A Backward-Compatible Inter-domain Multipath Routing Framework

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***Abstract*—We present a framework to facilitate the inter-domain multipath routing for carrier networks that are based on circuit switching technologies, without significant changes to the existing inter-domain protocols. We first introduce a simple mechanism, namely, *Single Routing Plane Multipath* (SRPM) which can be easily implemented in the existing PCE-based inter-domain architectures. The main idea behind the SRPM method is to represent multiple link disjoint paths as a single virtual edge in the PCE and thus use the existing single path routing mechanisms to enable multipath routing. We further present a more generic mechanism, referred to as *Multiple Routing Plane Multipath* (MRPM) method, with the goal to facilitate the provisioning of multipath connections over dynamically selected domain chains. In this method, we propose to virtualize the network into multiple slices and represent as multiple routing topologies by the PCEs. In this way, multiple routing planes are constructed to facilitate inter-domain routing. For both methods, we consider the buffer size as constraint for multipath routing due to the resulting differential delay. The results show that the proposed methods can significantly improve the blocking performance and are backward compatible, while only slightly impacting the intra-domain traffic.**

I. Introduction

In the past few years, the carriers have witnessed the ever-growing commercial and scientific applications demanding Quality-of-Service (QoS) guaranteed paths with enormous bandwidth requirements. For example, image processing in astronomy requires transmission of 100 GBs for a ten square degree sky image [1], and very high definition visualization [2] requires bandwidths in excess of 10s of Gbps. Given that the number of high-bandwidth services is only going to increase in the future, the current paradigm of dedicating single path to provision these services may not be feasible in the future, even in the optical WDM networks. Whereas it is not rare to see that connections are required to traverse multiple domains, inter-domain provisioning frameworks in carrier networks have not yet considered the possibility that one service maybe provisioned over multiple paths across multiple domains.

A large number of algorithms, and also commercial standards such as VCAT in SONET/SDH consider the use of multipath routing in carrier networks. However, multipath provisioning in multi-domain networks carry significantly larger challenges comparing to the single-domain scenario. First, to facilitate inter-domain multipath provisioning, current multipath approaches would require extensions or modifications to the existing protocols, such as BGP-TE [3]. Since operators are usually reluctant to migrate to new routing protocols, it is unlikely that a multipath solution based on a new inter-domain routing protocol would be adopted on a large scale. Although few vendors have developed the switches that can enable transmission of individual flows over Equal Cost Multi-paths (ECMP) [4] for the purpose of the inter-domain load balancing, the requirement for implementing the ECMP on specific hardwares furthermore limits the deployment of the inter-domain multipath routing on a larger scale. Second, the use of multipath routing leads to packet re-ordering at the receiver. While some applications such as bulk data transfer may not require packet re-sequencing, applications such as the real-time streaming have to restore the order of packets, which consequently requires buffering. In high bandwidth networks, buffering has to be properly dimensioned as it can amount to a significant size for Gb/s scale traffic flows.

In this paper, we attempt to work around these challenges and present a backward compatible framework to facilitate the inter-domain multipath routing in the carrier networks. We propose to use single path routing on individual *virtual routing planes* to enable multipath routing while avoiding modification of the widely deployed BGP protocol. Our framework is based on the renowned Path Computation Element (PCE) [5] architecture, where dedicated PCE servers in each domain cooperatively compute end-to-end multi-domain paths based on the abstracted information advertised by each domain. We first present a simple mechanism, referred to as *Single Routing Plane Multipath* (SRPM), in which the domain information is abstracted to a single virtual topology stored in the Traffic Engineering Database (TED) of the domain PCE. The main idea behind this mechanism is to utilize the inter-domain *single* path routing protocol for multipath routing and thus induce minimal changes to the network system. To make use of this idea, we represent the multiple link disjoint paths between the border nodes to be a single virtual edge in the virtual topology while a single domain chain is obtained by running BGP between PCEs. Each domain decides the transit segments in its virtual topology for the connection while the end-to-end path is computed by extending the Backward Recursive Path Computation (BRPC) algorithm [6] on the virtual topologies.

While the SRPM is a simple step forward the inter-domain path computation schemes based on PCE, it can not provide paths from alternative domain chains which is important for load balancing in the multi-domain networks. To this end, we present a mechanism, referred to as *Multiple Routing Plane Multipath* (MRPM), to enable multipath routing over multiple domain chains. PCEs virtualize its domain to multiple virtual slices which are represented as multiple virtual topologies.

Multiple virtual routing planes are composed using a single virtual slice from each domain, on which a BGP instance is run to facilitate the inter-domain routing. The connections can be served by utilizing the paths on a single virtual routing plane, or by utilizing multiple paths, with different paths computed on different virtual routing planes. To facilitate multipath provisioning in both schemes, we consider the traffic splitting of one individual flow over these computed paths with all synchronization operations e.g. re-sequencing taking place at the connection source/destination. Both methods proposed are backwards compatible with the PCE architecture as well as the inter-domain routing protocols and our results show that they can significantly improve the blocking performance in a multi-domain provisioning scenario.

The rest of the paper is organized as follows. In Section II, we briefly present the related work and our contribution. Section III presents the proposed inter-domain multipath routing mechanisms. Section IV presents the performance evaluation and the conclusions are presented in section V.

II. Related Work and Our Contribution

Mechanisms proposed to enable inter-domain multipath routing in the Internet have primarily focused on achieving flexible packet forwarding over diverse Autonomous System (AS) level paths towards the destination domain. Xu et. al. [7] presented a mechanism where domains can negotiate with each other in order to forward packets to an alternative down-stream domain. Kaur et.al. analyzed the the challenges associated with inter-domain multipath routing and presented a new mechanisms for the same. All proposed mechanisms to date required extensions or modifications of the existing inter-domain routing protocol.

Inter-domain multipath routing in connection-oriented carrier-grade networks is a new topic and previous work has primarily addressed single domain scenarios. In our past work [8], we have explored the usage of multipath routing with multi-domain reach in carrier-grade Ethernet. In order to facilitate the inter-domain multipath routing, we proposed a special virtual topology design mechanism, in which the shared segments have to be identified and represented to resolve the bandwidth reservation conflicts. However, the specialized virtual topology design may not be flexible in highly dynamic networks.

In this work, our goal is to propose a backward compatible approach to facilitate the inter-domain multipath routing. Therefore, we propose and analyze an approach which does not require significant changes in the existing inter-domain routing protocols, and is easy to implement, such as SRPM. Our approach is based on a standardized single path PCE-based inter-domain routing architecture [5]. Furthermore, we propose to utilize multiple routing planes, by means of network virtualization, which is novel. In addition, our mechanism, such as MRPM, can use alternative domain chains, in contrast to the current approaches where the domain chain is pre-defined in the inter-domain path computation. It should be noted that multipath solutions in our framework are only provisioned to the high bandwidth requests that single path can not serve, while directing the multiple individual flows with same source and destination over multiple paths for load balancing such as the applications using ECMP in MPLS networks is not considered.

III. Mechanisms to Enable Inter-domain Multipath Routing

A. Preliminaries and Assumptions

The multi-domain network, denoted as $G(V,E)$, is composed of M inter-connected domains and each domain is denoted as $G^m = (V^m, E^m)$, $m = 1, 2, ..., M$, where only border nodes and the connectivity between border nodes are included, i.e., $v_i^m \in V^m$ are the set of border nodes of the domain G^m and $e_{ij}^m \in E^m$ is the virtual edge between node v_i^m and v_j^m. The available capacity and delay of e_{ij}^m is given by b_{ij}^m and d_{ij}^m respectively. Based on the virtual topology graph, we also define the set of border nodes which are connected by inter-domain links, i.e., the set $\mathcal{BN}(G^n, G^m)$ includes the border nodes of domain G^n which are connected to border nodes in domain G^m. We compute up to K distinct paths between a pair of border nodes v_i^m and v_j^m in domain G^m represented as $\mathcal{P}(e_{ij}^m) = \{p_{ij_1}^m, p_{ij_2}^m, ...p_{ij_K}^m\}$. The value of K is decided by the domain and restricted by the maximum available link-disjoint paths between the nodes. The available bandwidth of path $p_{ij_k}^m$ is denoted as $b_{ij_k}^m$ and the delay is denoted as $d_{ij_k}^m$. The connection request is denoted as $r(s, d, B_r, D_r)$, where s, d are the source and destination nodes and B_r, D_r are the required bandwidth and end-to-end delay constraint respectively. The available buffer size at node $v_i^m \in V^m$ is denoted as M_i^m.

The differential delay caused by the usage of multiple paths for provisioning a connection is defined by the difference in the delay between the paths used to provision a request. The delay of an end-to-end path P is given by d_P, the differential delay between two paths P and P' is defined as:

$$dd(P, P') = |d_P - d_{P'}| \quad (1)$$

The re-sequencing buffer size requirement is decided by the differential delay between the path with highest delay and other paths and the traffic routed on each path [9]. Assume the set of paths for a connection request r is the path set $\mathcal{P}(r)$, with $\tilde{P}$ as the path with highest delay, and traffic on path P is denoted by t_P, the re-sequencing buffer size required is calculated as:

$$M_r = \sum_{P \in \mathcal{P}} t_P \cdot (d_{\tilde{P}} - d_P) \quad (2)$$

The two mechanisms proposed in this paper, i.e., SRPM and MRPM, both rely on the PCEs to abstract and exchange domain information for the inter-domain routing. The virtual links represent the connectivity information between border nodes and include information about TE parameters such as capacity, delay, etc. We now present both methods.

B. Single Routing Plane Multipath (SRPM)

SRPM is a simple extension to today's PCE-based inter-domain path computation schemes. The domain chain is obtained by the BGP running between PCEs while the end-to-end path computation is done based on the BRPC. However, in order to facilitate the multipath routing, the multiple link disjoint paths are first calculated between border nodes and represented as a single edge in the virtual topology of the domain. The capacity of the virtual link given by the sum of the available bandwidth of the paths between the pair of the border nodes, i.e., $b^m_{ij} = \sum_k b^m_{ij_k}$, and the delay of virtual link e^m_{ij} is set as the maximum delay in the $\mathcal{P}(e^m_{ij})$, i.e., $d^m_{ij} = max\{d^m_{ij_k}\}$. The steps involved in computing the path/paths for a given request is shown in Alg. 1.

Algorithm 1: Single Routing Plane Multipath Mechanism

Input: $r(s, d, B_r, D_r)$
Output: Provision connection for $r(s, d, B_r, D_r)$
Step 1: Compute the domain chain from $s \in G^s$ to $d \in G^d$ as $\mathcal{G}(r) = G^s, G^1, ..., G^M, G^d$
Step 2: Initiate PCE Signaling using the modified BRPC algorithm (Alg. 4)
Step 3: If path computation in PCE is successful, initiate inter-domain path setup

Algorithm 2: Multiple Routing Plane Multipath Mechanism

```
Input: r(s, d, B_r, D_r)
Output: Provision connection for r(s, d, B_r, D_r)
computedPathArray[|K|] = null;
for each virtual routing Plane do
    Step 1: Compute the domain Chain from s ∈ G^s to
    d ∈ G^d as G(r) = G^s, G^1, ..., G^M, G^d
    Step 2: Initiate PCE Signaling using the standard BRPC
    algorithm [6](Compute Max Available Bandwidth path)
    if path computation in PCE is successful then
        initiate inter-domain path setup;
    end
    Store computed path information in
    computedPathArray[k];
end
if no Single Path Found then
    Use algorithm described in computeTransit (Alg. 3) to
    compute min-delay min-buffer requirement multi-path;
    if multi path found then
        initiate inter-domain path setup over the multiple
        computed paths;
    end
end
```

In this mechanism, we assume the use of conventional inter-domain routing protocols to compute the domain chain, which in this case use the shortest path algorithm on the virtual topology. Once the domain chain is computed, the modified BRPC proposed in Alg. 4 is initiated by the PCE in the destination domain. In the modified BRPC, instead of using only a single path between a pair of ingress and egress routers inside a domain, the PCE is allowed to use multiple paths between the given pair to facilitate the request.

Each domain attempts to compute a set of path segments with the shortest delay which simultaneously minimize the differential delay, utilizing the $computeTransit$ function in Alg. 3. The set of transit paths is ordered by the path delay, and the algorithm iteratively chooses a path from this ordered list as the path with the maximum delay, and then goes on to compute the required path set while ensuring that the re-sequencing buffer availability constraints are met. Note that as each individual domain can decide upon using a single path or a multipath solution to provision a request, i.e., it is the domains' responsibility to compensate for differential delay and therefore the use of a multipath solution is constrained by the availability of the buffer at the domain border nodes.

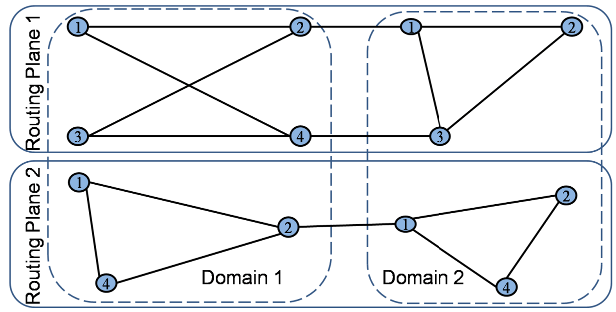

Fig. 1. The multiple virtual topology representation of a two-domain network

The complexity of SRPM is decided by the number of link disjoint paths per virtual link and the number of border nodes pair. Assume each domain has M pair of border nodes and K paths between each pair of border nodes, the complexity of SRPM in a network with N domains is $O(N \cdot M^2 \cdot K^2)$, while the complexity of using BRPC in the same network is $O(N \cdot M^2 \cdot V)$, where V is the set of all nodes in the networks.

C. Multiple Routing Plane Multipath (MRPM)

The MRPM mechanism composes the multipath solutions by running single path routing on different virtual routing planes. Each virtual routing plane is in turn generated using different virtual topologies advertised by all domains. In MRPM, each domain advertises multiple virtual topologies in order to construct multiple routing planes. To facilitate the inter-domain multipath routing, each domain calculates K link disjoint paths between each pair of border nodes and picks one from each to compose a virtual topology. The various combinations of the paths between the border nodes lead to the multiple virtual topologies of the domain. A simple illustrative example is shown in Fig. 1. Each domain advertises two virtual topologies to construct two virtual planes. The Alg. 2 provides a multipath solution to a connection request. It should be noted that connection request will only be served with multipath routing when it can not be served by single path routing.

In this mechanism, domain chain is obtained by the BGP on each virtual routing plane and the standard BRPC is initiated by the PCE in the destination domain on each routing plane to compute an end-to-end path with maximum available bandwidth. The MRPM first checks if there exists an single path solution for the connection request before the multipath routing. The paths used for the multipath routing are decided by the PCE in the source domain by selecting from the computed paths from each routing plane, using the $computeTransit$ function in Alg. 3. The available buffer size and bandwidth requirement are considered as constraints.

It should be noted that the MRPM is not exclusively designed for inter-domain multipath routing. Instead, it also provides multiple options for the inter-domain single path routing. The final solution for the connection demand should have the total bandwidth no less than the bandwidth requirement, and the available buffer is sufficient to support resequencing of the flow. Note that the total number of routing planes used in the multi-domain scenario depends on the number of virtual topologies advertised by individual domains. For example, in a two-domain network, if we assume that K_i and K_j virtual topologies are advertised by the domains, then the number of virtual routing planes that can be constructed is $max\{K_i, K_j\}$. Assume that each domain has M border nodes, the complexity of the MRPM mechanism in a network with N domains and K virtual routing planes is $O(K \cdot N \cdot M^2)$.

D. Common Functions

In order to compute the multi-path transit segment inside a domain, we make a minor modification to the BRPC algorithm, which only checks the distinct paths between border nodes instead of searching all paths towards the upstreaming border nodes. As shown in Alg. 4, the modified BRPC initiates the virtual shortest path tree (VSPT) in the destination domain (Step 1), and then in every subsequent transit domain (Step 2b), it uses the function *computeTransit* (Alg. 3) to compute multipath transit segments. The *computeTransit* function orders the path in increasing order of delay, and then sequentially chooses a path segment to be set as the highest delay segment. The algorithm then iterates over all paths with delay less than or equal to the delay of the selected segment to see if sufficient bandwidth is available and that the re-sequencing buffer constraints are not violated.

Algorithm 3: Function computeTransit: compute the transit path with minimal buffer requirements

Function computeTransit(ingress v_i, egress v_j)
Output: Optimal Intra-domain Multi-Path Segment $s(Path, Bw)$ from v_i to v_j
Sort the K paths in $\mathcal{P}(e_{ij}^m)$ in the increasing order of the path delay;
for $k = 1$ *to* K **do**
- Segment s=null; $B_w = b_{ij_k}^m$;
- $s.add$(Path $p_{ij_k}^m$, Bw $b_{ij_k}^m$);
- The required buffer $M_r = 0$;
- **for** $l = k-1$ *to* 1 **do**
  - $B_w + = b_{ij_l}^m$;
  - $M_r + = b_{ij_l}^m \cdot [d_{ij_k}^m - d_{ij_l}^m]$
  - **if** $M_r \geq \{M_i^r + M_d^r\}$ **then**
    - break;
  - **end**
  - **if** $B_w \geq B_r$ **then**
    - $reqBw = B_r - s.bandwidth$;
    - $s.add$(Path $p_{ij_l}^m$, Bw reqBw);
    - return s;
  - **end**
  - s.add(Path $p_{ij_l}^m$, Bw $b_{ij_l}^m$);
- **end**

end

IV. Performance Evaluation

In this section, we evaluate the performance of the SRPM and MRPM on a multi-domain network composed by four domains as shown in Fig. 2. The link delay of all topologies is proportional to the geographic distance of the physical network. The representative topologies used for the domains are scaled to comparable sizes, i.e., the link delay of the $Janos\_US\_Ca$ and $Cost266$ topologies are scaled down to be in the same order as the delays in the *France* and *Germany50* topologies. The delay of the inter-domain links is assigned proportionally to the physical distances depicted in Fig. 2. The border nodes of each domain are marked in black and the capacity of internal links in each domain is assumed to be $40Gb$ and the capacity of the inter-domain links is assumed to be $100Gb$. The bandwidth required by all intra-domain connections are assumed to be $1Gb$ and the bandwidth required by the inter-domain connections randomly varies from $5Gb$ to $10Gb$. The connection demands are assumed to arrive in a Poisson process and are uniformly distributed in the networks. The buffer constraint is set to $100MB$ when multipath is used for the connections. All the results shown in the following are based on the scenario that the inter-domain traffic load is constantly set to be $30Erlang$, while the intra-domain traffic load changes dynamically. It is based on the fact that the inter-domain connections usually less dynamic compared to the intra-domain traffic. Three link-disjoint paths are computed between each pair of border nodes for the virtual topology construction. In order to achieve a fair comparison, it is assumed that the traditional inter-domain single path routing can use all these paths between the border nodes too, while only one path can be used at one time.

In the results that follow, we first evaluate the performance of the SRPM and MRPM on inter-domain traffic, and then study their impact on the intra-domain traffic. Finally, we show the cost of using the SRPM and MRPM with regard to the inter-domain signaling load. 95% confidence interval is used in all the results for the blocking probability. It should be noted that the network load shown in all the results that follows is the intra-domain traffic load which does not include network load caused by the transit traffic.

A. Impact on Inter-domain traffic

The impact of SRPM and MRPM on the inter-domain traffic is shown in Fig. 3. It can be seen that both SRPM and MRPM can reduce the blocking of the inter-domain connections, as compared to the inter-domain single path routing, especially when the networks are heavily loaded. As both SRPM and single path routing use the same set of paths when computing an inter-domain path, the advantage of using multipath routing in SRPM only becomes clear when network load is high. However, significant reduction is obtained by the MRPM, about 3% at $130Erlang$, due to the fact that the MRPM allows for alternative domain chains in the inter-domain routing.

Algorithm 4: Modified BRPC Algorithm to support Multi-path computation Inside Single Domain

Input: Domain Chain $\mathcal{G}(r) = G^1, G^2, ..., G^M$, $r(s, d, B_r, D_r)$
Output: Optimal Inter-domain Path from s to d
//Step 1: Initialize BRPC Tree in Destination Domain
Tree T(r) = null;
for *all BNs* $v_x \in \mathcal{BN}(G^{M-1}, G^M)$ **do**
  Compute Min Delay Single Path from d to v_x
  if *Path found* **then**
    Add path to $T(r)$
  end
end
//Step 2: Recursively Extend the BRPC Tree through all intermediate Domains
for *index* = $M - 1$ *to* 1 **do**
  //Step 2 (a): Extend tree to ingress nodes of current domain
  for *all BNs* $v_x \in \mathcal{BN}(G^{index+1}, G^{index})$ **do**
    Use inter-domain links between domains $G^{index+1}$ and G^{index} to extend $T(r)$ to v_x;
  end
  //Step 2 (b): Compute Intra-domain Path Segments
  for *all BNs* $v_x \in \mathcal{BN}(G^{index+1}, G^{index})$ **do**
    bestPath=null;
    for *all leaf nodes* $v_y \in T(r)$ **do**
      Obtain multi-path intra-domain segment information using function computeTransit(v_x, v_y) Alg. 3
      if *obtained segment better than bestPath* **then**
        bestPath = obtainedSegment;
      end
    end
    if *bestPath!=null* **then**
      Insert bestPath in T(r)
    end
  end
end
//Step 3: Choose optimal path in Source Domain
for *all leaf nodes* $v_x \in T(r)$ **do**
  Compute Min Delay Single Path from s to v_x
  if *Path found* **then**
    Add path to $T(r)$ by checking if better than an existing path to s in $T(r)$
  end
end
if *path found to* $s \in T(r)$ **then**
  return path;
end

B. Impact on Intra-domain Traffic

In order to show the impact of enabling multipath routing on the inter-domain connection requests, we study the blocking probability of the intra-domain traffic in all domains. The intra-domain blocking probability in case of inter-domain single path routing is also studied as the benchmark. We show two representative figures here. It can be seen in Fig. 4 and Fig. 5, the SRPM has a slightly negative impact on the intra-domain traffic due to the fact that it can accept more inter-domain traffic. However, the MRPM obtains a slight reduction in performance for $Janos\_US\_Ca$ network as shown in Fig. 4. It is due to the fact that the MRPM can utilize alternative domain chains and balance the network load over the domains. The inter-domain traffic can be routed over the preferable domain chain more often which increases the network load in some domains, while leading to the decrease in some domains. For instance about 6% increase in the intra-domain connection blocking is observed in the $Cost266$ network, and about 0.7% reduction is observed in $Janos$ network.

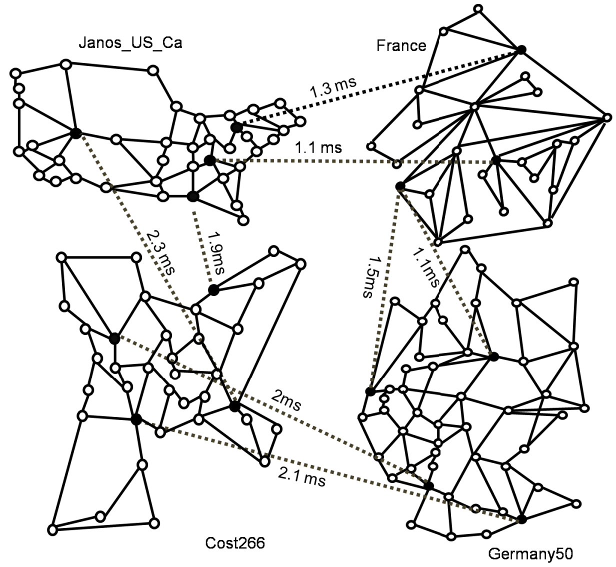

Fig. 2. The multi-domain network used for simulation

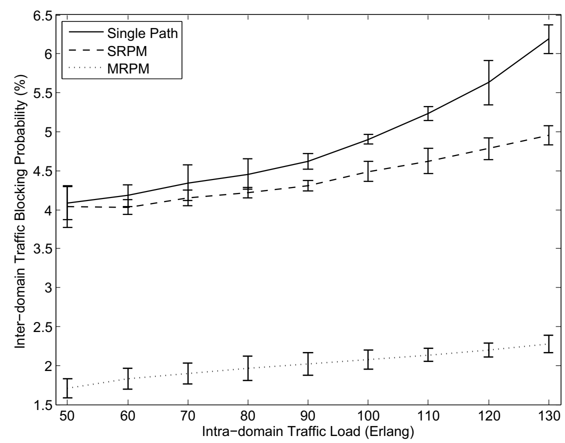

Fig. 3. The average blocking probability of inter-domain connections

C. Signaling Cost

Finally, we study the cost of enabling inter-domain multi-path routing with regard to the signaling cost. Table I shows the number of inter-domain updates circulated in the network observed per second. In our simulation, an update is triggered when the available capacity on any of the advertised virtual links is affected. It is clear here that the inter-domain single path routing has the lowest signaling frequency, which can be attributed to the fact that this technique exhibits higher inter-domain blocking, and therefore in cases when an inter-domain connection is blocked, an advertisement is not triggered. The highest update frequency is observed by the SRPM due to its lower inter-domain blocking. In case of MRPM, we show the number of updates triggered for each routing planes initiated in the simulation, here $K = 3$, and see that while

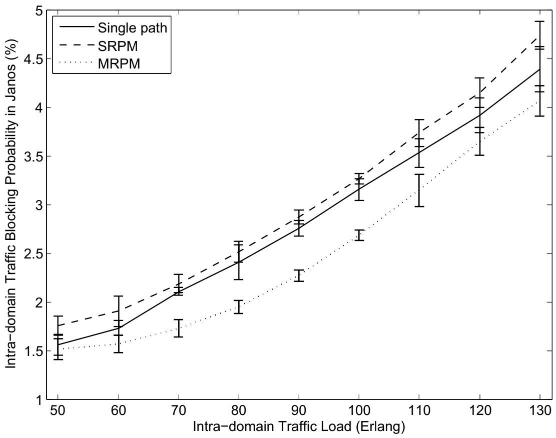

Fig. 4. The average blocking probability of the intra-domain traffic in $Janos\_US\_Ca$ network

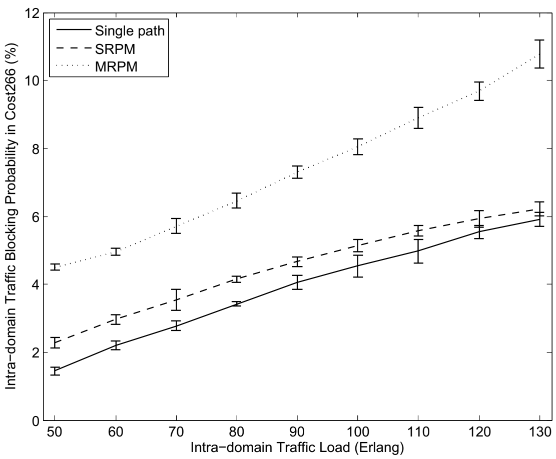

Fig. 5. The average blocking probability of the intra-domain traffic in $Cost266$ network

for each individual routing plane, the update frequency is not much higher than the inter-domain single path routing. Although the update frequency is comparably rather high when combined together, the results indicate that the total inter-domain update rate increases only linearly with the number of virtual topologies K.

TABLE I
INTER-DOMAIN TOPOLOGY UPDATES PER SECOND

Single path	SRPM	MRPM-0	MRPM-1	MRPM-2
4.134063	6.288143	5.645099	5.653716	5.714527

D. Discussion: Impact of TE on inter-domain links

In practice, inter-domain links usually are deployed with significant high bandwidth comparing with the internal links of the domains. Therefore, slicing the domain into multiple virtual routing plane may not lead to the congestion on the inter-domain links. However, the policies applied for the Traffic Engineering (TE) on the inter-domain links can lead to the different domain chains, which is not considered in this paper but as the future work of this study.

V. CONCLUSION

In this paper, we presented a backward compatible framework to facilitate the deployment of multipath routing in the inter-domain service provisioning without significant changes to the existing inter-domain routing protocols. Our framework is based on the existing PCE-based inter-domain service provisioning architecture, which compute end-to-end path based on the abstract domain information advertised by each domain. We first presented a simple approach (SRPM) which represents multiple transit paths between border nodes as a single virtual link in the virtual topology to facilitate the utilization of the traditional inter-domain single path computation. We further presented an approach which can provide multiple paths over multiple domain chains, which requires the PCEs to virtualize its domains to multiple virtual topologies, where we considered the most challenging multipath routing scenario where traffic of an individual flow is split into multiple paths and considers constrained on the available re-sequencing buffer. The results showed that our framework can enable inter-domain multipath routing with superior blocking performance and acceptable increase in signaling with respect to single path routing. Both mechanisms can reduce the inter-domain connection blocking, especially, the MRPM method. While both mechanisms have slight negative impact on the connection request inside domains, the MRPM can balance inter-domain traffic load among multiple domains which leads to the less blocking of the intra-domain connections in some domains. In terms of signaling overhead, the method MRPM needs further optimizations, as it seems to exhibit a high signaling load, especially the number of routing planes is high.

VI. ACKNOWLEDGMENT

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