

Modeling and Automating ISP Peering Decision Process: Willingness and Stability

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Abstract—The importance of peering in traffic exchange between ISPs is rapidly increasing. With continuing growth in content delivery networks, large content ISPs are becoming increasingly inclined to exchange traffic through peering relationships rather than using transit services. The stability and performance of these peering relationships dictate the satisfaction of the ISP pair and the durability of the peering. Quantification of various parameters that indicate the efficiency of peering contracts is however difficult. From the perspective of any ISP pair, there are two key decisions to be made: whether to peer or not, and at which location(s) to peer. We propose two metrics, *peering willingness* and *peering stability*, towards quantifying an ISP's decision to peer at a location with another ISP, and the stability of that relationship. We compute these metrics using publicly available data to characterize peering relationships for different ISP pair types. We observe that peering between Content and Access ISP pairs results in the most stable and efficient relationship.

Index Terms—Peering; Internet Service Provider; Internet eXchange Point; Network Management; Traffic Engineering.

I. INTRODUCTION

Internet Service Providers (ISPs) exchange traffic outside of their network either using transit services or forming peering relationships with other ISPs. Most ISPs can be categorized into three major types: Access, Content, and Transit. Content ISPs are the content providers, while Access ISPs (a.k.a. Eyeball ISPs) ensure content delivery to end-users. Lastly, Transit ISPs act as a bridge allowing traffic exchange between other ISPs. Historically, ISPs have followed a self-emerging hierarchical structure with large Transit ISPs at the top, and the Transit ISPs collectively forming a customer-provider hierarchy that serves Content and Access ISPs as customers at lower tiers. Recently, this hierarchy has been flattened by peering relationships between ISPs, and peering at Internet eXchange Points (IXPs) has been on the rise [1], [2].

Peering is not a perfect replacement for transit service, and only provides a more direct path for traffic exchange among a subset of the ISPs, thus allowing more room for ISP-specific optimizations [3]. Recent studies show that propagation and queuing delays are often significantly reduced by peering compared to transit services. Shortening of the path length to large ISPs, and minimizing the detour of local traffic are also among the advantages of peering [4], [5]. Although transit costs have reduced significantly in recent years, the overall Internet traffic is rising exponentially, and the performance of peering in terms of path lengths and traffic exchange rates are better than transit services. As a result, the number of IXPs, along with the number of ISPs peering in those IXPs, have increased more than threefold in the past ten years [1].

Peering at an IXP can be of two types: *public peering* between more than two ISPs (generally settlement-free), and *private peering* between two ISPs (often involving payments). In a peering relationship if one ISP gains significantly more benefits than the other, paid peering may take place where the beneficiary ISP pays some fees to the other ISP [6]. Both these peering relationships are vital in the growth of the Internet. It is estimated that more than 20% of the Internet traffic flows through IXPs, and at least 80% of the IPs all over the world can be reached through peering [1], [7], [8]. Hence, aiding the ISP peering decision making process in a way so that any ISP can find potential ISP to peer with – along with the suggestion of stable peering locations – could be hugely beneficial to the Internet ecosystem. A recent survey focused on peering practices suggests that ISPs are eager to evolve toward next generation Internet practices, where they expect to establish peering relationships faster, and improve network performance along with the revenue earned [9].

In this paper, we aim to define some key metrics that can help model and automate the ISP peering decision making process. More specifically, we make the following contributions:

- We define and evaluate two novel metrics: *Peering Willingness (PW)* and *Peering Stability (PS)*, that can be used to model the peering decision process.
- We provide a peering decision solution for any ISP pair that uses only publicly available data and can easily be automated.
- We show that for an ISP pair, there is usually a peering location that gives a very stable solution (high *PS*) for both ISPs.
- We perform a comparative analysis between three types of ISP pairs and show that Access-Content ISP pairs typically attain the highest *PS* and *PW* scores in peering.

II. RELATED WORK

The problem of finding peering locations to obtain near-optimum performance has been assessed from different perspectives. Johari *et al.* argued that the peering location selection is an NP-hard problem. Further, they show that if nearest exit routing is used then the Price of Anarchy (*PoA*) (i.e., the worst-case ratio of the cost of a stable contract to the minimum achievable cost) with linear cost structure (cost linearly proportional to distance) is 3 [10]. Mahajan *et al.* proposed a negotiation-based routing solution and showed that a socially optimum solution can be achieved when the ISP pair has similar metrics and mapping process. Moreover, they argued that collaboration among ISPs yields higher benefits

when compared to a selfish approach [11]. Most of these related research focused on the question of how to optimize peering locations, but did not address the issue of whether two ISPs should peer or not. Lodhi et. al. [12] focused on developing an interconnection model of the ISPs, where the transit and peering costs are incorporated. The authors pointed out three major issues that make the peering decision problem hard to solve, namely, the uncertainty in traffic flows, the uncertain after-effect of peering, and the infeasibility of finding the optimal set of peers.

Several studies tried to solve the peering decision problem from an economic perspective using game theory, e.g., [13]–[15]. However, these works focused mainly on the systems perspective, i.e., to optimize the solution for the entire system instead of from the perspective of one of the peers. Further, while these papers theoretically analyze the equilibrium properties and PoA values; measures of the eagerness of an ISP pair to peer or choose a set of locations to peer are not provided.

To the best of our knowledge, Dey *et al.* is the first to numerically address the question of whether two ISPs should peer or not [16]. They propose an automated process (termed Metapeering) to find out the peering willingness between two ISPs and where they should peer. While our work is closely related to [16], it differs in several important aspects, and extends the earlier work in significant ways. Firstly, [16] does not consider the effect of internal routing cost, whereas we use the network topology for all ISP pairs to get a proper measure of the routing cost of peering at a location. Moreover, to get the coverage area of ISPs, [16] only focused on the Point-of-Presence (PoP) locations, while we extracted information on routers (i.e., location, density) of the ISPs. Furthermore, while [16] calculates the traffic matrix using population data of the corresponding areas, we consider customer distribution and router frequency to obtain more realistic traffic estimates. Lastly, while [16] only considers PoP locations as possible peering points, in our case along with the PoPs, we also considered the locations where both ISPs have high router density as possible peering points.

III. SYSTEM MODEL AND PRELIMINARIES

A. Network

To model the network structure of an ISP (or AS) we gathered information on its routers (from CAIDA [17]), coverage area (from FCC [18]), and PoPs (from PeeringDB [19]). From FCC’s website (Form 477) we obtained the service area of access ISPs, along with a customer distribution with a census tract granularity. This helped us to approximate the amount of traffic that the access ISPs have at a given location. On the other hand, the router level information, i.e., how many routers are located at which location, were obtained from CAIDA database for Content and Transit ISPs (using their AS number(s)). Lastly, PeeringDB has information on IXPs and the ISPs peering (public and private) at those IXPs. Fig. 1 shows the US map with routers and PoPs for an AS pair, where Router-1 and PoP-1 denote the router and PoP locations for ASN 4181, and Router-2 and PoP-2 those for ASN 11,492.

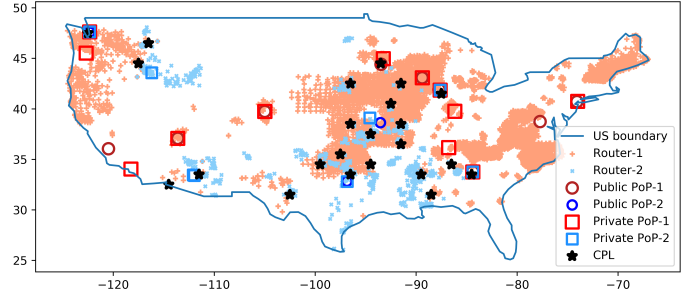


Fig. 1. Router and PoP distribution for a sample ISP pair (on US map).

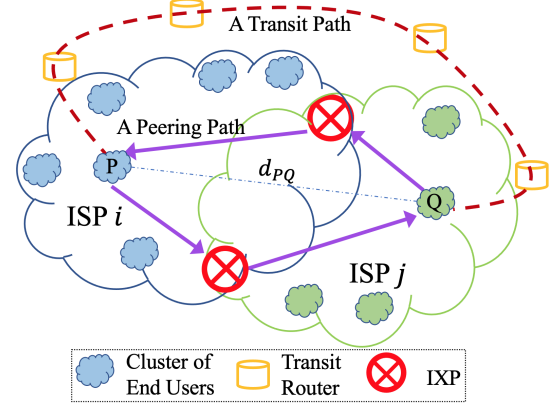


Fig. 2. Sample peering and transit path for an ISP pair.

B. Cost of Traffic

The dollar cost of sending traffic from one point to another is difficult to determine in general. For an ISP, a major part of the cost of carrying traffic through its network involves increased congestion and the cable network it needs to deploy for carrying that traffic. On the other hand, if the ISP decides to send traffic via a transit provider, then the cost is in terms of fee that the transit provider charges. Although in practice these cost functions can involve many parameters, some studies (e.g., [20]) show that we can model the cost in terms of the distance that the traffic needs to travel. For demonstration purposes, let us assume a scenario like Fig. 2, where the ISPs i and j have two peering locations (red crossed circle) at two IXPs, and are connected to those locations by their internal routing (purple path). On the other hand, they have the option to exchange their traffic via transit service, which follows a path (red dashed) through the transit provider’s routers (orange cylinders). Since the transit path is usually longer than the shortest available path and sometimes longer than the peering path, a parameter known as the *path stretch factor* is used to calculate the actual distance that the traffic might have to travel via a transit path. A detailed discussion on the path stretch factor is provided in the next section. Now, let us assume that some traffic needs to travel from point P (of ISP i) to Q (of ISP j), and d_{PQ} is the distance between those two points (Fig. 2). Also, let us denote d_I as the distance that the traffic needs to travel while passing through the internal routes of the ISP up to the peering location. Then we can estimate the internal routing cost of the ISP, $C_I = a \times d_I$, where a is some constant, and the transit cost $C_T = a \times d_{PQ} \times f$, where f is the path stretch factor.

C. Path Stretch Factor

A route in the Internet may not always take the shortest available path due to several reasons. Path stretch factor (f) between two end-points, P and Q , can be loosely defined as the extent to which a path taken from P to Q is longer than the shortest available one. This can be measured as the ratio of the actual path to the shortest path. The transit path shown in Fig. 2 is one example where the traffic has to take a longer detour because of some constraints such as policy.

Several studies measure router-level hop path stretch factor for the Internet. Tangmunarunkit *et al.* conducted one of the first few studies [21] to measure router-level path stretch because of routing policies, and Gao *et al.* extended this to include AS-level hop stretch [22]. Both these papers report the trends seen in path stretch, but do not report the global averages. Similarly, Mühlbauer *et al.* computed the path stretch factor on a large-scale simulated AS-level graph constructed using CAIDA [23]. They calculate the path stretch in terms of AS-level hops (1.3), router-level hops (2.1), and geographical distances (2.9). Ming *et al.* study the relation between path stretch and inter-AS collaboration using multiple randomly populated simulated AS graphs, but do not report any average path stretch factor values.

IV. METRICS FOR PEERING DECISION-MAKING

Peering decision between two ISPs is a pairwise decision, and peering might not take place if one of them does not have enough motivation to peer. Also, as part of this decision-making process, they need to choose the peering locations so that these locations are desirable from the perspective of both ISPs.

A. Peering Willingness

The first metric that the ISPs are likely to compare when making a peering decision is the cost of sending traffic via transit (*transit cost*) with the cost of exchanging traffic under a peering relationship (*peering cost*). We define *peering willingness* of an ISP i , denoted by PW_i , as the ratio of transit cost to peering cost from the perspective of that ISP. If PW_i is greater than 1, then ISP i will be willing to peer with the other ISP, say j . We further define *pairwise peering willingness* between ISPs i and j as $PW_{ij} = \sqrt{PW_i \times PW_j}$, which expresses the overall peering willingness of the ISP pair.

Although peering willingness is a good indicator for whether both ISPs have the incentive to peer, it does not differentiate between public and private peering. If an ISP pair (i, j) has a similar amount of traffic to exchange, then their peering (and transit) cost will be similar, and hence with $PW_{ij} > 1$, they will be eager to form public peering. On the other hand, for highly asymmetric traffic (a usual case for Access-Content (A-C) ISP pair), if the cost of peering is highly asymmetric as well, then even with high PW_{ij} , the ISP pair may only be willing to do private peering where some monetary exchange may take place. As discussed in the introduction, Content ISPs are expanding rapidly; with a peering relationship between themselves, these content ISPs with their heavy backbone networks can connect to almost

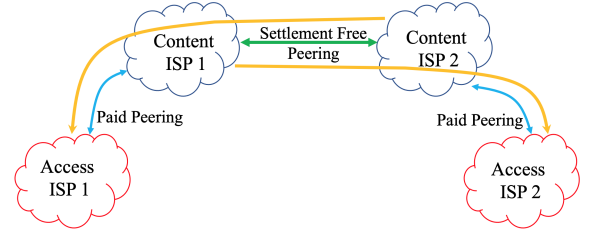


Fig. 3. Peering relationship between Access and Content ISPs.

all Access (or Eyeball) ISPs. Thus, it is fair to assume that Content-Content (C-C) peering is going to be settlement-free (public) peering in most cases, whereas paid peering may be more common for A-C type ISP pairs (Fig. 3).

B. Peering Stability

When forming a peering relationship, each ISP tries to find location(s) where it can exchange traffic cost-effectively. The presence of an ISP at an IXP or a heavily clustered region of routers of that ISP denotes a *probable peering location (PPL)* for it. Let us denote the *PPL* of ISP i as PPL_i . To express the priority of a location over others, we model an ISP's preference in terms of different weights on its respective *PPLs*. For ISP i , if a location has the m^{th} highest weight according to i 's preferences, then the weight of that location is denoted as W_{im} . If ISP i wants to peer with ISP j then the *common peering locations (CPL)* of ISP pair (i, j) are the locations where both ISPs are present (via IXP or routers). One sample *CPL* set (the first 23 according to the weights) is shown in Fig. 1 for an ISP pair (using star markers). The *CPL* list is the set of locations where the ISP pair might agree to peer with one another and the total number of locations in *CPL* is N . If, for K peering locations, any of the $\binom{N}{K}$ combinations ensure a favorable cost solution from the perspective of both ISPs (i and j), then they will form a peering agreement at those K locations. Let us say P is one of the combinations of the peering locations (consisting of K locations), then for this set we define *Peering Stability (PS)* for an ISP as the ratio of minimum cost attainable to the cost with P as the peering location set. Hence, for an ISP i , the *PS* for peering location set P is, $PS_i(P) = \frac{\min(C_i)}{C_i(P)}$, where $\min(C_i)$ is the minimum cost that ISP i would have incurred for all the different peering sets (with K locations in each set), and $C_i(P)$ is the cost for the specific set of locations, P .

To get a better understanding of *PS* refer to Fig. 4. As we can see the coverage area of ISP i (blue) and the coverage area of ISP j (green) has three locations (*CPL*) where they can peer due to the availability of IXPs at those locations. Now, for $K = 2$ the best solution from the perspective of ISP i may be to select the two IXPs at the top, whereas for ISP j it is to select the bottom two IXPs. When these two ISPs consider peering and if they can only peer at two locations (due to some constraint), then no matter which solution is agreed upon, one of the ISPs will not get the best solution from its perspective. However, if the solution does not deviate much from the minimum possible solution, both ISPs are likely to peer. Hence, we define the peering stability for an ISP pair

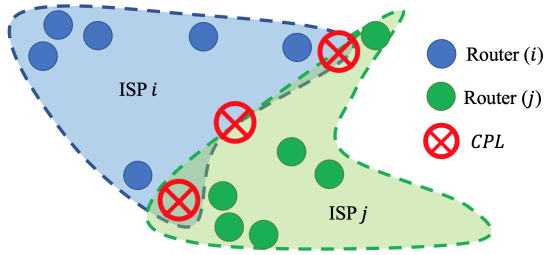


Fig. 4. Sample peering locations for an ISP pair.

(i, j) as $PS = \sqrt{PS_i \cdot PS_j}$, which quantifies the overall stability of the peering relationship.

V. SIMULATION RESULTS

Using public datasets, we simulate and discuss results on our peering metrics. We first consider peering at a single location, and then explore adding more peering points. We evaluate peering between three types of ISP pairs, namely Access-Access ($A-A$), Access-Content ($A-C$) and Content-Content ($C-C$).

A. Simulation Setup

To construct a scenario representative of the peering process where the ISPs take individual as well as pairwise decisions and decide under what circumstances they would peer, we follow a step-by-step algorithm for each ISP pair:

- *Initialize* the ASNs of the ISP pair.
- *Load* router and peering data of both ISPs.
- *Determine* the *PPL* of both ISPs and assign priority to each *PPL*.
- *Determine* the *CPL* and sort them in common priority.
- *Calculate* the transit cost from the perspective of each ISP.
- For K peering points in *CPL*, *calculate* the peering cost for all peering combinations from each ISP's perspective.

In the procedure above, using the ASNs of the ISPs, router and peering information can be obtained from CAIDA and PeeringDB (as discussed in Section III-A). The *PPL* of an ISP is sorted according to the frequency of PoP(s) and Router(s) at some location (of the *PPL*) in a decreasing order. Then a weight is calculated by inverting their position value, i.e., if a location (of *PPL*) is at 5^{th} place, then the weight is assumed to have a value of $1/5$. After determining the *PPL* sets for the ISP pair, we form the *CPL* as the intersection of the two *PPL* sets. Now, the weight of these *CPL*s need to be determined from the perspective of both ISPs, which we have estimated as a geometric mean of their weight from the point of view of each ISP. Hence, the location with the m^{th} highest weight in the *CPL* list has a weight $W_{(i,j)_m} = \sqrt{W_{i_p} W_{j_q}}$, where it is assumed that the current location is at p^{th} and q^{th} position of the sorted *PPL* list of i and j , respectively.

The peering cost for an ISP i is calculated as the sum of the costs that it incurs to exchange traffic between locations from inside of its network to outside of its network. Let us say there is some location A that is inside the network coverage of ISP i , and B is some location outside of i 's network but inside the network of another ISP j . Then the amount of traffic

that ISP i has for ISP j is $y_{AB}^{ij} \propto \frac{R_j}{d_{AB}^2}$ (using a modified gravitational model as in [24]), where R_j is the number of routers (or customer in case for access ISP) of ISP j and d_{AB} is the distance between A and B . The peering cost for ISP i to exchange y_{AB}^{ij} traffic is then $C_{PAB}^i \propto y_{AB}^{ij} \cdot d_I$, where d_I is the distance that the traffic need to travel internally in i 's network, and the total peering cost for ISP i is $C_P^i = \sum_A \sum_B C_{PAB}^i$. On the other hand, the transit cost for the traffic y_{AB}^{ij} is $C_{TAB}^i \propto y_{AB}^{ij} \cdot d_{AB} \cdot f$, and the total transit cost for ISP i is $C_T^i = \sum_A \sum_B C_{TAB}^i$.

B. Single Point Peering

1) *Peering Stability*: We calculated the peering stability as defined in Section IV-B for single point peering ($K = 1$). Since all the peering locations from the *CPL* set are used, a lot of the locations had very poor *PS*. The *PS* distribution for three types of ISP pair is plotted in Fig. 5. It can be seen that apart from $A-A$ type ISP pair, the other two types have a lot of peering locations with very poor *PS*, and more than 50% has peering stability within a range of $[0, 0.2]$. For the case of $A-A$ ISP pair, the *PS* distribution is much evenly distributed and there are a lot of locations where the peering cost is not that bad compared to the best peering solution.

The peering stability distribution gives us an idea of the cost comparison between peering locations across different points; however, if an ISP pair decides to peer at some location, we just need to focus on the *PS* for that specific point only. Fig. 6 depicts the box plot of the best *PS* for each ISP pair, and shows the existence of at least one highly stable peering location for all three types of ISP pairs. As expected, most of the $A-A$ ISP pairs have at least one peering location that has a *PS* value very close to 1 (both ISPs have close to minimum cost).

2) *Peering Willingness*: The most important question about peering is if two ISPs are going to form a peering relationship or not. Peering willingness (as defined in Section IV-A) for an ISP pair gives the ratio of peering cost to transit cost for some peering location(s). We calculate the ratio of transit cost (C_T) to peering cost (C_P) using the method described in Section III-B and V-A, while varying the path stretch factor (f) from 1 to 5. Fig. 7 depicts the percentage of ISP pairs that have *PW* value more than 1 (peering cost is less than transit cost) for the locations with highest *PS* for each ISP pair. The reason behind using the location with highest *PS* for each ISP pair only is that it corresponds to the most stable peering location from the perspective of both ISPs. From the figure we observe that with the increase of the value of path stretch factor (f), the willingness of peering increases for all types of ISP pairs. Moreover, for smaller value of f , the ISP pair with the higher peering willingness is the $A-C$ type, followed by $C-C$; and $A-A$ type do not have any willingness to peer for small values of f . However, for higher values of f ($f > 3$), we see a different picture, where the willingness to peer increases almost exponentially for $A-A$ type ISP pairs.

C. Multiple Point Peering

1) *Optimum and Sub-optimal Solutions*: The total number of locations in the *CPL* can be as large as 50 (or more)

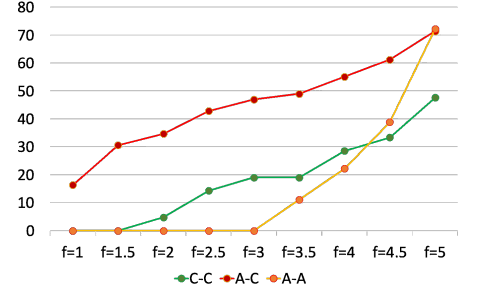
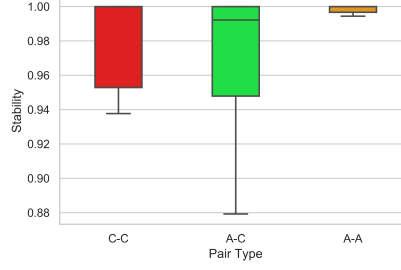
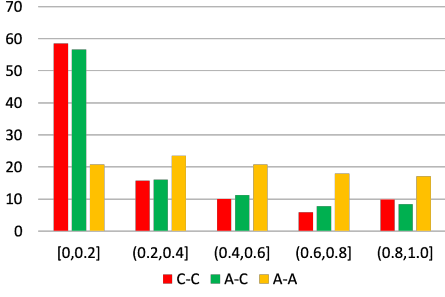


Fig. 5. Stability distribution (single peering point). Fig. 6. Existence of stable peering location.

Fig. 7. Peering willingness with path stretch factor.

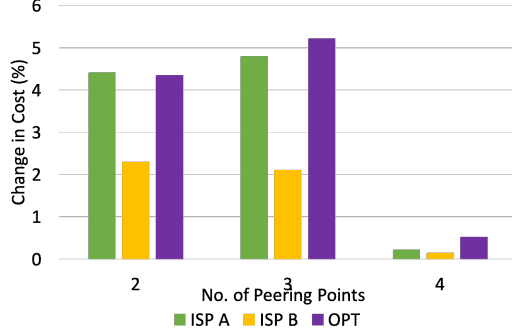


Fig. 8. Comparison between optimal and greedy solution.

for large ISPs. When calculating cost for multiple peering points, if $K > 2$, then the possible combinations of peering locations $\binom{N}{K}$ becomes very large, and it becomes computationally challenging to calculate cost for all the peering combinations. Therefore, we utilized a greedy algorithm where the peering locations are picked sequentially to find the peering combination that gives the best PS . Let us say that we need a set of $K = 3$ peering locations. Then our algorithm will first calculate the PS values individually for each N locations (similar to single point peering). If the location X has the highest PS , then in the next step we fix X and choose the next location Y that maximizes the PS among all the remaining $N - 1$ locations, given that X is already chosen. This process continues until we have K locations. In a few cases that we have compared, we found out that the peering cost calculated from our greedy algorithm is quite close to the optimum solution. Also, the highest deviation was seen when $K = 2, 3$ (the reason is similar to what we observed in Section IV-B); however with increasing K beyond 3, we observed that our greedy algorithm gave peering cost values very close to the optimum (highest PS) solution. Simulating for 21 ISP pairs we found that the average difference in cost between our greedy solution and the optimum is 4.4%, 5.215% and 0.52% for $K = 2, 3$, and 4 respectively.

2) *Peering Stability and Willingness*: The concept of PS and PW being the same as before, we now discuss these metrics for multiple peering points. We used the greedy algorithm outlined earlier to calculate the minimum peering cost for both the ISPs, and the peering cost with the highest PS . Although there may be a fixed cost and sometimes a monthly cost to peer at some location, since it is difficult to relate that cost with the routing or transit costs, such costs are ignored in our calculation. As expected, with the addition of peering points, the peering willingness increases for both $A - C$ and $C - C$ type ISP pairs. Due to high computational

TABLE I
PEERING STABILITY WITH MULTIPLE PEERING POINTS.

Points	C-C (avg)	C-C (min)	A-C (avg)	A-C (min)
1	0.99035	0.96835	0.98576	0.91806
2	0.95428	0.67226	0.98040	0.77798
3	0.93977	0.68838	0.97936	0.83070
4	0.89055	0.53858	0.97384	0.86933

time needed for $A - A$ ISP pair we could only generate very few results and are not shown here. Similar to the single peering point case, the $A - C$ ISP pair types are more willing to peer and almost 80% of the ISPs will want to peer if given the choice to peer at 4 locations (assuming negligible cost for peering). For $C - C$ type pair, we see more than 60% pairs to have $PW > 1$ for $K = 4$.

On the other hand, the PS does not increase with the addition of peering locations. The main reason behind is that when multiple peering locations are considered, the peering points that give the minimum cost for one ISP usually do not coincide with the other ISP. However, that effect is not so significant and usually PS retains a very good value even for large values of K . Table I displays the values of PS for different values of K (points). For $A - C$ type ISP pair, the minimum PS over all the ISP pairs is 0.86 and the average is 0.974, which is very close to 1. So, multiple point peering is quite stable from the perspective of $A - C$ type pairs. For $C - C$ type pairs, the stability is not that good and there is a PS value as low as 0.54. However, on an average the PS value is still not very bad (0.89) for the $C - C$ pairs.

3) *Price of Stability*: From the perspective of both ISPs, a stable peering relationship is implied by a high PS value. We define the equilibrium cost for an ISP pair as the total cost that the ISP pair incurs when they agree to peer at the location(s) with highest PS for some value of K . Also, the optimum cost (OPT) is the total cost that the ISPs would have faced (for the same value of K) if they followed some system level solution which aims to minimize the total cost. With a slight abuse of terminology we define the price of stability (PoS) for our current problem as the ratio of cost at equilibrium to OPT. Fig. 10 portrays the average PoS for two types of ISP pair with single and multiple peering locations. The average PoS values for single point peering ($K = 1$) is very close to 1 and hence the equilibrium solution and OPT have nearly the same cost. With the increase of peering points the PoS values for $C - C$ type ISP pair increases faster than $A - C$ type pair. We observe that for multiple peering points, even with $K = 4$, on an average the equilibrium cost for $A - C$ ISP pair is only 1.05 times the minimum cost achievable.

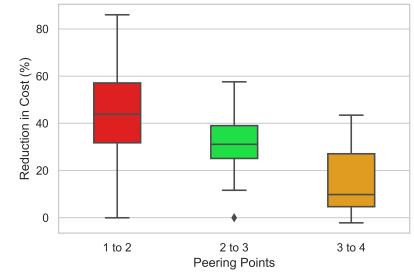
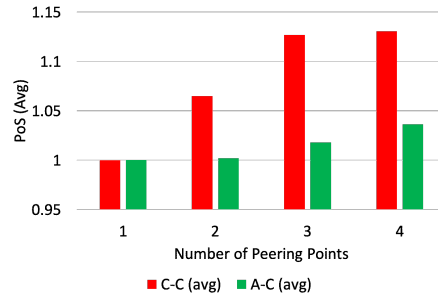
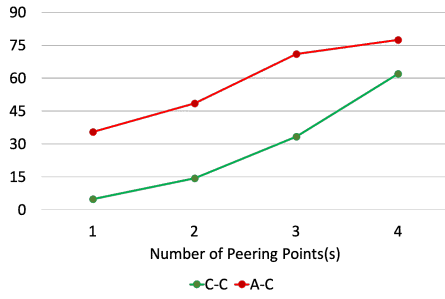


Fig. 9. Peering willingness (multiple peering points). Fig. 10. PoS for multiple peering points.

Fig. 11. Reduction in cost with peering points.

4) *Cost Reduction with Multiple Peering Points*: The reduction in cost with the addition of peering locations is expected and is depicted in Fig. 11. Although the addition of peering locations decreases the cost, the percentage decrease tends to follow a diminishing pattern. On an average, the cost reduction from $K = 1$ (single point peering) to $K = 2$ is 45%, whereas the average reduction is only 10% when going from $K = 3$ to 4. Hence, in most cases, an ISP pair can attain a stable and economically efficient peering relationship by peering at fewer than 4 peering locations.

VI. CONCLUSION

We modeled ISP peering with the help of publicly available databases to develop a method that automates the decision of peering and peering locations. For an ISP pair, our method computes the peering willingness of that ISP pair, which being more than 1 indicates that the ISP pair is motivated to peer. Moreover, the approach defines the peering stability and price of stability (PoS) for multiple peering points, which quantify the stability of the peering relationship. Extensive simulations with real data from different public databases provide insight about peering for three types of ISP pairs. The Access-Content ISP pair type shows high peering willingness along with higher peering stability and low PoS , hence making it the ideal pair for having peering relationship. On the other hand, although Access-Access type ISP pair has the highest stability for single point peering, it exhibits low peering willingness. We envision that proper application of the willingness and stability metrics outlined in this paper, along with their method of calculation, can help towards making peering more automated as well as more effective.

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