On Resource Provisioning for Multi-Domain Networks

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Abstract: We study the performance of multi-domain resource dimensioning/routing techniques with limited information sharing, and provide motivation for considering fairness issues.

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1 Introduction

As optical networks evolve to support the growing need for on-demand services (based on establishing lightpaths) across multiple network domains, being able to efficiently manage the network under a dynamic environment becomes critical. Recently, there has been much progress in the development of new standards for optical networking. These standards improve support for multi-domain services at the optical layer and have opened the door for new problems that arise in designing algorithms and evaluating performance as multi-domain provisioning, routing and management is considered [1]. In this paper, we quantify the performance of optical network dimensioning and dynamic multi-domain routing techniques while considering the level of information sharing between the different domains.

Network domains are divided based on different reasons from management and geographic locations to vendor-specific component technologies. Dissemination and sharing of proprietary information such as the complete network topology should be limited especially as network domains can also be owned/operated by different entities, but the overall network performance can suffer significantly as inter-domain traffic is considered. The amount/type of information shared needs to be carefully considered. To this end, we provide a simple example of conflict of interest that may arise when considering inter-domain call setup. For our study, we use two networks (NSF and ARPA) connected by three border nodes as shown in Figure 3. (There can be many Sub/domains in each of the networks, but we consider the two domains with significant number of nodes to generate meaningful results in simulation.) Between node pair (A, B), there are two global shortest paths, path 1 and path 2. Path 1 favors ARPA as less hops are used on the ARPA side (and path 2 favors NSF). When one network must bear extra costs, which one takes the hit? Assuming available capacity, the domain initiating the request can always choose what is best for itself. On the other hand, the other domain can also reject calls it does not like. Our results show that by limited information sharing and by playing fair, the overall network performance can be significantly improved. With the different dimensioning and routing schemes, we consider the impact of traffic load changes as well as network scaling.

2 Multi-Domain Network Dimensioning and Routing

A dynamic network must be properly dimensioned for both inter-domain and intra-domain traffic. As previously shown, network dimensioning is critical in maximizing blocking performance in a dynamic network [3]. Inside each network, dimensioning the network for inter-domain traffic is equivalent to dimensioning for additional connections from internal nodes to border nodes. For illustration purposes, we use two domains, but it can be extended to more domains. We define some network parameters first. \( C_e \) is the total capacity on link \( e \in E \) provisioned for local traffic (\( C_e' \) is for external traffic). We separate the two just for the purpose of analysis, but in practice (and our simulations) they are used together. \( R = N \times N \) is the set of all local connections (node pairs), where \( N \) is the set of nodes. \( R' = N \times S \) is the set of inter-domain connections, where \( S \) is set of nodes in the other domain. \( R'_L = N \times N' \) is a special subset of local connections where one of the end nodes is a border node, where \( N' \) is the set of border nodes. \( C_{e}'' \) is the total provisioned capacity of the inter-domain link for the border node \( b \in N' \). \( \lambda_i \) is the average arrival rate per local connection \( i \in R \). \( \mu_i \) is the average departure rate for \( i \in R \). \( \kappa_i \) is the average capacity request for \( i \in R \). \( \lambda', \mu', \kappa' \) are similar definitions for the foreign domain. \( TSL_i \) is the topological shortest path length (TSL) for pair \( i \in R \).

Eq. 1 and Eq. 2 compute the local and inter-domain traffic loads, respectively. The same load computation metric is used on all dimensioning techniques to provide a fair comparison. Each internal node \( n \in N \) (including the border nodes) will generate total external traffic at an aggregated arrival rate \( \sum_{i \in (n) \times S} \lambda_i \) that is effectively augmented to the rate from \( n \) to all borders \( N' \). The average resource used for each external path is the average shortest path lengths to all border nodes. Therefore, the traffic on the local network is the sum of two traffic matrices, the local traffic matrix (\( T = \{(\lambda_i, \mu_i, \kappa_i) | i \in R \} \)) and the inter-domain traffic matrix (\( T'_L \) in Eq. 5).
Fig. 1: Computation of \( p_{n,s,b} \) for GS dimensioning.
1: for each inter-domain connection pair \((n,s)\) do
2: for each border node pair \((b,k)\) from each domain do
3: Compute the total path length \( l_b = TSL(n,b) + TSL(b,k) \) for border \( b \).
4: end for
5: pick up the set of borders \( B \in N' \) of minimal \( l_b \).
6: for each shortest path border nodes \( b \in N' \) do
7: \( p_{n,s,b} = \frac{1}{|\mathcal{B}|} \) for \( b \in B \), \( p_{n,s,b} = 0 \) for \( b \notin B \)
8: end for
9: end for

Fig. 2: Dimensioning with inter-domain traffic.
1: Set infinite available capacity on each link \( C_e \leftarrow \infty \forall e \in E \)
2: while System has not reached steady state do
3: Generate a new request \( i \) from traffic matrix \( T \cup T'_L \).
4: Route \( i \) by shortest path first algorithm (SPF).
5: end while
6: \( \bar{C}_e \) is the actually used network capacity of each link.
7: Repeat from Line 1 to get the distribution of \( \bar{C}_e \), mean \( E_i(\bar{C}_e) \)

\[
Id_{loc} = \frac{E_i \in R(\bar{X}_{n,s}) \sum_{i \in E} TSL_i}{\sum_{e \in E} C_e} \quad (1) \]

\[
C_b = \sum_{n \in N} \sum_{s \in S} p_{n,s,b} \frac{N_{(n,s)}(n,s)}{\mu(n,s)} \quad (2)
\]

\[
T'_L = \left\{ \left( \sum_{n,s \in S} p_{n,s,b} \frac{N_{(n,s)}(n,s)}{\mu(n,s)} \sum_{n,s \in S} p_{n,s,b} R'(n,s) \right) \right\} \quad (3)
\]

\[
penalty = \sum_{i \in N' \times S} \frac{N_{(n,s)}(n,s)}{\mu(n,s)} \sum_{b \in N'} p_{n,s,b} TSL(n,b) - \min_{n,k \in N'} TSL(n,k) \quad (5)
\]

\[
Id_{ext} = \frac{\left| S \right| E_i \in R'(\bar{X}_{n,s}) \sum_{i \in E} TSL_i'}{\sum_{e \in E} C'_e} \quad (4)
\]

\[
= \sum_{i \in N' \times S} \frac{N_{(n,s)}(n,s)}{\mu(n,s)} \sum_{b \in N'} p_{n,s,b} TSL(n,b) \quad (4)
\]

\[
\]

\[ p_{n,s,b} \] is the probability that border \( b \) is picked for provisioning a connection from local node \( n \in N \) to a foreign node \( s \in S \). Depending on different joint provisioning scheme, it specifies how much inter-domain traffic from node \( n \) will be routed through border node \( b \). One can see that dimensioning the local network to support traffic to another network can be the same as dimensioning a single network with an estimation of external traffic split ratio on the traffic matrix \( T'_L \). Once we have the matrices, same basic dimensioning algorithm (Fig. 2) proposed in [3] can be used to dimension each network separately. In this study, we assume that each border node in one domain is connected to one other border node in the other domain. In practice, they may be situated at the same site/building. The capacity of links connecting the border nodes to other border nodes (inter-domain links) is provisioned by using Eq. 3. Depending on the level of information shared, the split ratios are determined as follows.

**Independent dimensioning (ID)** is used when the networks only advertise which nodes are in its domain (without this information, routing cannot be done). One domain lacks information about the use frequency of other domain’s border nodes. Therefore, expected traffic is split equally among all border nodes. In this case, \( p_{n,s,b} = \frac{1}{|\mathcal{B}|} \). **Global shortest path dimensioning (GS)** provides the network using the least cost route. It can be used when two networks are willing to share cost (path length) information to select a global shortest path. The traffic load to each border node is weighted by the chance it is picked using SPF routing. Fig. 1 shows the computation of \( p_{n,s,b} \). **Normalized shortest path dimensioning (NS)** is similar to GS, except line 3 of Fig. 1 is replaced by Eq. 4. GS can favor the choice of the larger network if two domain sizes are different. Since one network is larger and more likely to have longer paths to the border, their internal shortest path length can dominate the length of the global shortest path and force the small network to use unfavorable paths. To improve fairness, the shortest paths from each domain are normalized by their average TSL. We use the penalty ratio to measure fairness in resource usage on each network domain. The penalty of each network is computed by Eq. 6. It basically sums the normalized number of extra hops it takes for each inter-domain requests. The penalty ratio of the two networks is the ratio of the penalty of each domain.

Similarly, three dynamic routing algorithms are used. In concatenated shortest path routing (CSR), the source domain initiates the call setup and greedily selects what is best for itself. The other domain accommodates the setup request from the border node (chosen by the source node). In end-to-end global shortest path routing (E2E) global available shortest path is chosen. These two algorithms are consistent with [2]. Normalized E2E (nE2E) is similar to E2E, but Eq. 4 is used to compute the paths.
3 Results and Discussion

We utilize a joint NSF-ARPANET topology, and assume uniform arrival/departure rates and requested capacity. The 95% CI is within ±5% of the data value. In our network configuration, the computed penalty ratio for NSF to ARPANET is 2.46 using GS-E2E and 0.99 using NS-nE2E (NS-nE2E is a more fair dimensioning/routing scheme since the ratio is close to one). Figs. 4, 6, 8 show the inter-domain call blocking, intra-domain blocking on NSF and ARPANET as the inter-domain load deviates from the expected traffic load. Additional information shared in GS and NS allow a significant reduction in blocking (e.g., 90% reduction over ID at load ratio 0.95). However, using shared routing when the networks are independently dimensioned (ID-E2E) does not improve performance over ID-CSR. Therefore, it is essential to jointly dimension the networks in order to benefit from using shared routing schemes. Using NS-nE2E reduces blocking on NSF by over 80% (vs. GS-E2E). In terms of resource allocation, NSF has a higher external/internal capacity ratio (2.82) compared to ARPANET (1.38) because NSF is a smaller network. NSF has to pay more in capacity to support inter-domain traffic relative to its own size. Therefore, NSF’s blocking should be lower in a fair scheme. Figs. 5, 7, 9 illustrate the effect of one network (NSF) rescaling itself. Note that with NS-nE2E, NSF can afford to use less capacity (ratio 0.95 to ARPANET) and sustain the same performance. It is interesting to see that over-provisioning by NSF adversely affects ARPANET (blocking increases when independent routing schemes are used). As an over-provisioned network accepts more inter-domain traffic, more pressure is put on the other network on the local traffic of the other network. As NSF’s capacity further increases, the blocking of inter-domain traffic and local traffic on ARPANET becomes remains the same because the inter-domain links become saturated. Impact of scaling both domains and varying the load ratios of all traffic classes were also studied, which revealed interesting relationships, but this discussion is outside the scope of this introductory paper, and will appear in the near future.

4 Conclusion

We studied the performance of various routing and dimensioning schemes with two simple levels of information sharing between network domains. We provide motivation for considering fairness issues (as conflict of interest may arise in multi-domain networks) and presented an initial study by quantifying the impact of on performance. The results confirm our intuition that joint dimensioning/routing is crucial to performance. We also showed that independent scaling of a network can affect the performance of other networks.

References