Impact of Path Granularity and Operation Interval on Dynamic Path Network Control

Hiroyuki Ito, Hiroshi Hasegawa, Ken-ichi Sato
Dept. of Electrical Engineering and Computer Science, Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan
h_ito@echo.nuee.nagoya-u.ac.jp, {hasegawa, sato}@nuee.nagoya-u.ac.jp

Abstract: We investigate the effect of path granularity and operation interval on dynamic path network operation with the aim of minimizing unused capacity and operation frequencies. We use various Internet traffic data sets to clarify the relations, and elucidate the general trends that enable us to effectively implement dynamic path control.

1 Introduction

Internet traffic continues to increase rapidly all over the world. In order to efficiently utilize network resources, path layer control must be responsive to the Internet traffic changes. Typical path operation granularities in current backbone networks are VC-3/4 in SONET/SDH networks and Label Switched Path (LSP) in MPLS networks. Currently, larger bandwidth paths, optical paths that carry 2.5 Gbps or 10 Gbps, are widely implemented using ROADMs. Thus, we have different levels of path granularities to manage. Furthermore, recent advances in network control technology based on GMPLS [1] allow us to dynamically control paths with different granularities through a unified interface. Dynamic path operation enables us to adapt the number of optical path connections to fluctuating traffic volume and, as a result, more effectively utilize the limited network resources, which will be essential in creating future networks that can accommodate explosive increases in traffic cost-effectively.

When we consider the dynamic path operation scenario, it is desirable to minimize both unused capacity in each path and the number of path operations since the former increases total traffic volume that can be accommodated in the network and the latter minimizes operation cost and related mishandling. They have, however, a trade-off relation. We can achieve both objectives simultaneously only by selecting the proper path granularity and the operation interval. We also need to develop an algorithm that can estimate the necessary and sufficient number of paths in the near future by using observed traffic volume data. To the best of the authors' knowledge, only a few works [2] have presented primitive optical path operation algorithms; no paper has resolved the path granularity optimization problem.

The objective of this paper is to develop a principle for path granularity that permits efficient optical path operation. Here we assume fixed path granularity for simplicity, and hence total path bandwidth is measured by the number of paths. The discussion can be easily extended to variable bandwidth paths such as LSPs. Since the path granularity and the path operation algorithm are closely related, we first develop a simple algorithm to estimate the number of paths necessary by using the current magnitude of the low-frequency component of traffic change and the standard deviation of the high-frequency component. We then evaluate the performance on several sequences of traffic data obtained from different types of networks that accommodate business, home, and university users. We demonstrate that regardless of the network type, a range of path granularities exists that can effectively reduce both the number of path operations and the unused capacity.

2 Dynamic path control algorithm

In the following, we focus on path control operations at a link using past traffic volume information. We assume that the capacity of each path, C, is uniform and fixed. We also assume knowledge of the averaged traffic volume, $trf(n)$, and the peak traffic volume, $peak(n)$,between $n-1$ and n, where $\{\ldots, n-1, n, n+1, \ldots\}$ is a set of equally spaced time samples. Our objective is to determine the number of paths necessary, $m(n+1)$, at time $n+1$ using only the information of past traffic volumes, $\{\ldots, trf(n-1), trf(n)\}$. The number of paths should satisfy $m(n)C \geq peak(n)$ while keeping unused capacity $m(n)C - trf(n)$ sufficiently small. It has already been known that network traffic exhibits long range dependency [3, 4] and it is hard to exactly predict traffic volume at the next time instant. Thus we divide the traffic volume into a slowly changing component $l_{\mathrm{trf}}(\mathrm{n})$ and fluctuating noisy component $trf(n) - l_{\mathrm{trf}}(n)$. $l_{\mathrm{trf}}(\mathrm{n})$ is extracted by applying a typical low-pass filter, the Butterworth filter [5]. Next, we approximate the averaged traffic volume at the next time instant $n+1$, $\widehat{trf}(n+1)$, by $l_{\mathrm{trf}}(\mathrm{n})$ since we can expect that $l_{\mathrm{trf}}(n) \approx l_{\mathrm{trf}}(n+1)$. Let σ be the standard deviation from $\widehat{trf}(n)$ to $trf(n)$, i.e. the square root of average of squared error between the series. This parameter mainly characterizes the behavior of the high-frequency component. With a fixed positive value t, the number of paths necessary at $n+1$ is predicted by

$$m(n+1)C < \widehat{trf}(n+1) + t \times \sigma \leq (m(n+1)+1)C.$$

If the error follows a normal distribution, t=3 gives the violation probability $\approx 0.13\%$. In the next section, we discuss the importance of selecting C.

3 Numerical experiments

(1) Effect of path granularity

As we mentioned in the previous section, we focus on the path control operation on a link as a first step. We assessed four sets of traffic volume data for a day observed in different environments. The data set "Home" was observed at a link in an ISP backbone network that accommodates home users [6]. The data set "Business" was observed in a private network for corporate customers. The data set "University" was observed at the University of Leipzig Internet access link [7]. The data set "WIDE_2008" was a trace of a trans-Pacific line in the WIDE backbone network in 2008 [8]. Set resolution is 5 minutes. In this experiment we assume that *peak*(n) is equal to *trf*(n). The cutoff frequency was set to 60π radians per day and threshold t was set at 3. The standard deviation σ was evaluated on the same data in advance. Each set consisted of 288 samples (i.e. one day) and the first 6 samples were used only to stabilize the output of the low-pass filter. Therefore, we used the remaining 282 data samples. Hereafter, the volume data is normalized by its maximum value and the path capacity C is also normalized by its maximum. We evaluate the number of traffic samples exceeding $\widehat{trf}(n)+t\sigma$, which means that buffering is necessary to accommodate the traffic. In each traffic volume data set, the violation times were less than three among the 282 samples, in other words, about 1.1%.

Figure 1 shows the variations in the frequency of path operations and the average of normalized unused bandwidth subject to C. Very similar tendencies are observed among the four different traffic sequences. As C increases, the number of path operations decreases drastically whiles the average of unused bandwidth increases linearly. Thus, $0.1 \le C \le 0.2$ is regarded to be the sweet spot in terms of achieving effective bandwidth control. The best C value in terms of cost can be determined from this investigation when operational cost and facility cost are given.

(2) Effect of the interval of controlling path

In this section, we show the results gained from three traffic volume data sets; captured over one day with resolution of 100ms. The data set "WIDE_2006" was taken from a link in the WIDE backbone in 2006 [8]. Operation intervals were set at 100ms, 10s, 60s, and 300s. For each interval, *trf*(n) is the average over the interval while *peak*(n) is the maximum value of the original data within the interval. The standard deviation σ is calculated every 100ms for all operation intervals. The first 18,000 samples were used only for stabilization. The volume data is normalized by the maximum value of the data whose interval is 5 minutes. Other conditions are the same as in the previous experiment.

Figure 2 shows the result of "WIDE_2008". The other two data sets show almost the same trend. Fig. 2 demonstrates that changing the interval from 100ms to 300s has little impact on path operation frequency and the average of unused bandwidth. Table 1 shows the results for three traffic volume data sets for all operation intervals when normalized path capacity is 0.1. The results indicate that the operation interval of 5 minutes (300s) should be chosen to minimize the operational cost for the traffic tested.

Table 1 Comparison of traffic patterns (normalized path capacity is 0.1)

	The number of path operation				Average of unused bandwidth			
Interval / Traffic data	100ms	10s	60s	300s	100ms	10s	60s	300s
University	34	34	34	32	0.387	0.387	0.387	0.387
WIDE_2006	31	31	31	31	0.301	0.301	0.301	0.303
WIDE_2008	40	40	40	44	0.556	0.556	0.556	0.557

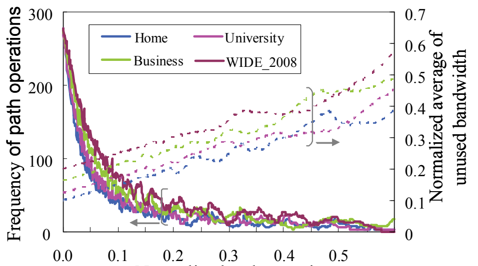

Fig. 1 Effect of path granularity

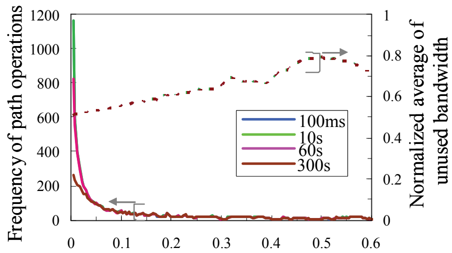

Fig. 2 Effect of operation interval

4 Conclusion

We investigated the relations among path granularity, operation interval, and unused path capacity for dynamic path control. It was demonstrated that several different traffic volumes exhibit common trends. The results enable us to effectively determine the best path control granularity considering operational cost and facility cost.

5 References

[1] IETF, RFC 3945, "Generalized Multi-Protocol Label Switching (GMPLS) Architecture", Oct. 2004
[2] S. Yamamoto, I. Shake, T. Kurahashi, Y. Tarui, W. Imajuku, Y. Tsukishima, K. Sasayama, O. Moriwaki and M. Fukutoku, "Theoretical and Experimental Study of Statistical-Decision Method for Link-Capacity Adjustment", IEEE JLT, vol 25.no.9, pp.2864-73, Sep. 2007
[3] S. Mallat, "*A WAVELET TOUR OF SIGNAL PROCESSING*", Academic Press, ISBN 0-12-466606-X, 1999
[4] W. Leland, M. Taqqu, W. Willinger, and D. Wilson, "On the Self-Similar Nature of Ethernet Traffic(extended version)," IEEE/ACM Trans. on Networking, vol.2, no.2, pp.1–15, Feb. 1994.
[5] A. V. Oppenheim and R. W. Schafer, "*DISCRETE-TIME SIGNAL PROCESSING*", Prentice Hall, ISBN 0-13-083443-2, 1999.
[6] http://qos.plala.or.jp/traffic/flets/
[7] http://pma.nlanr.net/
[8] http://mawi.wide.ad.jp/mawi/