recovery commits for the best effort traffic. Simulations have demonstrated that the service differentiation with respect to *recovery time* is held with the gold class traffic obtains the fastest recovery service, the silver one attains the middle level recovery service, and followed by the bronze one.

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