Handling IP Traffic Surges via Optical Layer Reconfiguration

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Abstract: Through a dynamically reconfigurable optical layer, we propose a simple approach to handle traffic surges in IP networks. Its effectiveness is established by analysis of data traffic in a large ISP.

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1. Introduction

Large Internet Service Providers (ISPs) are in the process of upgrading their links from lower rates, (e.g., 45Mb/s to 620Mb/s) to above 2.5 Gb/s. The lower speed links are characteristically routed over Digital Cross-connect Systems (DCSs) and/or SONET OC-48/OC-192 (SDH STM 16/64) rings. However, almost all the higher speed links that have been installed today are routed directly onto Wavelength-Division Multiplexing (WDM) systems. Optical Cross-connects (OXCs) are now becoming available on the market, some with photonic fabrics and some with electronic fabrics. This OXC layer, along with distributed signaling and routing capabilities, can establish connections quickly and on-demand. This ability, coupled with a signaling mechanism between the routers and OXCs, such as the User Network Interface (UNI) [1], establishes the foundation for a rapidly "reconfigurable" topology for the IP layer (see [2]). While most managers of large ISP networks agree that at some point in time the volume of high-speed links that needs to be provisioned will mandate their deployment over an OXC layer, they are also keenly concerned about containing costs. Consequently, they are looking for other concrete advantages to accelerate this deployment, as well as justify the need for such a dynamically reconfigurable topology.

We have identified three potential advantage areas for establishing IP-layer links over a reconfigurable OXC layer: 1) more efficient restoration at the OXC layer or through integrated OXC-layer and IP-layer restoration 2) establishment of temporary IP-layer links for high bit rate IP data flows and 3) the ability to rapidly change the IP topology in response to IP traffic shifts or very long bursts, which we call ***surges***. We have studied item 1), restoration, and report the results in another paper [3]. Because of the characteristically low rate of access links (business or residential) and early evolution of high-bit rate applications, item 2) is still under study. This paper examines the third area of potential advantage and, in particular, the existence of sustained traffic bursts or temporary link overloads that could take advantage of the optical layer's ability for fast reconfiguration. First, we report on our evaluation of data to determine the characteristics of traffic surges. Then we investigate the opportunity for the optical layer to handle them. A simple burst handling mechanism is proposed and evaluated. See [4] for other studies of ISP network traffic patterns.

2. Network Topology and Traffic Data

Our studies focus on a backbone (inter-city) network. We analyzed traffic measurements based on SNMP incoming and outgoing byte counts from all router-to-router backbone links in a large ISP: 19 different cities with 41 OC-48 backbone links. Some router pairs have multiple OC-48 links and share load. The byte counts were polled at five minute intervals and were converted to bit rates using linear interpolation. Measurements were taken over a seven month interval.

3. Definition of a Traffic Surge

We define that a traffic surge has occurred when the traffic load on a link exceeds 40% of the normal load. For example, if a link usually operates at 1 Gb/s, and the bandwidth increases above 1.4 Gb/s, then this qualifies as a surge. We define the normal bandwidth level by using a moving average of the daily maximum (averaged over a one week interval). By using this definition, the threshold of a surge is resilient to link upgrades or routing protocol updates which effect link utilization levels. For example, if the utilization of a link is typically 50% (i.e., the "normal" maximum traffic load is 50% of capacity), a surge happens when link utilization exceeds 70% for a sustained period. To further refine the definition and to filter out measurement errors, the following more detailed criteria must be met for a measured traffic burst to qualify as a surge. 1) All links that share load between a pair of routers must experience the burst. 2) The maximum load period of the burst is less than link capacity (a boundary condition). 3) The burst lasts for at least 15 minutes (3 measurement intervals). This prevents detection of a false surge caused by an erroneous jump of byte counts. Because of linear interpolation, one erroneous byte count jump will effect up to three consecutive bit rate computations. 4) The duration of the burst ends when the load falls below the normal level or stays between the normal and burst threshold level for more than 30 minutes (6 measurement intervals). This definition allows the load of a surge to decrease temporarily.

Fig. 1 shows an example of surges between two large cities. The dotted line illustrates the moving average of the normal link utilization. Using the data set described in Section 2 and the definition of surges given above, we detected all the surges and calculated distributions for the following measurements: surge inter-arrival time, duration, and magnitude (load).

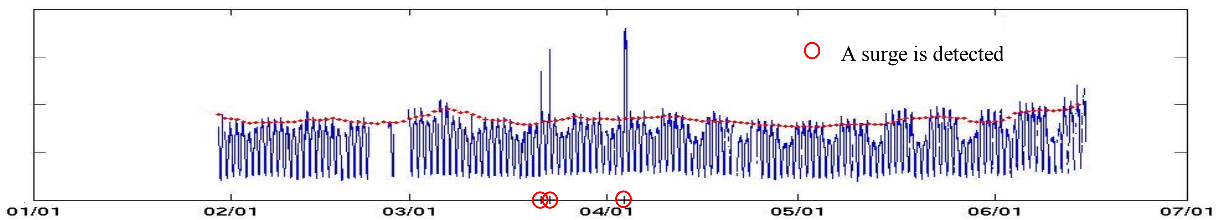

Fig. 1. Surge detection on a large inter-city link

Table 1 gives the first and second order statistics of these distributions. For the surge magnitude, we normalized the "normal" utilization on all links to 50% of link capacity. Therefore, the unit of surge magnitude is the percentage of link utilization with respect to the 50% "normal" load level.

Table 1. Surge Attributes

Surge Attributes	Bin Width	Median	Mean	Std Deviation
Interarrival Time	51 hours	7 days	26 days	39 days
Duration	7 minutes	40 minutes	1:50 hours	2:15 hours
Magnitude	9%	82%	98%	68%

These surge attributes show that traffic surges are significant. The data we examined suggest that surges happen about once a month on average, and more than half of the time they will take up all the bandwidth on a link.

4. Methods to Handle Surges

To maintain consistent network performance of the ISP network, four possible approaches can be taken to handle this surge phenomenon: 1) Eliminate or reduce sources of surges. 2) Maintain link utilization low enough to accommodate the magnitude of most traffic surges. For example, hypothetically suppose that to maintain network performance, the link utilization over maximum load periods should not exceed 50%. If we wish to accommodate surge magnitudes up to 40% of normal maximum, then we must install enough capacity so that the link utilization under normal load periods does not exceed 35.7%. 3) Dynamically reroute traffic at the IP layer over less loaded links. 4) Augment IP-layer link capacity via a reconfigurable OXC layer. Although it may be possible to accomplish approach 1), we note that occasional focused traffic overloads have long been a characteristic of circuit-switched networks in which the approach has been to accept their existence and methods have been implemented over the years to handle them, such as dynamic routing and network management techniques. Approach 2) will prove to be expensive. Approach 3) may be fruitful, but assuming that an OXC layer is eventually deployed, it may not be as attractive as approach 4) because it requires implementation of more sophisticated routing than commonly exists in today's IP networks. Moreover, approach 3) may prove to be more costly since it requires ***ubiquitous*** and ***fixed*** link capacity, whereas approach 4) makes more flexible use of capacity. Therefore, we propose a method for approach 4).

When we analyze the surge magnitude distribution, we find that the addition of one extra, temporary link between affected router pairs will support up to 97% of all surges. Furthermore, we find that if the additional link lasts as long as 6 hours, 90% of all surge cases can be effectively handled. If we assume a reconfigurable OXC layer, as described previously, then a method to accomplish this is to place one unassigned port (wired to an OXC) on each backbone router.

When a surge is detected between a pair of routers, one of the routers can dynamically create a new link (between the OXC ports that interface to the unassigned router ports) by requesting a connection from the OXC layer via inter-layer signaling, such as the OIF UNI. Surge detection may follow guidelines similar to those in Section 3. If we assume that extra (spare) capacity exists in the OXC layer for normal provisioning, then this spare capacity is borrowed to route and set-up the connection request by the OXC layer. A key to this approach is the capability of routers to auto-configure links. Such a capability could be enabled by implementation of a Link Management Protocol (LMP) in the IP layer (see [1]). When the surge passes, the router signals the OXC to disconnect, the connection is torn down by the OXC layer, the temporary IP-layer link is removed, and the router ports are returned to the unassigned state. The duration of the connection can either last for a fixed time or vary, equal to the duration of the surge itself. Since only one port is available at each router, the effectiveness of this method depends on the occurrence of ***simultaneous surges*** on the same router. A measurement interval is defined to have simultaneous surges if there are at least two surges that involve the same router occurring during that interval. Our analysis found a total of 44 simultaneous surges (over 819 measurement intervals) out of 592 surges (over 4071300 measurement intervals) during the entire data set. Simultaneous surges only occurred on eight out of 37 backbone routers and never occurred on more than two links at once. They are therefore negligible over our data set.

To capture the effect of a fixed connection time on simultaneous surges, we define a measurement interval to be ***blocked*** if, during the interval that a connection is created to alleviate a surge, a surge occurs over another router pair, one of which coincides with an endpoint router of the connection. Note that by definition all measurement intervals with simultaneous surges will be blocked. However, under a fixed connection duration, there may be intervals that do not have simultaneous surges, yet are blocked (because the surge for which the connection was created has subsided, yet the connection persists). Therefore, a lower bound for the number of blocked intervals is the number of simultaneous surges (819), which also coincides with the number of blocked intervals when the connection time is allowed to vary with the duration of traffic surge. The left graph of Fig. 2 shows how many blocked measurement intervals occur as a function of fixed connection duration. Decreasing the connection duration reduces the number of blocked surges at the expense of more connection setup overhead. The right graph shows how many connections must be set up as a function of the fixed connection duration. Therefore, the best policy (if possible) is to maintain the spare connection until each surge subsides. This achieves the least possible number of blocked surges while keeping the overhead of spare connection setup moderate.

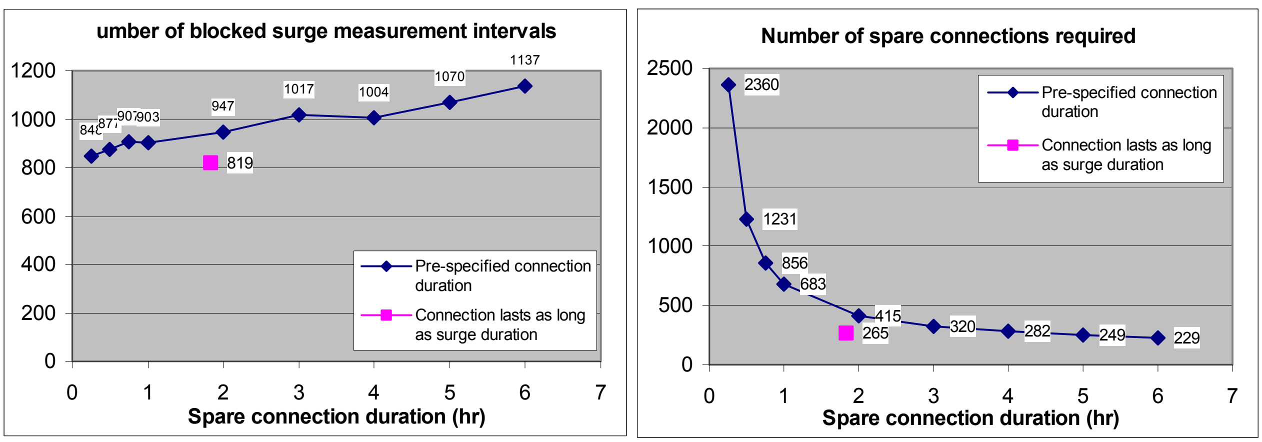

Fig. 2. Number of blocked surges and required spare connections as a function of spare connection duration

5. Conclusion

We proposed a simple method to handle IP-layer traffic surges by rapidly augmenting IP-layer link capacity over a rapidly reconfigurable optical cross-connect layer. We established both the need for this approach as well as its effectiveness by analyzing the statistical properties of actual traffic surges in a large ISP network.

6. References

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