Constraint Conditions to Eliminate AS Incentive of Lying in Interdomain Routing

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***Abstract*—Autonomous Systems(ASes) discover routing paths to the destination AS via BGP announcements advertised by neighbor ASes in interdomain routing. However, the actual packets forwarding paths of ASes may be inconsistent with their announced routing paths. Lying about data routing path is the main cause of path inconsistency. Prior work on this issue could not stop ASes announcing *non-best* routing path. This paper search for constraint conditions on routing policy to make the single AS have no incentive to unilaterally lie about its actual routing path, if the other ASes in the network honestly advertise their actual routing paths. We model routing policy with AS business relationships and propose AS revenue function to quantify AS incentive. Relying on traffic attraction models, we propose the constraint conditions. We demonstrate, both theoretically and experimentally, that the conditions could eliminate AS incentive of lying completely.**

Keywords—Interdomain routing, Path inconsistency, Incentive of lying, Constraint conditions

I. INTRODUCTION

Internet is composed of Autonomous Systems(ASes), including Internet service providers(ISPs), campus networks, and enterprise networks. Based on Border Gateway Protocol(BGP)[1], AS can learn several alternative routes, which are announced by different neighbors, to reach a particular prefix. The routing policy of each AS depends on its commercial, performance, or other considerations. AS applies its routing policy to select a best route to be used for data forwarding and to be potentially announced to its neighbors. Unfortunately, BGP does not include any mechanism to ensure announced routing path matches data forwarding path. Misconfigurations[2], compromised routers, or equipment failures[3, 4] can cause announced routing path to deviate from data forwarding path. However, lying about data routing path is the main cause of path inconsistency. AS could advertise *non-best* routing path to neighbor ASes to attract extra traffic to increase the revenue, or drop, tamper the packets[5, 6]. While neighbor ASes lose commercial benefits, even their routing policies are meaningless since announced routing paths they received are not the actual routing paths.

Much work[7, 8] had been devoted to securing the announced routing path or verifying the path inconsistency. These methods focused on the loosely-stated goal of ensuring "correct operation of BGP". However, they are either expensive data plane path enforcement, or some useless control-plane path verification. Goldberg[6] suggested that imposing very strong restrictions on ASes policies could make ASes have no incentive to lie. It showed that in a constructed attraction model, satisfying some combination of the conditions, any utility an AS gained by lying could equivalently be obtained if that AS had instead honestly announced paths to neighbors. Intuitively, it seems that the conditions work well. However, ASes are not simple nodes in a mathematical graph. In the Internet, it exists business relationships between ASes[9], which is widely believed to play a great role in determining the routing policies. Nevertheless, the attraction models and conditions in[6] were unreasonable under the interpretation of business relationships[1]. Our analysis also finds that the proposed conditions could not eliminate ASes incentives of lying completely.

In this paper, we focus on eliminating AS incentive of lying about routing path. We propose a combination of constraint conditions on routing policies of ASes to enable the single AS has no incentive to unilaterally lie if the other ASes in the network honestly advertise their actual routing paths. Based on business relationships which are believed to capture the majority of the economic relationship of ASes, we model AS routing policy. In the routing policy, ASes prefer customer routes and consider other preference when relationships of different paths are the same.

Before eliminating AS incentive of lying, we should determine whether ASes have the incentive. AS revenue function is proposed to quantify AS incentive. We calculate AS revenue as honest revenue when it advertises the actual routing path to neighbors, and as lying revenue when it announces *non-best* routing path to neighbors. Comparing the two revenues, we could decide whether AS has an incentive to lie about its routing path. According to different ASes relationships, we build two traffic attraction models as *customer attraction model* and *provider attraction model*. In these models, we analyze the incentive of the manipulator AS and propose the combination of constraint conditions. Finally, we prove the validity of the conditions from the theory and experiment separately.

The remainder of this paper is organized as follows: Section II models AS routing policy and revenue function. Section III builds two attraction models. Section IV proposes the combination of constraint conditions and proves the validity of conditions in theory. SectionV presents the experiment to evaluate the performance of the conditions. SectionVI discusses the deployment of the conditions. SectionVII introduces related work. Section VIII concludes this paper and points out the future work.

[1]Goldberg had admitted the limitation of models and conditions, and thought that finding a more appropriate model with business relationships remained open.

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II. AS ROUTING POLICY AND REVENUE FUNCTION

In this section, we model AS routing policy with ASes business relationships. With AS routing policy. AS revenue function is defined to quantify AS incentive. Finally we analyze the variation of AS revenue to determine whether AS has the incentive to lie.

A. AS routing policy

In practice, routing policies are decided locally by each AS, which are arbitrary and not publicly known. ASes relationships possibly constitute the most popular policy model. Gao and Rexford[9] firstly described business relationships between ASes. The relationships consist of three aspects: *customer to provider*(c2p), *provider to customer*(p2c) and *peer to peer*(p2p). Customer is typically a smaller AS that pays a larger AS for access to the rest of Internet. Provider may be a customer of a larger AS. Two peers are typically of comparable size and find it mutually advantageous to transit traffic between their respective customers. A Gao-Rexford network obeys the following conditions:

Acyclicity: there is no customer-provider cycles in the AS graph, i.e., no node is its own indirect customer.

Export rule: a node *b* only exports to node *a* paths through node *c* if at least one of nodes *a* and *c* are customers of node *b*.

Prefer customer: nodes prefer outgoing paths where the next hop is a customer over outgoing paths where the next hop is a peer or a provider, and prefer peer links over provider links.

Although business relationship is believed to be the first preference of ASes, some ASes may have other unknown considerations in their policies, so we combine them together and model routing policies: *ASes obey export rule of Gao-Rexford network and prefer forward traffic to customer AS; if different paths have the same relationship, ASes choose their best routing path with other considerations. The considerations include shortest path, lowest AS number or even arbitrary selection, etc.*

B. AS revenue function

ASes are business entities in the Internet and pursue more economic benefits. Their benefits or revenues could be influenced by lots of factors. In the routing topology, the direct influence factors are *in-path* and *out-path*. *In-path* is the path along which packets are forwarded to the AS. *Out-path* is the path along which AS itself forwards packets to neighbors. Hence, before introducing AS revenue function, we propose path revenue function firstly.

Much work[10, 11] had analyzed the path revenue, they all agreed that path property and path traffic were important parameters of path revenue. Relying on these parameters, we refer to AS relationship of the path to define path revenue.

Definition 1 (Path revenue)**.** Adjacent ASes a and b is connected by path *P*. The revenue u of *P* is:

$$u = \lambda \times ttr \tag{1}$$

	Customer path	Peer path	Provider path
in-path	< 0	< 0	> 0
out-path	> 0	< 0	< 0

TABLE I: Influence of relationship on λ of *in-path* and *out-path*

where λ is the path parameter which depends on the relationship and customer cone difference between *a* and *b*, ttr is the data traffic in the path.

Customer cone[12] of AS *a* is *a* itself plus all the ASes that can be reached from *a* following only p2c(not c2p or p2p) links. In other words, *customer cone* of *a* is *a*, plus customers of *a*, plus customers of its customers, etc. ASes with larger *customer cone* have an especially important role in the capital and governance structure of the Internet. ISPs commonly known as *Tier-1 ASes* have the largest *customer cone*. Customer cone difference between two ASes could reflect the business relationship. *Customer cone* of provider AS is larger than customer AS. The larger the difference is, the more customer AS has to pay provider AS.

The same relationships have different influences on λ of *in-path* and *out-path*. According to different ASes relationships, paths could be characterized to three classes:

Customer path: path *mn* is a customer path if *n* is a customer of *m*.

Peer path: path *mn* is a peer path if *n* and *m* are peer ASes.

Provider path: path *mn* is a provider path if *n* is a provider of *m*.

Assume path *ab* is *in-path* of *b*, and it is a *customer path*, so *b* is a customer of *a* and has to pay *a* for traffic in the path. *b* would lose some revenues, and we could get $\lambda_{ab} < 0$. To the contrary, if *ab* is *out-path* of *a*, and it is a *customer path*. *a* could be paid by *b* and its revenue is increased, so we could get $\lambda_{ab} > 0$. *Peer path* is a special path, because ASes of the path share the costs of maintaining the connection. These costs are significantly smaller than transit charges for similar traffic settings but are not negligible nevertheless, so $\lambda_{peerpath} < 0$. Formally, influence of AS relationship on λ is summarized in Table. I. For the path revenue, if customer cone difference is large, the absolute value of λ is large, and vice versa.

Based on path revenue function, we give the definition of AS revenue function.

Definition 2 (AS revenue)**.** The revenue u of AS *m* is:

$$u_m(T) = v_m(T) + \alpha_m(T) \tag{2}$$

where *T* is the current routing topology of *m*. v_m is *in-path* revenue, while α_m is *out-path* revenue.

We define *T* as the topology when *m* advertises best routing path, and *Q* as the topology in which it lies about routing path. Because ASes lies to gain more revenues, we could conclude that ASes have incentives to lie only if $u_m(Q) > u_m(T)$. In the following sections, we all rely on this conclusion to infer AS incentive.

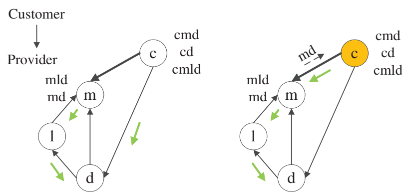

Fig. 1: Customer attraction model

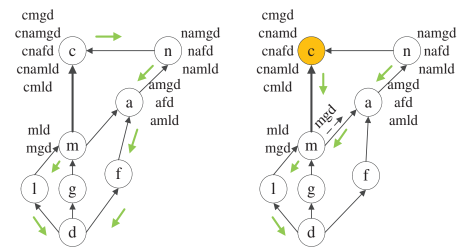

Fig. 2: Provider attraction model

III. TRAFFIC ATTRACTION MODEL

According to different ASes relationships, we present two traffic attraction models. In these models, the manipulator AS tries to export *non-best* routing path to attract traffic from customer or provider ASes to increase its own revenue.

A. Preliminaries

We set $G = (V, E, R)$ denote network routing topology. The nodes vertex V denotes ASes in G. The vertex E denotes directed edges between ASes in network G. Edges E are annotated with AS relationships $R = p2c, c2p, p2p$. For example, $R(e) = p2c$ for an edge $e =< u, v >$ implies that u is a provider of v. $P = (n_1, n_2, ..., n_i)$ denotes announced path P in G. If node m is not in P, $P_m = mP$ denotes the routing path from m to n_i. Let $w(P)$ denote the weight of path P. Without loss of generality, we assume that more preferred path is assigned with a higher weight. And P is a *permitted path* for m if $w_m(P) > 0$.

Following the literature[13], we assume that there is a unique destination node d to which all other nodes attempt to establish a path(it means that we ignore the issue of route aggregation[4]). And we always consider networks with *no dispute wheels*[14](nodes always prefer to route to the destination node directly rather than through the other nodes) and *path verification*[7](all the announced paths are verified and exist in the network).

B. Customer attraction model

We define that there is a customer attraction relationship if the provider node could increase its revenue when it attracts traffic from customer nodes.

Fig. 1 shows a simple customer attraction model, the black arrow line represents the c2p relationship, the green arrow line represents the traffic flow. Node m is the single manipulator node and tries to advertise its *non-best* routing path to attract traffic from customer node c.

In the left topology, m honestly announces its best routing path *mld* to c. Node c chooses *cd* to forward traffic, since *cd* has a higher weight than *cmld*. According to AS revenue function, it could get m revenue as:

$$u_m(T) = v_m(ml) + \alpha_m(0) \tag{3}$$

where $v_m(ml) = \lambda_{ml} \times ttr_m$ and $\alpha_m(0) = 0$.

While in the right topology, m lies about its routing path and exports path *md*, rather than the more preferred path *mld*, to c. With routing policy of c, *cmd* is its best routing path. Node m revenue is:

$$u_m(Q) = v'_m(ml) + \alpha'_m(cm) \tag{4}$$

where $v'_m(ml) = \lambda_{ml} \times (ttr_m + ttr_c)$ and $\alpha'_m(cm) = \lambda_{cm} \times ttr_c$.

For the manipulator m, *in-path cm* is a *provider path*, *out-path ml* is a *customer path*, so $\lambda_{cm} > 0$ and $\lambda_{ml} > 0$. Then we could get $u_m(Q) - u_m(T)$:

$$u_m(Q) - u_m(T) = ttr_c \times (|\lambda_{ml}| + |\lambda_{cm}|) \tag{5}$$

It reveals that $u_m(Q) > u_m(T)$, and m increases its revenue. We could confirm that m has an incentive to lie about its routing path.

C. Provider attraction model

Fig. 2 is a provider attraction model. The left is the topology in which m advertises its best routing path *mld* to c and a. Best routing path of c is *cnafd*, and m revenue is

$$u_m(T) = v_m(ml) + \alpha_m(0) \tag{6}$$

where $v_m(ml) = \lambda_{ml} \times ttr_m$, $\lambda_{ml} > 0$,$\alpha_m(0) = 0$.

m announces *non-best* routing path *mgd* in the right topology. c applies its routing policy to choose the highest weight path *cmgd* to forward data traffic. Node m revenue is

$$u_m(Q) = v'_m(ml) + \alpha'_m(am) + \alpha'_m(cm) \tag{7}$$

where $v'_m(ml) = \lambda_{ml} \times (ttr_m + ttr_c + ttr_a + ttr_n)$, $\alpha'_m(am) = \lambda_{am} \times (ttr_a + ttr_n)$, $\alpha'_m(cm) = \lambda_{cm} \times ttr_c$, $\lambda_{ml} > 0$, $\lambda_{cm} < 0$ and $\lambda_{am} < 0$.

Then we could get $u_m(Q) - u_m(T)$:

$$u_m(Q) - u_m(T) = (ttr_c + ttr_a + ttr_n) \times [|\lambda_{ml}| - (|\lambda_{am}| + |\lambda_{cm}|)] \tag{8}$$

Assume that $|\lambda_{ml}| > |\lambda_{am}| + |\lambda_{cm}|$, it could get $u_m(Q) > u_m(T)$, and m could lie about its routing path to increase its revenue.

Internet is fundamentally a hierarchical topology. As discussed earlier, the top layer ASes are back bone ISPs and have large *customer cone*. The bottom layer ASes are some small ASes even *stub* ASes which are on the edge of the Internet. The same layer ASes are mostly peer nodes and have the similar *customer cone*. In provider attraction model, we assume that $|\lambda_{ml}| > |\lambda_{am}| + |\lambda_{cm}|$. According to the relationship between

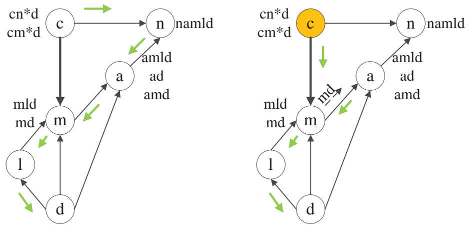

Fig. 3: The topology satisfying the conditions

customer cone difference and λ of path, we could get that $ml_{ccd} > (cm_{ccd}+am_{ccd})$, where *ccd* represents customer cone difference. It means that nodes *c*, *a* and *m* are in the similar layers, while *l* is in the lower layer. Node *m* attracts provider nodes traffic and forwards traffic to lower layer customer nodes to gain more revenues, and it exists exactly in the Internet[12].

IV. Constraint conditions

In this section, we try to find the constraint conditions on routing policy to ensure the single AS honestly announces its path in both customer and provider attraction models.

A. Incomprehensive restrictive conditions

Before analyzing the restrictive conditions proposed by Goldberg[6], we introduce some definitions of the conditions on routing policy:

Policy consistent: if node *b* sends route advertisements to *a*, whenever node *b* prefers some path *bPd* over *bRd*(neither path goes through *a*), then *a* prefers *abPd* over *abRd*.

Next-hop policy: a node only cares about the neighbor node through which its traffic is routed and nothing else. Although $w_b(bPd) > w_b(bRd)$, paths from *b* have the equal weight for *a* and $w_a(abPd) = w_a(abRd)$.

Consistent export rule: if *b* exports to *a* some path P_1, it must also export every other *permitted path* that is ranked at least as high as P_1.

Consistent export rule is compatible with *export rule*. And the restrictive conditions in[6] could be described as: *Consider a policy-consistent, Gao-Rexford network, in which attractees use next-hop policies with their providers and peers. Suppose that all nodes, except a single manipulator node m, use a consistent export rule that satisfies export rule of Gao-Rexford network. Then m has no incentive to lie about its actual routing path.* In actual network, ASes are business entities and have no obligation to export their routing paths to neighbors. Even with *consistent export rule*, nodes may only export their highest weight path to their neighbor nodes, or export no path to their neighbor nodes at all.

Fig. 3 shows the topology which meets the required conditions. In the left topology, *m* announces path *mld* to *a* and *c*. Due to *consistent export rule*, *a* exports its highest weight path *amld* to *n* and *n* advertises *namld* to *c*. With AS revenue function, *m* revenue is:

$$u_m(T) = v_m(ml) + \alpha_m(am) \tag{9}$$

where $v_m(ml) = \lambda_{ml} \times (ttr_c + ttr_n + ttr_a + ttr_m)$ and $\alpha_m(am) = \lambda_{am} \times (ttr_c + ttr_n + ttr_a)$.

In the right topology, *m* advertises *non-best* path *md* to *a*. And at the same time, *d* would notice *a* that *a* could forward traffic directly to *d*. According to routing policy of *a*, it chooses *ad* as its best routing path. However, due to some ulterior reasons, *a* would not export *ad* to *n*, and *n* has no path to *d*. As a result, *c* chooses *cm*d* as its best routing path, and *m* revenue is:

$$u_m(Q) = v'_m(ml) + \alpha'_m(cm) \tag{10}$$

where $v'_m(ml) = \lambda_{ml} \times (ttr_c + ttr_m)$ and $\alpha'_m(cm) = \lambda_{cm} \times ttr_c$.

For the manipulator *m*, *in-path am* is a customer path and *cm* is a provider path, while *out-path ml* is a customer path, it could get that $\lambda_{ml} > 0$, $\lambda_{am} < 0$ and $\lambda_{cm} > 0$. Formally express $u_m(Q) - u_m(T)$ as $u_m(Q) - u_m(T) = ttr_c \times (|\lambda_{cm}| + |\lambda_{am}|) + (ttr_n + ttr_a) \times (|\lambda_{am}| - |\lambda_{ml}|)$ If $|\lambda_{am}| > |\lambda_{ml}|$, we could get $u_m(Q) > u_m(T)$. It means that *m* could still announce *non-best* routing path to attract customer nodes traffic to gain more revenue.

B. Constraint conditions

Since the main cause of the problem is *consistent export rule*, we need to explore some new conditions which satisfy *export rule* and could also solve the problem. The new conditions are *same neighbor export rule*:

Same neighbor export rule: if node *b* had exported path *bad* to its neighbor node *n*, then it must advertises all the *permitted paths* which contains *a* as the next hop node to *n*.

Same neighbor export rule and *consistent export rule* are complementary.

Now we give the definition of the constraint conditions:

Definition 3 (Constraint conditions)**.** In Gao-Rexford network, all nodes, except a single manipulator node *m*, use *consistent export rule*, *same neighbor export rule* with their neighbor nodes. They use *next-hop policy* with their providers and peers, and are *policy consistent* with their customers.

C. Proving the validity of constraint conditions

Firstly we propose the Lemma. 1.

Lemma 1. *Satisfying constraint conditions, nodes c and n are neighbor nodes of m. P_1, P_2 are permitted paths of c. P_1 passes through n rather than m, and P_2 passes through m. If best routing path of c is P_1 when m honestly advertises its routing path, m could not announce its non-best path to n to make c choose P_2 as its best routing path.*

Proof. Since *c* is not a manipulator node and P_1 is its best routing path, clearly we could get $w_c(P_1) \geq w_c(P_2)$. $w_c(P_1) = w_c(P_2)$ if *c* is a customer node, because it uses *next-hop policy* with its provider and peer nodes.

Suppose P_{m1}, P_{m2} are *permitted paths* of *m* and $w_m(P_{m1}) \geq w_m(P_{m2})$, best routing path of *n* is P_n. Because P_1 passes through *n*, we could get P_n does not pass through *m*. And since *n* and *m* are *policy consistent*, we could get

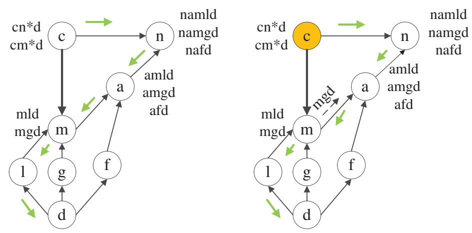

Fig. 4: Attract customer nodes traffic

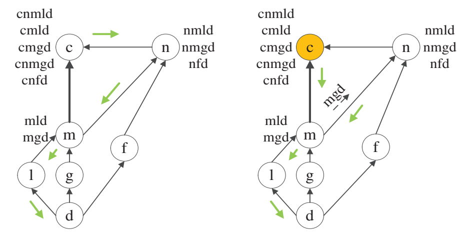

Fig. 5: Attract provider nodes traffic

$w_n(P_n) > w_n(nP_{m1}) \geq w_n(nP_{m2})$. Due to lowest weight of $w_n(nP_{m2})$, *n* would not change its best routing path when *m* announces *non-best* routing path P_{m2} to *n*.

P_1 could be denoted as $c * P_n$. Because *n* does not change its best routing path, P_n is still advertised to neighbor nodes, so P_1 is still best routing path of *c*. □

Now we get the Theorem. 1 to prove that constraint conditions could eliminate ASes incentives of lying in customer attraction model.

Theorem 1. *Satisfying constraint conditions, m has no incentive to lie about its actual routing path to attract traffic from its customer nodes.*

Proof. Relying on constraint conditions and Lemma. 1, we construct the topology as Fig. 4 and prove the theorem in the topologies. We prove the theorem by reduction to absurdity, and assume that *m* still has an incentive to lie about its routing path. With revenue function, it could get $u_m(Q) > u_m(T)$.

The left of Fig. 4 is the topology when *m* announces its best routing path *mld* to *a* and *c*. Node *m* revenue is $u_m(T) = v_m(ml) + \alpha_m(am)$. Node *m* advertises *non-best* routing path *mgd* in the right topology. Due to the *next-hop policy* of attractee *c*, the only way for *m* to attract traffic of *c* is to make path *cn*d* become invalid. Because *a* and *n* are *policy consistent*, and apply *consistent export rule*, *same neighbor export rule*, both of them have received all the paths advertised by *m* and have the same ranking of these paths. If *m* sends *mgd* to *a*, then *a* chooses path *amgd* and advertises *amgd* to *n*. Finally *n* exports *namgd* to *c* and *c* still chooses *cn*d* as its best routing path. Node *m* revenue is $u_m(Q) = v_m(ml) + \alpha_m(am) = u_m(T)$.

With the above analysis, we could conclude that the result $u_m(Q) = u_m(T)$ violates our assumption. The theorem is proved. □

Due to *export rule*, customer node *a* could not export path *abd* which passes through its provider node *b* to another provider node *n*, so we could not require provider nodes to use *next-hop policy* with their customer nodes. However, without *next-hop policy*, it leaves a chance for *m* to attract traffic from provider nodes even with constraint conditions(described in Lemma. 2).

Lemma 2. *Satisfying constraint conditions, node m could announce non-best routing path to attract data traffic from its provider nodes.*

Proof. To prove the Lemma. 2, we build the topology(shown in Fig. 5) which satisfies constraint conditions. Node *c* is a provider node of *m* and it does not apply *next-hop policy*. When *m* announces routing path *mld* to *c* and *n* in the left topology, *n* chooses *nmld* and exports it to *c*. Node *c* chooses *cnmld* to forward traffic.

Node *n* uses *consistent export rule* and *same neighbor export rule* with *m*. When *m* advertises *mgd* in the right topology, *n* is not influenced and its routing path is not changed. However, paths ranking of *c* is $w_c(cnmld) > w_c(cmld) > w_c(cmgd) > w_c(cnmgd) > w_c(cnfd)$, *c* receives *mgd* from *m* and would choose *cmgd* to forward data traffic. Finally *m* attracts traffic of *c*. □

Recall that ASes incentives of lying are to increase their revenues. Although Lemma. 2 claims that *m* could attract its provider nodes traffic, fortunately its revenue does not increase.

Theorem 2. *Satisfying constraint conditions, node m could not attract provider nodes traffic to increase its revenue.*

Proof. We prove the theorem by reduction to absurdity, and assume that provider attraction could increase *m* revenue. With revenue function, it could get $u_m(Q) > u_m(T)$.

Node *m* revenue is $u_m(T) = v_m(ml) + \alpha_m(nm)$ in the left topology of Fig. 5. In the right topology, *m* advertises *mgd* to *n* and *c*. Node *c* chooses *cmgd* as its best routing path. Node *m* revenue is $u_m(Q) = v'_m(ml) + \alpha'_m(nm) + \alpha'_m(cm)$. *In-path* of *m* is changed, however, *out-path* and traffic forwarded to *m* is unchanged, so it could get $v_m(ml) = v'_m(ml)$. Further we could get $\alpha_m(nm) = \lambda_{nm} \times (ttr_c + ttr_n)$, $\alpha'_m(nm) = \lambda_{nm} \times ttr_n$, $\alpha'_m(cm) = \lambda_{cm} \times ttr_c$. *In-path nm* and *cm* are both *customer paths*, *out-path ml* is a *customer path* either, so $\lambda_{ml} > 0$, $\lambda_{nm} < 0$ and $\lambda_{cm} < 0$. Finally, $u_m(Q) - u_m(T) = ttr_c \times (|\lambda_{nm}| - |\lambda_{cm}|)$.

The absolute value of λ is revelant to customer cone difference of ASes of the path. Since *c* is a provider of *n* and *m*, and *n* is a provider of *m*, it could get $m_{customercone} < n_{customercone} < c_{customercone}$, so $|\lambda_{nm}| < |\lambda_{cm}|$. Finally we could get $u_m(Q) < u_m(T)$, and it violates our assumption. The theorem is proved. □

V. Evaluation

In this section, we design the experiment to evaluate the performance of the constraint conditions to prove the validity. We run simulations on several datasets from CAIDA[15], including $ASrelationships$_2011.03.04, $AScustomercone$_2011.03.30 and $ASlink$_2012.01.06. Here we sort ASes by their *customer cone* and choose the first 1000

	Upper bound	Lower bound	AS number
Tier-1	∞	22000	25
Tier-2	22000	12700	82
Tier-3	12700	100	598
Small scale	100	0	295

TABLE II: AS layers based on *customer cone*

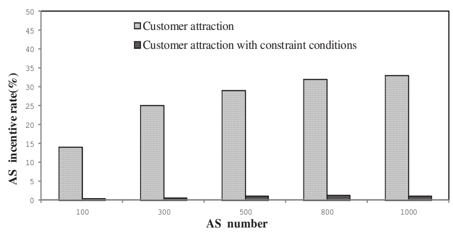

Fig. 6: ASes with the incentive of lying in customer attraction model

ASes to build the topology. Table. II illustrates four layers of the topology. The first 25 ASes are the *Tier-1 ASes* and providers of the other ASes. *Small scale* ASes are mostly stub ASes which are on the edge of the Internet.

We set five sets as the first 100 ASes, the first 300 ASes, the first 500 ASes, the first 800 ASes and all the ASes. We search for ASes that may have the incentive of lying with different attraction models in these sets separately. The percentage of ASes with incentive of lying is calculated. In the Fig. 6, it could find that ASes which may have incentive of advertising *non-best* path to customer nodes are widely distributed, even in the *Tier-1*. However, there is no obvious growth trend for them among different sets, because ASes outside the first 800 have very little customers. After deploying the constraint conditions in the topology, the result shows that percentage of ASes with incentive of lying is reduced to 1%-2% significantly. A small part of them still exist, the reason is that sibling relationship which is a special relationship would cause little influence on the result. And we will discuss it in the full version.

In the Fig. 7, provider attraction cases are not found in the sets of 100 and 300, because ASes in these sets are mostly providers of other ASes. However, in the sets of 800 and 1000, ASes with the incentive of lying are 45% for the total number. With the deployment, the constraint conditions also show a good performance, in which ASes with incentive of lying are 2%-3% for the total number. Both of two results reveal that the constraint conditions could eliminate AS incentive of lying effectively.

VI. DISCUSSION

The constraint conditions proposed in this paper could solve the problem of incentive to lie, even have some challenge of deployment. ASes may think that deploying the conditions could restrict their routing policies. To address this issue, we could find a small ISPs group as early adopters, in which ASes have an agreement to resist dishonest path announcement. The conditions could ensure that no single AS could deviate from the agreement. Then neighbors of adopters deploy the conditions because it could increase their revenues[16]. The process continues until all the ASes deploy the conditions.

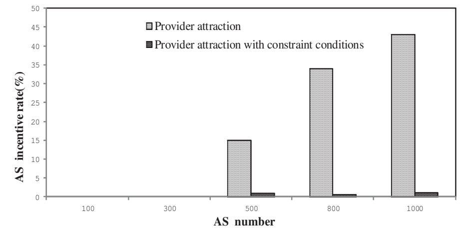

Fig. 7: ASes with the incentive of lying in provider attraction model

VII. RELATED WORK

Traditional research work(such as SBGP[7, 8]) was not sufficient to ensure the consistency of announced routing path and actual routing path. They could be summarized as path verification[17] which ensured that announced paths actually existed and loop verification[6] which prevented routing loops forming. Some data plane enforcement protocol[3, 18–21] had been studied to check the routing paths. Stealth probing[18] detected the fate of data traffic in a non-intrusive, coarse-grained, end to end fashion. It established IPSec tunnel between the source AS and the destination AS, and had a great overhead on network routing. Secure traceroute[21] established a shared secret predicate between ASes. ASes chose some packets as probe packets and verified if probe packets arrived the destination AS. It required router to compute a message authentication codes(MAC) for each response to a probe packet. The data plane countermeasures all need cryptographic operations and caused high overhead in interdomain routing.

VIII. CONCLUSION AND FUTURE WORK

In this paper, we design the constraint conditions to eliminate ASes incentives of lying. With the constraint conditions, the single AS has no incentive to unilaterally lie about its actual routing path if the other ASes in the network honestly advertise their actual routing paths.

To our knowledge, our work is the first to utilize AS revenue function to quantify AS incentive of lying. In future, we will inspect the validity of the conditions in actual network. And we also aim to propose a systematic mechanism to control interdomain routing to guarantee the consistency between actual routing path and announced routing path.

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References

[1] Y. Rekhter, T. Li, and S. Hares, "A border gateway protocol 4(bgp-4)," *RFC 4271*, Jan 2006. [Online]. Available: http://tools.ietf.org/html/rfc4271, 2006

[2] K. Butler, T. Farley, P. McDaniel, and J. Rexford, "A survey of bgp security issues and solutions," *Proceedings of the IEEE*, vol. 98, no. 1, pp. 100 –122, Jan 2010.

[3] E. L. Wong, P. Balasubramanian, L. Alvisi, M. G. Gouda, and V. Shmatikov, "Truth in advertising: lightweight verification of route integrity," in *Proceedings of the twenty-sixth annual ACM symposium on Principles of distributed computing*, ser. PODC '07, 2007, pp. 147–156.

[4] Z. M. Mao, J. Rexford, J. Wang, and R. H. Katz, "Towards an accurate as-level traceroute tool," in *Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications*, ser. SIGCOMM '03, 2003, pp. 365–378.

[5] P. H.Ballani and X.Zhang, "A study of prefix hijacking and interception in the internet," in *ACM SIGCOMM*, 2007.

[6] S. Goldberg, S. Halevi, A. D. Jaggard, V. Ramachandran, and R. N. Wright, "Rationality and traffic attraction: incentives for honest path announcements in bgp," in *Proceedings of the ACM SIGCOMM 2008 conference on Data communication*, ser. SIGCOMM '08, 2008, pp. 267–278.

[7] S. Kent, C. Lynn, and K. Seo, "Secure border gateway protocol (s-bgp)," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 4, pp. 582 –592, april 2000.

[8] R. White, "Securing bgp through secure origin bgp(sobgp)," in *The Internet Protocol Journal*, 2003, pp. 15–22.

[9] G. Lixin and R. Jennifer, "Stable internet routing without global coordination," *IEEE/ACM Trans. Netw.*, vol. 9, pp. 681–692, December 2001.

[10] H. Chang, S. Jamin, and W. Willinger, "To peer or not to peer: Modeling the evolution of the internet's as-level topology," in *INFOCOM 2006. 25th IEEE International Conference on Computer Communications. Proceedings*, April 2006, pp. 1 –12.

[11] P. Bangera and S. Gorinsky, "Impact of prefix hijacking on payments of providers," in *Communication Systems and Networks (COMSNETS), 2011 Third International Conference on*, Jan 2011, pp. 1 –10.

[12] "As commercial relationships data," in *http://as-rank.caida.org/data/*.

[13] G.Hustom, "Interconnection, peering, and settlements," in *Internet Glob.Summit(INET)*, Jun,1999.

[14] W. G. Griffin Timothy G, Shepherd F Bruce, "The stable paths problem and interdomain routing," *IEEE/ACM Transaction on Networking*, vol. 10, pp. 232–243, April 2002.

[15] [Online]. Available: http://as-rank.caida.org

[16] P. Gill, M. Schapira, and S. Goldberg, "Let the market drive deployment: a strategy for transitioning to bgp security," in *Proceedings of the ACM SIGCOMM 2011 conference*, ser. SIGCOMM '11, 2011, pp. 14–25.

[17] H. Levin, M. Schapira, and A. Zohar, "Interdomain routing and games," in *Proceedings of the 40th annual ACM symposium on Theory of computing*, ser. STOC '08. New York, NY, USA: ACM, 2008, pp. 57–66.

[18] I. Avramopoulos and J. Rexford, "Stealth probing: Securing ip routing through data-plane security," in *In Proc. of USENIX Annual Technical Conference*, 2006, pp. 267–272.

[19] K. Argyraki, P. Maniatis, O. Irzak, S. Ashish, and S. Shenker, "Loss and delay accountability for the internet," in *IEEE International Conference on Network Protocols,ICNP 2007*, Oct 2007, pp. 194 –205.

[20] X. Liu, X. Yang, D. Wetherall, and T. Anderson, "Efficient and secure source authentication with packet passports," in *In Proc. USENIX Wkshp. Steps to Reducing Unwanted Traffic on the Internet(SRUTI)*, July 2006.

[21] V. N. Padmanabhan and D. R. Simon, "Secure traceroute to detect faulty or malicious routing," *SIGCOMM Comput.Commun.Rev*, vol. 33, pp. 77–82, January 2003.