A Case Study on Evaluating the Benefits of MPLS Traffic Engineering through Constraint-Based Routing and Network Controls

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ABSTRACT

In this paper, we attempt to understand the benefits of MPLS traffic engineering through a case study. Specifically, we do a comparative study of MPLS traffic engineering in the presence of constraint-based routing compared to destination-based routing. For this case study, we use an actual data set obtained from a real-life network. Different control schemes that can be deployable for MPLS traffic engineering are also considered. This case study shows that services can indeed obtain benefits from constraint-based routing and traffic engineering controls.

I INTRODUCTION

In the last couple of years, multi-protocol label switching (MPLS) has emerged as a viable technology for the backbone Internet. An important feature of MPLS is the ability to set up label switched paths for different services to reserve bandwidth, if and when needed. Further more, the possibility of doing constraint based routing in general, and for specific services, if needed, is another attractive feature.

The IETF literature (both RFCs and Internet drafts) has been deluged recently with various aspects and capabilities of MPLS [6] and the use of various features that allow deployment of controls and architectures such as virtual private networks [7]. While most of these works describe the benefits in a qualitative manner (sometimes, from the point of view of “good features”), very few discuss the actual quantitative benefit. For example, there is a school of thought that believes that MPLS is not necessary; the current best-effort routing (rather destination based routing) is good enough if enough bandwidth is available in the network. Further, there is very limited work that discuss whether different controls that can be deployed in a MPLS environment for traffic engineering are actually beneficial from the network performance standpoint.

Given this debate, we have set out to study these trade-offs. Our approach is basically simple. Consider an actual network with given topology where multiple different services are already provided and where we have a good idea of the traffic mix. The question we posed: “How would different services receive grade-of-service depending on a combination of routing possibilities and various network controls that may be placed (if MPLS is used) for traffic engineering?” In this sense, our work is a case study. The actual data used in this study is similar to Sprint’s nationwide backbone network.

Through this case study, we attempt to gain some insight into the tradeoffs. By no means, do we address all the possible issues regarding deployment or capabilities of MPLS, such as signaling exchanges. We study the performance by different services in this example network, especially if a particular service class receives the best grade-of-service.

The rest of the paper is organized as follows. First, we discuss the different scenarios considered in our study such as destination-based routing, and different constrained-based routing schemes (with path caching). We then discuss different logical and partial sharing of link bandwidth concepts that can be deployed in a MPLS-based network for traffic engineering (note that how the actual labels may be used to deploy these concepts is outside the scope of the present paper.) In the section III, we discuss the network topology and data, and the performance metrics. The results are presented in section IV. We close with a summary of our observation for the case study in section V.

II VARIOUS SCHEMES

In this section, we will discuss the various traffic engineering schemes used to manage networks and bring out the differences and similarities between these methods.

A Destination Based Routing (DBR)

Destination-Based Routing, also referred to as Hop-Count Routing, uses hop count as the only metric and chooses the path with minimal hops. So, if a node-pair generating traffic has a direct link connecting them, alternate paths will never be used unless the direct link fails.

B Constraint Based Routing (CR)

Constraint-based routing schemes attempt to find a path that satisfies one or more constraints of interest and that is optimal with respect to some scalar metric. The constraints can

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include residual bandwidth, delay, jitter, administrative policies, etc. While a feasible path can be selected using a simple hop-count based algorithm, additional constraints can be considered to improve the resource utilization by load balancing to a certain extent. By imposing state varying constraints, updates on present availability on the links is necessary for all nodes in the network in order to route incoming flows. One of the major factors affecting the performance is the periodicity of these updates. If the period between successive updates is too long, the bandwidth availability information is no longer valid. So, the flows can get blocked even if the best path (according to the last update) is chosen. As an offset, crankback mechanism (used in Telephone networks) can be supported by the routing mechanism by trying another path without dropping immediately. Since crankback involves signalling overhead, maximum number of crankbacks should be limited to one or two.

The routing computation framework [1] discussed here consists of three phases. In the first phase, a set of shortest paths are computed based on simple hop count and cached by every source to all possible destinations on the network, Preliminary path Caching (PPC). In the second phase, the cached paths are ordered from most acceptable to least acceptable path (e.g., in terms of residual bandwidth), Upadated Ordering Phase (UOP). The third phase, selects a specific route among the ordered paths to attempt a newly arrived flow, Actual Route Selection. The routing schemes are explained here with respect to this framework.

- **Dynamic Random Routing (DRR)** - This scheme is a simple and an efficient routing scheme based on the Dynamic Alternate Routing [3]. In the PPC phase, a set of paths is cached based on the K-shortest path algorithm. There is no UPO phase. For the ARS phase, at any time, the routing table maintains two paths: the direct path and an alternate path. A newly arriving flow tries the direct path first, if it exists and if the bandwidth can be guaranteed. Otherwise, the flow tries the alternate path and leaves the system if it gets blocked. If a newly arrived flow gets blocked and cleared, the alternate path is reset and a new path is chosen randomly from the cached paths for future flows. On the other hand, if the flow is accepted on the alternate path, the path is maintained.

- **Maximum Available Capacity Routing with Periodic updates and Crankback (MACRPC)** - In this scheme, PPC phase is similar to that of the DRR scheme. In the UPO phase, the paths are sorted from most available bandwidth to least available bandwidth paths. This is done periodically with period being the routing update interval. In the ARS phase, a path with maximum available bandwidth is chosen. But, if a direct path exists, the direct path is chosen irrespective of the bandwidth availability on it. When the flow is blocked on the selected path, it is crankbacked and tries the next best path.

- **Maximum Available Capacity Routing with Periodic updates and No Crankback (MACRPNC)** - This routing scheme is very similar to MACRPC, except that, when a flow fails on the second or subsequent links of the first path chosen, the flow is blocked and not allowed to crankback in the ARS phase.

- **Maximum Available Capacity Routing with Instantaneous Computation (MACRIC)** - This utopian routing scheme is of theoretical interest. In the PPC phase, a set of paths are computed and cached. When a new flow arrives, the entire network is scouted to find a path with the most available bandwidths. This process is repeated for every new flow arriving into network. From the framework perspective, the UPO phase is merged with the ARS phase.

### C Traffic Control

- **Trunk Reservation (TR)**

  Trunk reservation [2] is a simple call admission control scheme that favours direct traffic. When the available bandwidth on a link falls below a particular threshold value, the alternately routed flows will be blocked even if the flow can be accommodated. In essence, once the threshold value is reached, only the direct traffic has access to the link. The threshold is set as a percentage of link bandwidth.

- **Service Class based Trunk Reservation (SCTR)**

  In the previous case, all flows belonging to direct traffic are treated equally in accessing the TR area. In the SCTR approach, only flows belonging to the GoS stringent service class have access to the link once the threshold is reached. This means, the non-GoS stringent class flows will be blocked similar to alternately routed flows, even if they are direct flows.

- **Service Class based Multi-Link Trunk Reservation (SMTR)**

  SMTR extends the SCTR approach by allowing both direct and overflow traffic of GoS stringent service class to access the TR area. This means, alternately routed flows of a GoS stringent class still can access the link in addition to the direct flows of a GoS stringent class when the available bandwidth falls below the threshold.

- **Pseudo Partition**

  Every link has a reserved area of bandwidth as a percentage of total link bandwidth for GoS stringent service class. The arriving flows of GoS stringent class access the reserved area first. If the reserved area cannot accommodate the new flow, the new flow is allowed to try the common area. It is a minor variant of the SMTR scheme in the order in which a flow from a GoS stringent class tries various regions for available bandwidth.

- **Partitioning**

  Due to different characteristics like delay requirements, loss requirements, different classes of service need to be treated differently by the network. The links are partitioned to construct many overlay networks based on the ratio of service classes rates and their respective requirements. Each service class has its own partitioned area.
III SIMULATION ENVIRONMENT AND NETWORK SETUP

We have extended the Multi-Service Dynamic Routing Simulator (MuSDyR) [5]. There is no packet level detail in this simulator which allows us to simulate thousands of simultaneous flows in an efficient manner. The simulator supports many service models from which service classes can be constructed. The models differ in the parameters that characterize their bandwidth requirement. Some of the implemented models include Constant Bit Rate (CBR), Uniform Constant Bit Rate (UCBR) and Variable Bit Rate (On-Off model). The flows are assumed to follow Poisson arrival processes with exponential holding times.

The network we considered comprised of 15 nodes spread over 9 sites connected by 58 links. Only 37 source-destination pairs are generating traffic and they always have a direct link between them, although its speed might not be comparable to the offered traffic. We took a snap-shot of traffic and hence it is not representative of the performance of the network at all times.

A Traffic Classes

The network traffic is comprised of four service classes and each node pair has a different input values for the given service class traffic. Each class sees its own routing table and makes its decision based on the status of the paths and the GoS requirement. The ratio between the bandwidth level loads of service classes is CBR:UBR:VBR-NRT:VBR-RT::4.9:4.5:90.6:0.008. The four classes are explained below from the perspective of effective bandwidth requirement:

- Constant Bit Rate (CBR): CBR is constructed from the UCBR traffic model. The effective bandwidth of a UCBR flow is sampled uniformly between the given bandwidth and 75% of it. The sampling is done only once and thereby the same bandwidth is used for all the CBR flows for that nodepair. The average flow holding time is assumed as 300 secs. The mean inter arrival time is calculated based on the number of connections and mean flow holding time.

- Unspecified Bit Rate (UBR): UBR is constructed from the CBR traffic model. It comes as a request with a minimum CBR which is allocated to the connection and a variable rate part, for which there are no guarantees. Every active source-destination pair generates UBR traffic with a CBR part that has inter arrival time as 10 secs and flow holding time as 180 secs.

- Variable Bit Rate-Non Real Time (VBR-NRT): VBR-NRT is constructed from the VBR traffic model. VBR-NRT comes with given peak and sustained cell rate requirements. The effective bandwidth of a VBR-NRT flow is computed using the formula derived in [4] with other parameters such as Active Burst Length assumed as 1 sec, Buffer Size taken as PCR – SCR and Cell Loss Ratio taken as 0.1%. The computation is done only once and thereby the same bandwidth is used for all the flows for that nodepair. The average flow holding time is assumed as 600 secs. The mean inter arrival time is calculated based on the number of connections and mean flow holding time.

- Variable Bit Rate-Real Time (VBR-RT): Same as VBR-RT with Cell Loss Ratio as 0.01% and Call Holding Time as 180 secs.

B Performance Metric

- Bandwidth Denial Ratio: It reflects the fraction of bandwidth requests that were blocked by the network of a specific service class or the over all network. Let \( N \) be the set of flows that arrive to a network and let the bandwidth requirement of flow \( j \) be given by \( w_j \). Let \( N_D \) be the set of flows which were denied service to the network. BDR is then given by

\[
BDR = \frac{\sum_{j \in N_D} w_j}{\sum_{j \in N} w_j}
\]

- K% Capacity: It signifies the percentage of the baseline network capacity (100%) used in the simulation. Unless otherwise stated, it increases each link bandwidth in the same ratio.

IV RESULTS AND DISCUSSION

We have attempted to compare routing along with traffic control mechanisms in terms of their capability to guarantee a 1% bandwidth denial ratio for the Constant Bit Rate service class. The class of such mechanisms have been broadly classified into two sections based on their fundamental approach. In scenario I, we present GoS passive approaches which intend to improve overall performance of the network and thereby provide better GoS for the specific class. In scenario II, we present GoS proactive mechanisms, which do not intend to improve the overall network performance, rather they attempt to give different grade of service to different classes. In the process of providing better service to a specified class, entire network behavior might be degraded. These approaches give the network designer an effective way of providing GoS guarantees without having to do massive upgrades.

A Scenario I

In this section, we experiment with the GoS passive approaches which do not provide any bias to any service class but intend to improve the overall network level performance. These methods have been popular in the class-less internet and the performance of a service class depends on its own traffic characterization, i.e., bandwidth of flows for CBR, PCR and SCR for VBR-RT and VBR-NRT classes and the overall load of all classes on the network. Observe that the coupling between the classes is not the target but, rather optimal coexistence is the approach. We are not attempting to minimize the dependencies between the service classes rather we want them to compete with each other and help the system perform at its best.
For DBR, since many of the links have no traffic, we add capacity to the relevant links while keeping the overall addition the same as in other cases. So for an addition of $K%$ on each link (in other cases), we do a $K_{DBR} \%$ addition on the links with direct traffic between them. Let $L$ be the set of all the links in the network, with capacity of each link $j$ being denoted by $c_j$. Let $L_A$ be the set of links with direct traffic between them. $K_{DBR}$ is then given by

$$K_{DBR} = \frac{K \times \sum_{j \in L} c_j}{\sum_{j \in L_A} c_j}$$

(2)

For the Constraint Based Routing schemes, we add capacity to every link since the routing scheme itself is supposed to move the traffic around. We present results for the DBR and all the four routing schemes, the BDR as seen by the CBR service class in figure 1 and by the entire network in figure 2 for increasing network capacity. Observe that the BDR of the CBR class falls dramatically since the bandwidth of active links increases by $K_{DBR}$. With almost twice the present capacity in the network, the objective of providing 1% blocking can be achieved with the DBR scheme. No upgrade in the routers is needed but, the network capacity has to be increased to more than 2.6 times of its original capacity. The network requires heavy upgrade in terms of bandwidth in case, an upgrade of the routers is avoided.

The Constraint Based Routing schemes bring down the network denial drastically from 0.35 at 100% capacity for DBR to about 0.28 at the same capacity. The benefits are reaped from the capability of the routing schemes to utilize the indirect links and help flows go across on multi-hop paths. The performance of various routing schemes do not seem to vary much and the BDR is reasonably steady for changes in routing schemes. However, the network BDR for best routing schemes does switch around 140% capacity. Hence depending upon the operating point we might choose different routing schemes. We may observe that the BDR with most routing schemes are almost equal, the one which requires minimal upgrade in the routers could be chosen. Since the routing schemes are not giving much differing performance, we give the results for only two routing schemes, namely MACRPC and DRR, representatives of classes of schemes with and without periodic updates respectively.

In order to judge the impact of trunk reservation, it is incorporated on each link which is shared between multiple classes of service. Trunk reservation prevents the network from going into overloaded steady state and keeps the path lengths as small as possible. This makes the network less loaded and thereby brings down the overall bandwidth denial ratio of the network as well as that of CBR service class. The results in terms of BDR for CBR service class are given in figure 3 and for the overall network in figure 4 with 5% and 10% trunk reservation on each link and for the above observed routing schemes. Observe that the BDR of the CBR class and the overall network remains same as that of Constraint Based Routing scheme implying that the trunk reservation does not significantly impact the given network. We conjecture that, in a network where only a subset of all pairs have traffic between them, and the network is fully connected for this subset with additional links, lack of benefit of TR may be possible.

### Scenario II

In the previous section, we tried to minimize the overall network BDR and hence in the process, provide better performance to the CBR service class. But no exclusive treat-
ment is provided to any service class and they get the performance which depends on their traffic characteristics. The only way a provider can give 1% BDR to CBR service class is by reprovisioning the entire network and bringing the overall BDR low enough so as to provide the CBR service class its desired performance. In this section, we are attempting to provide special treatment to the CBR class. The idea is that there might be scenarios where the service provider wants to avoid upgrades but still wants to provide some GoS to a particular service class. These approaches make sense when the provider does allow a little degradation in the overall performance as a price for providing GoS sensitive services to a specific class. The fundamental idea is to weaken the coupling between the CBR and other service classes and let CBR have enough bandwidth to get its own GoS while letting other classes have relatively degraded service. We have chosen 5% and 10% (in addition, 15%, 20% in case of partitioning) bandwidth of each link and tried various techniques to see the impact on the network BDR and on the BDR of the CBR service class.

Each active source-destination pair has a direct link between them and hence we attempt to give priority to the CBR service class on the direct link which helps the network provide better performance for the CBR service class. Since the overflow from the common area flows to the trunk reserved area, the CBR service class gets direct priority over other classes. Observe that, as compared to the previous section, the coupling between the performance of the CBR service class and the other classes is weakened by reserving a section of the direct link exclusively for it and letting the flow first compete with other service classes before using the trunk reserved area. So except for the direct link, all the service classes receive the same treatment. Using this approach, the service class performance still depends upon the load offered by other classes. Hence, the CBR service class is still vulnerable to performance deterioration. We present results of BDR of the CBR service class in figure 5 and that of network in figure 6, both having a Service Class based Trunk Reservation of 5% and 10%. With 5% SCTR, the BDR of CBR service class is 5% at 100% capacity while the network denial rate is at 30%. For 10% SCTR, these numbers are 2% and 33% respectively. Hence, when bringing the BDR of the CBR service class down from 5% to 2%, the network performance degrades from 30% to 33%. If the BDR of the CBR service class is to decrease to 1% using SCTR mechanism, the returns are diminishing. To ensure 1% BDR for CBR service class, we might have to resort to partial upgrade of the link capacities and suffer a partial degrading of the overall network denial by increasing the percentage of reservation.

In the case of Service Class based Multi-Link Trunk Reservation, we let the CBR service class have a reserved area in every link which can only be used by the CBR service class either direct or overflow traffic. In this way, the CBR service class is given prioritized handling even on the indirect links. This ensures that the overflow from the direct link first tries the common area of indirect links where it competes with other service classes and if blocked, it still has a reserved area to rely on. We present results of BDR of the CBR service class in figure 7 and that of network in figure 8 for Multi-Link Service Class based Trunk Reservation of 5% and 10%. Observe that even for 5% SMTR, the BDR of the CBR service class is nearly 1% and the overall network BDR is little less than 30% for 100% capacity. The BDR of the CBR service class can be brought into the acceptable region without any degradation in network performance. However, it may be worth observing that still the performance of the CBR service class depends on the load of other service classes. As the flows of the CBR service class always try the common area first in both direct as well as indirect paths, a fraction of
flows that were accepted have taken the bandwidth from the common area. The availability of bandwidth in the common area depends on the load and BDR of other service classes. In the case of 10% reservation, the BDR of CBR service class is approx. 0% but the overall network level BDR is 33% for the same 100% capacity.

In the case of Pseudo Partitioning, the CBR service class has a reserved area in every link which can only be used by the CBR service class either direct or overflow traffic. The only difference between SMTR and pseudo partitioning is that in this case a flow of the CBR service class first tries its reserved area on the direct link and then if blocked, tries the common area of the direct link, and behaves the same way on the alternate path too. We present results of BDR of the CBR service class in figure 9 and that of network BDR in figure 10 for pseudo partitioning with 5% and 10% reservation. As compared to SMTR, pseudo partitioning gives inferior performance for the CBR service class whereas it performs better at the overall network level. CBR service class has a minimum guaranteed throughput in both SMTR and PP mechanisms, but with PP, the CBR service class may not be able to get much more when it is ramping up due to a heavy load from some other class. So, indeed, in SMTR, the reserved space is held in reserve to handle the CBR service class’s peak behaviour, whereas in PP, the common area is shielded from occasional activity in CBR service classes from the other service classes and makes

CBR service class.

In the case of partitioning, we split the network into two overlay networks; one for the CBR service class and the other one for the remaining service classes. The GoS for the CBR service class can be made arbitrarily small by reserving more bandwidth for this class, of course at the cost of degrading the performance for the other classes and the network as a whole. We present results for BDR of the CBR service class in figure 11 and for overall network BDR in figure 12 with Partitioning at 5%, 10%, 15% and 20% with increasing capacity. Partitioning ensures complete immunity for GoS stringent
place for hard guarantees for the CBR service class. As long as the characteristics and the load of the CBR service class do not change, the performance of the CBR service class is independent of changes in the loads of other service classes. The CBR service class can be given arbitrarily low blocking guarantees but at the expense of increased BDR for other service classes and the overall network. Due to partitioning of resources the network encounters the partitioning loss.

V Conclusion

In the paper, we have discussed various routing and traffic engineering mechanisms which can be used in a MPLS based network. The MPLS framework provides the capability to control the traffic in a network. The performance of a network can be improved by employing right kind of control mechanism. However, the idea of best control is quite subjective and varied from network to network and from service provider to service provider. Moreover, the performance depends on network structure and the traffic characteristics. We have tried to answer the question for a given network and traffic for a specific scenario when a service provider plans to provide GoS in terms of bandwidth denial ratio to a particular class. The methodologies can be split into two classes: GoS passive and GoS proactive approaches.

GoS passive techniques try to improve the overall performance of the network by making the service classes compete with each other for bandwidth and in the process, give better performance to the GoS stringent service classes. Destination Based Routing imbalances the network into heavily loaded and lightly loaded links and in the chosen network, it performs poorly. The Constraint Based Routing schemes give good performance for each service class as well as for the overall network. They give a 5% improvement for the overall network BDR as compared to the DBR scheme. Trunk Reservation however, fails to improve upon the performance of the network.

GoS proactive approaches intend to give better performance for the GoS stringent service class at the cost of degrading the performance of the entire network. SCTR with 5% reservation takes the gain further to 1% BDR for the CBR service class with the same 30% overall network level BDR achievable by SCTR. Pseudo Partitioning leads to slight increase in the BDR for the CBR service class while bringing down the BDR for the overall network as compared to SMTR. As compared to SMTR and Pseudo Partitioning, Partitioning provides degraded performance for the benefit of complete immunity. It is worthwhile to observe that providing GoS for a traffic class hinges on the degree of dependency it has with other traffic classes.

The GoS passive schemes do not intend to decrease the coupling between the CBR and other service classes and hence the performance of the CBR service class depends on traffic characteristics of all the classes. The GoS proactive schemes hit at the dependency between the service classes. To achieve decreased dependency, the network provider reserves the required segment of the network for the GoS stringent service class. Hence, for the given traffic and network, 5% SMTR can be considered as one of the best ways of doing traffic engineering.

We would like to draw the reader’s attention towards the fact that these conclusions are only applicable and make sense with regard to the network under consideration. Would our results for this network hold for other networks? This remains to be seen as we are investigating further in this area. In fact, we don’t make any such claim based on our current study. Our attempt here is primarily to report and provide some insights into the benefits and tradeoffs through a specific case study. They don’t indicate in general superiority or inferiority of routing and control mechanisms with respect to one another.

REFERENCES