Toward Programmable Interdomain Routing

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Abstract

End-to-end route control spanning a set of autonomous systems (ASes) can provide opportunities to both end users to optimize interdomain control and network service providers to increase business offerings. BGP, the de facto interdomain routing protocol, and recent interdomain proposals provide limited mechanisms for such control. We provide the first, systematic formulation of the *software-defined internetworking (SDI)* model, where an AS exposes a programmable interface to allow clients to define the interdomain routes of the network, and maintains its autonomy, by keeping the control of its export policies, to avoid fundamental violations such as valley routing. We develop a blackbox optimization algorithm to quickly find optimal export-policy-compliant end-to-end routes in SDI, and validate its efficacy using real interdomain topology. To understand the operational implication of SDI, we evaluate the privacy leakage brought by exposing an AS' available interdomain routes. Preliminary results show that a small number of neighbors or a large number of exposed RIB samples allows accurate inference on an AS' BGP selection policy, indicating a potential risk of not only SDI, but the whole interdomain routing community.[1]

CCS Concepts

• **Networks → Network protocol design**; **Routing protocols**; **Programmable networks**.

Keywords

Interdomain Routing, SDN

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1 Introduction

Although flexible, end-to-end route control may provide substantial benefits to both networks and end users (*e.g.*, conduct traffic engineering, or prevent DDoS attacks), it is extremely complex and difficult to achieve, if not impossible, in the current Internet, where ASes are interconnceted by the Border Gateway Protocol (BGP) [16]. To fill this gap, several interdomain routing systems have been designed and deployed [1, 3, 9–13, 15, 21]. However, they either are point solutions, or may have datapath overhead such as tunneling processing on each data packet.

In this paper, we investigate a novel, systematic, low-overhead interdomain route control model which we call the software-defined internetworking (SDI) model. Motivated by the success of intradomain SDN models such as Openflow or P4 but extending to interdomain, SDI defines an interdomain programmable interface so that a network exposes to a client its available interdomain routes, *i.e.*, its interdomain routing information base (RIB), to a destination, and the client can then choose one of them, just as an intradomain SDN client can select a port as the next hop among a set of available output ports of an SDN switch. Different from intradomain SDN, however, SDI maximizes network autonomy, by allowing a network to maintain the control of its interdomain export policies, to avoid fundamental violations such as valley routing.

A fundamental challenge for SDI is for clients to find the optimal, export-policy-compliant end-to-end routes, because ASes keep their export policies private. To this end, we develop a blackbox optimization algorithm to sample end-to-end routes sequentially and find an optimal export-policy-compliant route with a small number of samples. We validate its efficacy via experiments on real interdomain topology data (Figure 1). Next, to understand the operational implication of SDI, we conduct a study to evaluate the privacy leakage brought by exposing a network's RIB and the selected route. Specifically, we investigate the feasibility of inferring the selection policy of an AS from its exposed RIB and the selected route. Results show that a small number of neighbors or a large number of exposed (RIB, selected routes) samples allows accurate inference on an AS' selection policy.

2 SDI Design: Model and Algorithm

SDI programmable network. The SDI model builds on top of existing BGP-connected interdomain networks. It uses the one-big-switch abstraction widely used in BGP studies (*e.g.*, [6–8, 16]). In addition to an actual BGP speaker, each AS

[1] Part of the results are reported in a long paper in IEEE INFOCOM 2020.

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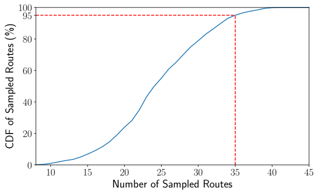

Figure 1: **CDF of the number of routes the blackbox optimization algorithm sampled to find the optimal, export-policy-compliant end-to-end route in SDI.**

also runs a virtual BGP speaker, which has the same route selection and export policies as the actual BGP speaker, and establishes BGP sessions with the virtual BGP speakers of the neighboring ASes. Given a destination IP prefix p, each AS exposes to clients (1) its RIB to reach p, (2) the price to use each route in the RIB, and (3) the currently selected route by the AS. Each AS provides three interfaces, *select_route*, *commit_route* and *delete_route*, for clients to select interdomain routes, but maintains the control of its export policies.

In SDI, a client uses a two-phase commit design pattern to test the export-policy-compliance of an end-to-end interdomain route before actually using and paying for it. Given a route **r**, a client can check its export-policy-compliance by iteratively interacting with the ASes along **r** in a backward order using the *select_route* interface. After finding an export-policy-compliance route **r** that she wants to use, a client can interact with the ASes along **r** in a backward order to setup the route on actual BGP routers using the *commit_route* interface. This design avoids (1) the disruptions and churns in the interdomain network caused by the client using a non-policy-compliant route; and (2) the waste of monetary expenses of the client paying for such a route.

Computing optimal routes in SDI. A fundamental challenge for the SDI model is for clients to find the optimal, export-policy-compliant end-to-end routes, because ASes keep their export policies private. We develop a blackbox optimization algorithm to sample interdomain routes sequentially and find an optimal export-policy-compliant route with a small number of samples. The algorithm iteratively leverages the prior belief about the problem to help direct the sampling, and to trade exploration and exploitation of the search space [4, 17], and properties from interdomain routing algebra [8, 18] to derive an accurate estimation on the expected improvement of an end-to-end route. Experiments using real interdomain topology (Figure 1) show that in a network with ~60k ASes and ~320k AS-level links, in 95% experiment cases, our algorithm finds an optimal policy-compliant end-to-end route with no more than 35 samples.

3 Operational Implication: Privacy Study

In SDI, each AS exposes its RIB and the selected route. To understand its operational implication, we investigate the privacy leakage of exposing such information, *i.e.*, whether BGP policies can be inferred from it. On a first glance, one may think there should be little or no privacy leakage, because (1) BGP is usually perceived to be good at hiding policies and in real world, such information is already exposed in BGP Looking Glass servers [19], and (2) inferring policies based on such information is a constraint acquisition problem, which is in general computationally intractable [2]. Our preliminary study, however, indicates the opposite.

BGP selection policy can be inferred from RIB and the selected route. We formulate the problem of inferring BGP selection policy of an AS from its exposed RIB and the selected route as a classification problem. We generate ground-truth datasets by simulating the operation of an AS connected with a fixed number of neighbors, which uses the typical BGP route selection procedure specified in RFC 4271 [16] to select the best route from RIB. We record the (RIB, selected route) tuple as a sample and randomly generate datasets with different numbers of neighbors (3-20), next-hop-based local preference assignments, and numbers of samples (200-20k). A total of 18k datasets are generated.

First, we implement a simple feed-forward neural network with 1 hidden layer of 30 neurons [14], and use it to infer the BGP selection policy of each dataset. Results show that when the number of neighbors is small (*i.e.*, <=8), even when the training dataset only has 160 samples (*i.e.*, 80% of the 200 samples in a small dataset), the simple neural network can learn the selection policy with a minimal of 95% accuracy. Next, leveraging the domain knowledge that the typical BGP route selection procedure is a ranking function, we tailor RankNet [5], a classical tool for learning the ranking function of search results, to infer the BGP selection policy. Results show that even if an AS has 20 neighbors, with 10,000 samples, our tailored RankNet can learn the selection policy with a minimal of 91% accuracy. These preliminary results indicate the potential risk of an AS' BGP policies being inferred when its RIB and the selected route are exposed. More importantly, we point out that this risk is not unique to SDI, but to a general context of interdomain routing (*e.g.*, looking glass servers). Details of this study can be found in [20].

4 Conclusion and Future Work

We propose the SDI model to enable flexible, end-to-end interdomain route control, and report our findings on its benefits (*i.e.*, efficient, flexible end-to-end route) as well as its operational implication on ISP's privacy (*i.e.*, exposing RIB allows accurate inference of AS' selection policy). Our on-going future work includes investigating optimal SDI route control under network outage, scalable BGP policy inference with few-shot learning, and policy protection mechanisms.

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References

[1] Gilad Asharov, Daniel Demmler, Michael Schapira, Thomas Schneider, Gil Segev, Scott Shenker, and Michael Zohner. 2017. Privacy-preserving interdomain routing at Internet scale. *Proceedings on Privacy Enhancing Technologies* 2017, 3 (2017), 147–167.

[2] Christian Bessiere, FrÃ©dÃ©ric Koriche, Nadjib Lazaar, and Barry O'Sullivan. 2017. Constraint acquisition. *Artificial Intelligence* 244 (2017), 315 – 342. https://doi.org/10.1016/j.artint.2015.08.001 Combining Constraint Solving with Mining and Learning.

[3] Rüdiger Birkner, Arpit Gupta, Nick Feamster, and Laurent Vanbever. 2017. SDX-Based Flexibility or Internet Correctness?: Pick Two!. In *Proceedings of the Symposium on SDN Research*. ACM, 1–7.

[4] Eric Brochu, Vlad M Cora, and Nando De Freitas. 2010. A tutorial on Bayesian optimization of expensive cost functions, with application to active user modeling and hierarchical reinforcement learning. *arXiv preprint arXiv:1012.2599* (2010).

[5] Chris Burges, Tal Shaked, Erin Renshaw, Ari Lazier, Matt Deeds, Nicole Hamilton, and Greg Hullender. 2005. Learning to rank using gradient descent. In *Proceedings of the 22nd international conference on Machine learning*. 89–96.

[6] Lixin Gao and Jennifer Rexford. 2001. Stable Internet routing without global coordination. *IEEE/ACM Transactions on Networking (TON)* 9, 6 (2001), 681–692.

[7] Timothy G Griffin, F Bruce Shepherd, and Gordon Wilfong. 2002. The stable paths problem and interdomain routing. *IEEE/ACM Transactions on Networking (ToN)* 10, 2 (2002), 232–243.

[8] Timothy G Griffin and Joäo Luís Sobrinho. 2005. Metarouting. In *ACM SIGCOMM Computer Communication Review*, Vol. 35. ACM, 1–12.

[9] Arpit Gupta, Robert MacDavid, Rüdiger Birkner, Marco Canini, Nick Feamster, Jennifer Rexford, and Laurent Vanbever. 2016. An Industrial-Scale Software Defined Internet Exchange Point.. In *NSDI*, Vol. 16. 1–14.

[10] Arpit Gupta, Laurent Vanbever, Muhammad Shahbaz, Sean P. Donovanand Brandon Schlinker, Nick Feamster, Jennifer Rexford, Scott Shenker, Russ Clark, and Ethan Katz-Bassett. 2014. SDX: A Software Defined Internet Exchange. In *Proceedings og SIGCOMM 2014*. IEEE, 233–239.

[11] Vasileios Kotronis, Xenofontas Dimitropoulos, and Bernhard Ager. 2012. Outsourcing the routing control logic: better internet routing based on SDN principles. In *Proceedings of the 11th ACM Workshop on Hot Topics in Networks*. ACM, 55–60.

[12] Karthik Lakshminarayanan, Ion Stoica, Scott Shenker, and Jennifer Rexford. 2004. *Routing as a Service*. Computer Science Division, University of California Berkeley.

[13] Pedro R. Marques, Jared Mauch, Nischal Sheth, Barry Greene, Robert Raszuk, and Danny R. McPherson. 2009. Dissemination of Flow Specification Rules. RFC 5575. https://doi.org/10.17487/RFC5575

[14] Michael A Nielsen. 2015. *Neural networks and deep learning*. Vol. 2018. Determination press San Francisco, CA, USA:.

[15] Simon Peter, Umar Javed, Qiao Zhang, Doug Woos, Thomas Anderson, and Arvind Krishnamurthy. 2014. One tunnel is (often) enough. In *ACM SIGCOMM Computer Communication Review*, Vol. 44. ACM, 99–110.

[16] Yakov Rekhter, Susan Hares, and Dr. Tony Li. 2006. A Border Gateway Protocol 4 (BGP-4). RFC 4271. https://doi.org/10.17487/RFC4271

[17] Bobak Shahriari, Kevin Swersky, Ziyu Wang, Ryan P Adams, and Nando De Freitas. 2015. Taking the human out of the loop: A review of Bayesian optimization. *Proc. IEEE* 104, 1 (2015), 148–175.

[18] Joao Luis Sobrinho. 2003. Network routing with path vector protocols: Theory and applications. In *Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications*. ACM, 49–60.

[19] Nippon Telegraph and Telephone. 2016. NTT Looking Glass. https://www.us.ntt.net/support/looking-glass/.

[20] Qiao Xiang and Jensen Zhang. 2020. SDI Technical Report. https://tinyurl.com/ycqfdogj.

[21] Wen Xu and Jennifer Rexford. 2006. Multi-path Interdomain Routing. In *In SIGCOMM*. Citeseer.