The practical way to understand relations between autonomous systems

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Abstract - Although Border Gateway Protocol (BGP) is broadly used among autonomous systems (ASes), the topology out of local autonomous systems is often mysterious to some Internet Service Providers (ISPs) or education institutions. Under the condition of unknowing routing policies of BGP neighbors and their uplink ASes, it is uneasy to understand to learn how to build a multi-homing environment and deal with congestion problems. Especially, some mistakenly announced prefixes on the Internet will continuously increase routing table and impact police-based routing. Therefore, this paper tries to analyze the whole adjacencies of autonomous systems running on the Internet, their relationships as well as the prefixes announced from every AS, and store them into a database. As a result, the whole topology among ASes becomes clearer, and then it is more practical to learn the way of building new networks, refining them and making a trouble shooting.

Keywords: BGP, autonomous systems, routing policies, network education, adjacencies, topology.

1. Introduction-Difficulty of understanding BGP and topology

As described in RFC 4271 [1] and RFC 4277 [5], the Border Gateway Protocol is an inter-Autonomous System routing protocol. It works among the autonomous systems, Internet Service Providers, nations and so on. BGP exchanges reachability messages between neighbors or peers, maintains three information databases as well as provides the routes that the BGP has selected by using local routing policies. Furthermore, this protocol supports Classless Inter-Domain Routing, RFC 1519 [3], and Variable Length Subnet Mask, RFC 1878 [4], which makes BGP speakers easy to advertise some appropriate IP prefixes not according to the classes and free to aggregate IP addresses to proper scales. And, the routing policy is a set of rules which regulates the traffic as well as relationships between the routers and other hosts in term of routes exchange and protocol interaction. Summarily, the routing policy allows a customer to define: (1) The collection of prefixes the router will receive or not receive from others; (2) The collection of prefixes the router will advertise or not advertise to others; (3) The redistribution of prefixes between the various routing protocols.

The BGP and routing policies are easy to understand. However, if putting them in real topology of the Internet, things will be changed. On one hand, the topology is blind for the students and instructors to learn; On the other hand, it is hard to learn to design a proper and robust [2] network for the real network according to its uplink topology. Finally, some irregular IP prefixes on the Internet make understanding of IP classification confused. For example, Figure 1 and Figure 2 explain this issue. Here, Fiure1 illustrates the normal situation of packet forwarding between AS 1 and C1. C1 chooses the link to AS2 as the default route to AS1, the link to AS3 as the backup link to AS 1, because it may be based on some commercial considerations. However, on the Internet, this is not necessarily the case. The Figure 2 shows a more complicated case which there is more than one ASes between AS1 and AS2, therefore

packets going through these ASes will be affected by their congestions, policies, hardware emergencies, and configuration error. Hence, only from text books and local view, students cannot clearly recognize the practical topology and the location of local area, and thus it is hard to give a proper BGP design and understand the essence of routing.
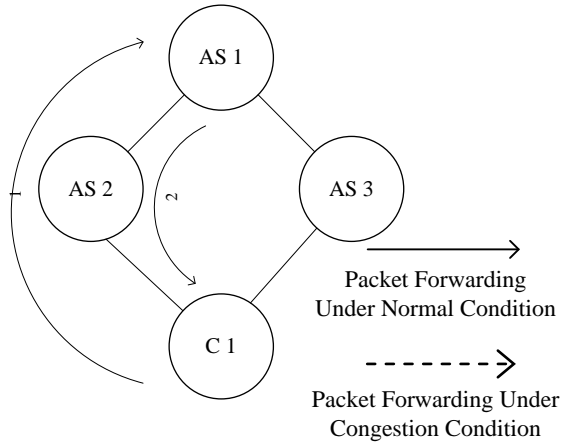

Figure 1. The situation of packet forwarding in normal condition and invisible to topology of uplink AS
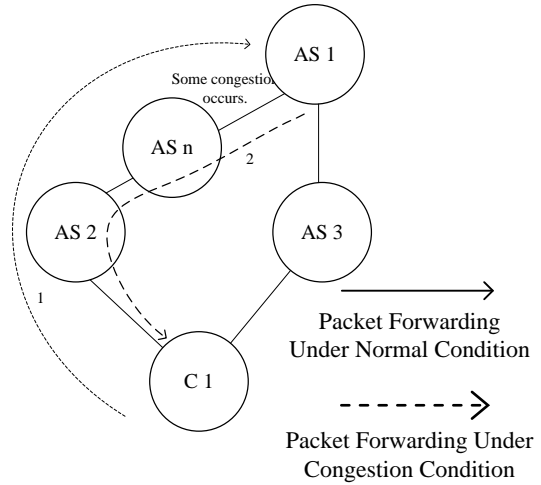
Figure 2. The situation of packet forwarding in congestion, multi-hop condition, and invisible to topology of uplink AS

Of course, it is not wise to show every autonomous system's route entries on a router and check them, but analyzing BGP routing table by use of a set of algorithm, making a statistics according of every AS, and then checking route entries as well as making policies in terms of the statistics are feasible and applicable. Therefore, this paper is trying to discover the whole relations among autonomous systems, and thus provide a clearer view for the network education for a better understanding BGP, topology, and the Internet.

2. The way to access Internet

Here, this article only discusses better education way of BGP and designing a network using BGP. By this, we introduce a database which contains two tables, table "as" and "routes_by_as" , presents the relations among ASes running on the Internet.

Table 1. Description of table "as"

Field	as_id	nei_num	nei_as
Description	AS number (primary key)	The number of BGP peers	The AS numbers of BGP peers

Table 2. Description of table "routes_by_as"

Field	as_id	route_number	route_entries
Description	AS number (primary key)	The number prefixes	The prefixes originated from this AS

Each line of table "as" contains binary relations of autonomous systems. Let R=(X, Y, G(R)) where R is the relation of X and Y, X consists of AS number identified in as_id field, Y consists of the AS number(s) of the EBGP neighbors of the one in as_id field, and G(R) means the graph of R. Equally, $R \subseteq X \times Y = \{<X, Y> | X \in as\_id, Y \in nei\_as\}$. For the comparatively better way to access internet, let R'=(Y, Z, G(R')), and $R' \subseteq Y \times Z = \{<Y, Z> | Y \in as\_id, Z \in nei\_as\}$. Here, Y may contain several AS numbers. Simultaneously, in the lines indexed by as_id of Y, each element of Y can also have one EBGP peer or several EBGP peers. The collection EBGP peers/peer of every element of Y is Z. If putting this action forward, the recursion will continue

until the last binary relation contains a proper IXP (Internet exchange point) or local area IXP. Then the shortest as-path to some IXP may be the better choice to access internet. Although one way to IXP or local IXP might be not the best choice to access Internet, the previous result can provide a visible topology of uplink AS and the nearest IXP, which may take some help to multi-homing design and choice of main uplink.

For example, $X = \{15430\}$, $Y = \{34, 981\}$, then R is the Cartesian product of X and Y. $R = \{<X, Y> \mid X \in (15430), Y \in (34, 981)\} = \{(15430, 34), (15430, 981)\}$. $R'_{Y=34} = \{<Y_{34}, Z_{Y=34}> \mid Y \in (34), Z_{Y=34} \in (2158, 7018)\} = \{(34, 2158), (34, 7018)\}$. $R'_{Y=981} = \{<Y_{981}, Z_{Y=981}> \mid Y \in (981), Z_{Y=981} \in (36, 1209)\} = \{(981, 36), (981, 1209)\}$. In this example, AS 7018, AT&T WorldNet Services, could be a proper IXP, therefore, AS 15430 may choose AS 34 as its main link and another one as the backup link.

Each line of table "routes_by_as" is indexed by as_id, and includes the prefixes originated from one AS. Let $M_i = \{i.prefix1, i.prefix2 \dots \mid i = as\_id\}$, $M' \subset M_i$, $N_j = \{j.prefix1, j.prefix2 \dots \mid j = as\_id\}$, and $N' \subset N_i$. Then $M' \cap N' = \varnothing$.

For another example, let $i = 38$, then $M_i = \{38.72.36.64.0/18, 38.128.174.0.0, 38.130.126.0.0, 38.130.126.0.145/32, 38.192.17.0.0/16\}$; Let $j = 9989$, then $N_j = \{9989. 202.125.9.0, 9989.202.125.10.0\}$ and so $M' \cap N' = \varnothing$.

3. The whole view of Internet

3.1 Algorithm description

The data source for discovery is the whole BGP routing table obtained from route-views server[7]. When finished, the data collected contain 38 peers' announcement and near 9 million lines route entries. The maximum prefix number of BGP routing table has reached 312900. In the next, the two following algorithms are designed to analyze near 9 million lines of BGP routing entries, regulate them, form topology relations among ASes and put each prefix's information into database by AS number. Here the algorithm for analyzing AS adjacencies and updating database is named "Analysis Algorithm", like Figure 3. The tasks of this set of programs are: (1) To filter peering relationships of ASes. (2) To remove the repeated AS number generated by "AS prepend". (3) To scan the string array, check the database by AS number, and update the database.

Analysis Algorithm	**Phase 2:** remove the repeated AS numbers	**Phase 3**: analyze strings and update database
Input BGP routing table collected from University of Oregon route-views server Output database BGP, table "as" **Phase 1**: regulate strings 1. read routing table into memory. 2. truncate the route entries, and put them into string array. 3. return string array in the certain pattern.	1. while the string array has elements. 2. if pointer is not at the end of one string. 3. check and remove overlapped ones. 4. else read next string from the array. 5. if pointer is at the end, break the loop. 6. return the disposed string array. 7. close database connection.	1. connect database. 2. while string array has elements. 3. while one entry has not been finished. 4 if this AS number_n exists in table "as" 5. locate the line, check to see whether it contains the ones (AS numbers) before/behind AS number_n. 6. if exist, continue. 7. else, update this line and continue. 8. else, insert one line, and update this line.

Figure 3. Analysis Algorithm for regulating and analyzing BGP routes

The second algorithm is designed to regulate and classify the BGP prefixes on the basis of their originating AS. The AS number is at the end of the line of BGP routing table. And, here, this set of programs is named "Class Algorithm", like Figure 4.
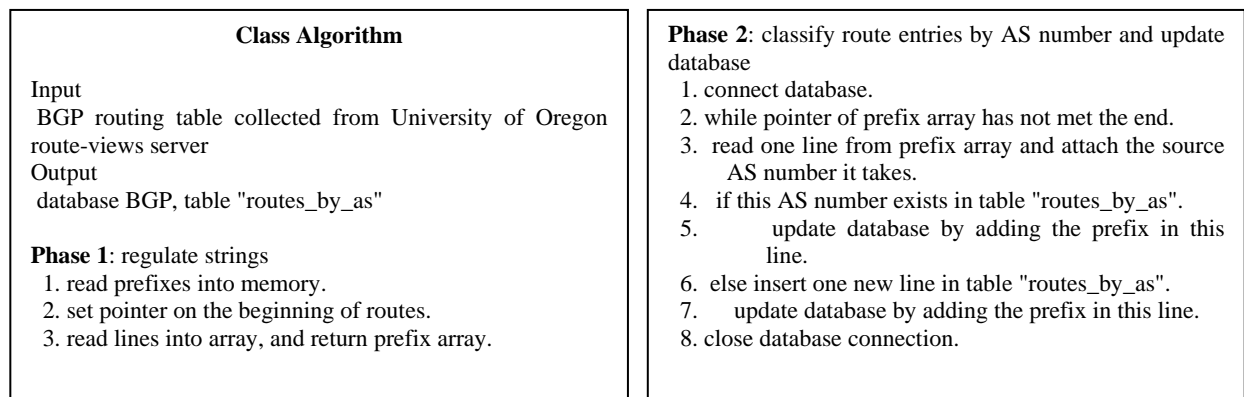
Class Algorithm

Input
 BGP routing table collected from University of Oregon route-views server
Output
 database BGP, table "routes_by_as"

Phase 1: regulate strings
 1. read prefixes into memory.
 2. set pointer on the beginning of routes.
 3. read lines into array, and return prefix array.

Phase 2: classify route entries by AS number and update database
 1. connect database.
 2. while pointer of prefix array has not met the end.
 3. read one line from prefix array and attach the source AS number it takes.
 4. if this AS number exists in table "routes_by_as".
 5. update database by adding the prefix in this line.
 6. else insert one new line in table "routes_by_as".
 7. update database by adding the prefix in this line.
 8. close database connection.

Figure 4. Class Algorithm for regulating and classifying BGP routes

3.2 The statistics of AS adjacencies provided by database

On the basis of the database, it is not difficult to make a statistics of AS adjacencies and their scale. Theoretically, when the peering relationships of ASes are visible to some institution and ISP, it is easy to learn how to design a proper new network according to peering relations and refine current topology. What's more, the students can easily locate their location among thousands of ASes, make a statistics, and build routing policies. The following figures, tables, and data are made to illustrate the current status of adjacencies among autonomous systems, their topology, and the characteristics of today Internet.

Here, there are two data granularities on Figure 5 in that the autonomous systems whose EBGP peers' number is more than 500 (containing 500) are comparatively rare, whereas the ones whose EBGP peers' number is less than 500 and more than 100 is much more than the previous ASes. To present the character of current network more clearly, Figure 7 puts them together and compares them as the description below. In Figure 5/6/7, the X axis presents the range of EBGP peers' number, and Y axis is the number of autonomous systems' entities (For discriminating the AS number namely AS_NUM and the number of AS, let the "number of autonomous systems' entities" or "the number of AS entities" represent the number of AS. At the same time, keep the AS number its original meaning unchanged.). In these figures, every point represents the number of autonomous systems whose EBGP peers are correspondent with the value in the X axis. And the lines between each two points describe trend from one group of ASes to another. As the Figure 5 shows, the number of AS entities whose EBGP neighbors are more than 500 is only 11, and the number of AS entities whose EBGP peers are more than 1000 is 5, much rarer. Comparing to the total number of autonomous systems, 30583, these AS entities, EBGP peers being more than 500, hold only 0.036% of total number of AS entities, 30583, on the Internet. Autonomous systems belonged to this area mainly contain backbone IXP, such as 701, 7018, 3356, 1239, 174, 209 and so on. From the text books, students and instructors maybe seldom pay attention to these ASes, however, they function importantly on the Internet, which play roles as the various centers of the Internet, and thus should not be neglected during the learning of BGP and routing policies.
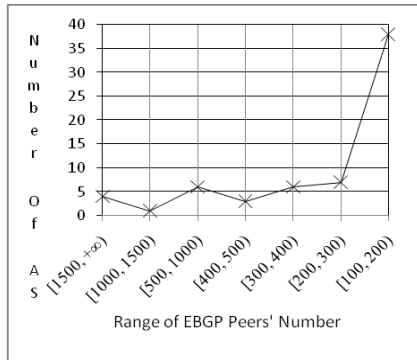
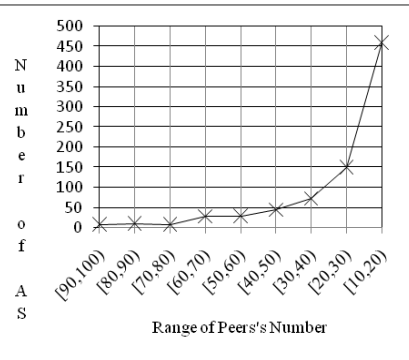Figure 5. Distribution of ASes whose EBGP peers are more than 100

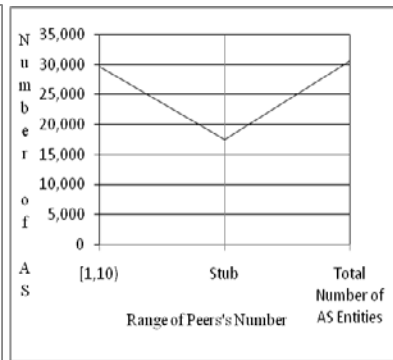Figure 6. Distribution of ASes whose EBGP peers are from 10 to 100

Figure 7. Distribution of ASes whose EBGP peers are from 1 to 10 and total number of AS entities.

Figure 6 shows the situation of distribution of those AS entities whose EBGP peers' number are from 10 to 100. From this graph, the number of EBGP peers rises slowly in the range [30,100), and the slope of the line goes up quickly at the scale of [10, 30). Even though the number of ASes for which EBGP peers are lower than 30 is much more than the number of those ASes whose EBGP peers ranging from 30 to 100, the amount of these autonomous systems still takes a little part , only 2.66%, to the total number of AS running on the Internet. There are some backbone-ASes of ISP in this range, for example 3215, 9050, 8447, 9304, etc. The Figure 7 also presents the situation of HUB-AND-SPOKE among the Internet. From that, Star topology is still typical and normal on the Internet from the respect of autonomous systems, since the style of stub ASes prevails. The number of total AS entities is 30583, and Figure 7 gives the comparison of number of ASes ranging from 1 to 10, stub AS entities' number, and the total number of autonomous systems on the Internet. Contrasting to other autonomous systems in Figure 7 and Figure 6, stub ASes on the Internet take the biggest part, 57.27%, of total AS entities. The number of stub area is 17516.

Table 3 presents the top 10 ASes to which stub ASes are mostly connected. Here, let "big AS" is the one in Figure 7, then most stub ASes are likely to build an EBGP peer with these "big ASes". Consequently, these stub areas make the big ASes their next-hop and obtain averagely shorter AS-Paths. Comparing with the amount of stub ASes, 17516, the number of stub areas who connect to those "big ASes", 4054, takes 23.1%, a relatively large part among stub areas.

Table 3. Distribution of the top ten autonomous systems to which stub ASes mostly connected

Rank	AS number	Stub EBGP Peer Entities' Number
1	7018	867
2	174	632
3	701	498
4	3356	484
5	1239	381
6	209	330
7	4323	319
8	7132	212
9	2828	166
10	3549	165

Generally speaking, Internet education will not straightforwardly take an actual experience for students to comprehend the running status of BGP hosts and their topology. Therefore, it is usually hard to understand the design of BGP topology and routing architectures. Nevertheless, knowing the popular peering relations and dominant linking status on the Internet, it is more easily for students to learn and for instructors to teach the theory of the Internet and routing protocols.

The Table 4 shows the whole percentage of various classes of AS, and the class is defined by the range of EBGP peers' number of one AS. As a result, the ratio of autonomous systems goes up as their EBGP neighbors' numbers fall. In the view of autonomous systems, though the ASes that have over 10 EBGP peers comparatively take a little part on the Internet, less than 1%, they are mainly responsible for the connectivity of other areas. While the other ASes whose EBGP peers ranging from 1 to 10 take a bigger ratio, on percentage, to the previous ones.

Table 4. List of percentage of some classified autonomous systems taken on the Internet

Range of EBGP Peers' Number	Number of Autonomous Systems	Percentage Comparing to Total number of Autonomous Systems
[500,+∞)	11	0.036%
[100,500)	54	0.176%
[10,100)	814	2.661%
[1,10)	29704	97.126%
Stub AS	17516	57.273%

3.3 The statistics of prefixes provided by database

Judging the scale and getting a statistics for some ASes according their prefixes is not easy. Not only is it impossible to show all BGP routing table and make a summary, but also the education tools for realizing this function are limited. On the basis of this situation, by using a set of algorithms to put AS number, routes' number originated from this AS and the route entries into a table becomes necessary as well as applicable. Table 5 shows distribution of ASes from which top 10 routes' number originated. Thus, from the respect of prefixes' number, the order of autonomous systems' scale is present. In this table, the field "as_id" equals to the AS number namely AS_NUM, and "route_number" is the number of prefixes originated from this AS.

Table 5. Distribution of autonomous systems from which top 10 routes' number originated

as_id	route_number
6389	4110
1785	1800
20115	1694
4323	1638
2386	1563
17488	1521
4766	1492
8151	1478
7018	1470
11492	1220

Of course, there are other standards to judge the scale of one AS; however, the prefixes number one AS announced to Internet is one of the most necessary considerations.

Normally, when some institution or customer access Internet by means of BGP, the IXP will filter the received prefixes or routes announced from EBGP peers. One of the important policies of controlling route table is to filter the route entries whose net masks are over 25. Unfortunately, this is not necessary the case. There are many these unusual prefixes existing on the Internet. By scanning and analyzing the database (as described in Algorithm for regulating and classifying BGP routes), it is practical to get a statistics of those unusual prefixes and the AS from which they are advertised. When checking the status of BGP routing table, there will always be question for the BGP study about the irregular IP addresses and loopback addresses. Sometimes, the abnormal addresses do exist on the Internet, which may be caused by configuration error and neglect of security consideration.

Figure 8 presents the result of analyzing database. In this graph, the X axis presents the unusual net masks, the Y axis is the number of prefixes, and the point shows the number of prefixes corresponding to the X scale. From Figure 8, the trend of number of unusual route entries announced to the Internet goes down as their net masks rise. This situation shows only a few ASes may be mistakenly announced their interface addresses and loopback addresses to the Internet. This is also may caused by redistributing some connected network to BGP in error. Although the whole number of unusual prefixes is quite limited comparing with the all BGP routing entries, this situation should be avoided when taking routing policy and security issue in consideration.
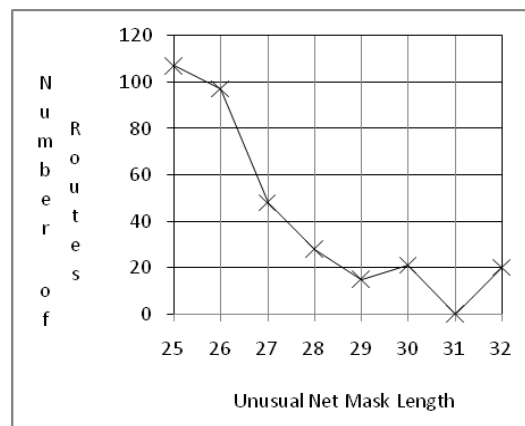

Figure 8. The distribution of prefixes whose net mask lengths are more than 25

4 Conclusion and perspective works

As "Glenn Branch" described in the paper [8], a central obstacle to accepting evolution, both among students and the general public, is the idea that evolution is "just a theory," where "theory" is understood in a pejorative sense as something conjectural or speculative. And, by now, most education of modern Internet and routing protocols focuses only on theories and local experiments. By this, however, it is hard to understand the actual topology, essences of routing protocols, security methods and the policies running on the Internet. This is caused by the fact that there is not an effective way to access the relations of the autonomous systems, their situation, dominant topology, and the status of announced IP prefixes. Therefore, as discussed in

the first section of this paper, the blindness of BGP topology will lead to remote congestion and unnecessary hops issues. In this paper, to make a clearer view of the Internet for students and thus take a more comprehensive understanding of routing architecture and theories of the Internet, there is an idea of discovering the entire topology of ASes, regulate it, and put their relations into database which facilitates the peer search, IP prefixes statistics, and ranking autonomous systems by various indicators. To do this, two algorithms are employed to discover the relations of autonomous systems and the route entries announced from them. What's more, the most important, some analysis and statistics based on the database are given, such as distribution of autonomous system, the current status of stub nodes, prevailing star topology, scale of ASes from the view of prefixes, and a statistic of those unusual route entries. All of these make a "picture" of the Internet out of text books clearer and thus make it more efficient and easier to learn network as well as routing theories.

REFERENCES

[1] Y. Rekhter and T. Li. A Border Gateway Protocol 4 (BGP-4). RFC 4271, "The Internet Society," 2006

[2] K. Sriram, O. Borchert, O. Kim, and P. Gleichmann, and D. Montgomery, "A Comparative Analysis of BGP Anomaly Detection and Robustness Algorithms," Proceedings of the Cybersecurity Applications and Technology Conference for Homeland Security (CATCH), Washington D.C., pp. 30-36, March 3-4, 2009

[3] V. Fuller, "Classless Inter-Domain Routing (CIDR)", RFC1519, September 1993

[4] T. Pummill, "Variable Length Subnet Table For IPv4," RFC1878, December 1995

[5] D. McPherson, "Experience with the BGP-4 Protocol," RFC 4277, Cisco Systems, January 2006

[6] Randy Zhang, Micah Bartell, "BGP Design and Implementation," Cisco Press, March 2003

[7] http://www.traceroute.org

[8] Glenn Branch, "Theory" in Theory and Practice , "National Center for Science Education, P.O. Box 9477, Berkeley, CA 94709-0477, USA", 2008, pp.287-289