Understanding the confounding factors of inter-domain routing modeling

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ABSTRACT

The Border Gateway Protocol (BGP) is a policy-based protocol, which enables Autonomous Systems (ASes) to independently define their routing policies with little or no global coordination. AS-level topology and AS-level paths inference have been long-standing problems for the past two decades, yet, an important question remains open: *"which elements of Internet routing affect the AS-path inference accuracy and how much do they contribute to the error?"*. In this work, we: (1) identify the confounding factors behind Internet routing modeling, and (2) quantify their contribution on the inference error. Our results indicate that by solving the first-hop inference problem, we can increase the exact-path score from 33.6% to 84.1%, and, by taking geolocation into consideration, we can refine the accuracy up to 94.6%.

CCS CONCEPTS

• **Networks** → **Network simulations**;

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1 RELATED WORK

The pioneering and most classic approach to infer AS-paths was proposed by Gao and Rexford in 2001 [4]. In 2007, Muhlbauer et al. introduced a new abstraction: next-hop atoms [9] which correspond to per-neighbor path choices. In 2012, Gill et al. [6] developed a novel routing tree algorithm that computes paths between all source-destination pairs in an AS graph. Recently, We et al. [14] developed a learning-based technique, taking into consideration the node, link, and path features related to route decisions in practice.

2 EXPERIMENTAL SETUP AND RESULTS

In this project, we infer AS-level paths using the simulator proposed by Sermpezis and Kotronis [13], which offers a Python implementation of the Gao-Rexford model [4]. Additionally, we collect the AS-paths followed in practice through the BGPStream API [10]. BGPStream utilizes vantage points (VPs) from RouteViews and RIPE RIS projects, which provide a partial view of the Internet topology graph. Nonetheless, not all ASes share their routing tables, thus, researchers rely on inferences to study paths from non-VP ASes. Finally, we leverage the following well-known metrics to capture the inference accuracy of the model:

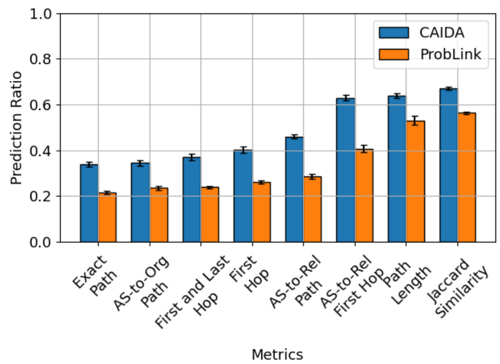

Figure 1: Average inference accuracy (vanilla model).

Exact AS-Path Match: The ratio of inferred AS-paths that are exactly the same as the observed AS-paths.

Path Length Match: The ratio of inferred AS-paths that have the same length as the observed AS-paths.

First-hop Match: The ratio of inferred AS-paths that have the same first-hop as the observed AS-paths.

First and Last-hop Match: The ratio of inferred AS-paths that have the same first and last hop as the observed AS-paths.

AS-to-ORG Path Match: The ratio of inferred AS-to-ORG paths[1] that are the same as the observed AS-to-ORG paths.

AS-to-Rel Path Match: The ratio of inferred AS-to-Rel paths[2] that are the same as the observed AS-to-Rel paths.

AS-to-Rel First-hop Match: The ratio of inferred AS-to-Rel paths that have the same first-hop as the observed AS-to-Rel paths.

Jaccard Similarity: The intersection of the inferred and observed AS-paths over the union of the inferred and observed AS-paths.

We conduct three rounds of Monte-Carlo simulations using the Gao-Rexford model and the current state-of-the-art AS-level topologies, CAIDA and ProbLink [2, 8]. In the first round, we study the performance of the vanilla Gao-Rexford model. In the second round, we explore the performance of the Gao-Rexford model given that we have knowledge over the first-hop. In the last round of simulations, we identify and quantify the confounding factors that affect the inference accuracy.

[1]A path of organization IDs.
[2]A path of AS-relationships.

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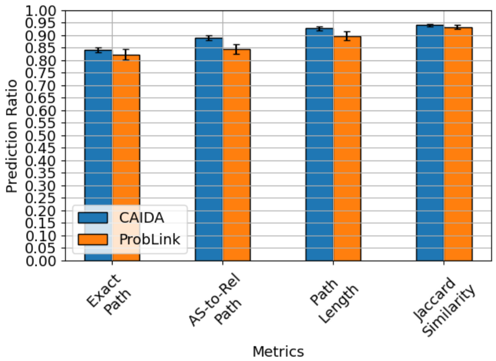

Figure 2: Average accuracy when first-hop known.

In Fig. 1, we plot the Gao-Rexford model inference accuracy. Overall, using the CAIDA topology we achieve at least 10% better accuracy across all metrics, compared against ProbLink. Regarding the main metric of our analysis, *Exact Path Match*, the model scores 33,8% and 21,4% using CAIDA and ProbLink respectively. This is evidence that the limitations addressed in recent work [1] still hold: *the Gao-Rexford model can predict AS-paths exactly as they are observed on the real Internet, only 1/3 of the times.*

To evaluate a first-hop aware model, we only consider inferences for which we can correctly predict the first-hop in the AS-path. In Fig. 2, we plot the inference accuracy of the first-hop aware model and observe that it yields 2,5 times higher accuracy than the vanilla model (84,1% and 82,1% for CAIDA and ProbLink respectively). This is a strong indicator that **(1) the ability to determine the first-hop can significantly affect the overall inference**.

Finally, we study the reasons behind the exact path misses, by identifying the first AS-link in the inferred path that differs from the actual path (see Table 1). The confounding factors are as follows:

Missing AS-relationship: The topology dataset does not include a link for the respective ASes in the observed path.

Valley-free violation: The actual path has a valley [7], hence, the model, by default, cannot predict this route.

Local preference violation: The model selects a route through a *less preferable neighbor* than the observed path.

Shortest path violation: The model selects a *longer* path than the observed path.

Location-agnostic path selection: Due to the Internet flattening [5], it is reasonable to consider the geographical distance between ASes in the BGP route selection process [12]. Yet, neither the actual BGP best path process [11] nor the Gao-Rexford model consider geolocation. We leverage country-level location information from the AS-rank API [3] and study whether the inferred paths go through longer distances than the observed paths.

From Table 1, we observe that **(2) having resolved the first-hop problem, the most important factor that affects the inference process is the *location-agnostic path selection*.** We neither plan to fix the missing links (0.95%), nor replace the valley-free model (4.36%), hence, the maximum achievable accuracy is 94.69%. Preliminary results show that we can improve the accuracy

	CAIDA	ProbLink
Exact Path Match	**84.1 %**	**82.1 %**
Missing AS relationships	0.95 %	0.53 %
Valley-free violations	4.36 %	1.32 %
Local-pref violations	**7.86 %**	**11.42 %**
Shortest path violations	2.93 %	3.62 %
Loc-agnostic selection	**8.54 %**	**10.31 %**

Table 1: Confounding factors

of existing inference techniques to 91.63%, given that we include a location-aware methodology in the inference process.

Currently, we are working on identifying the specific what-if questions that can be addressed with existing models, and explore the benefits of location-aware prediction modeling.

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