Second mini-project: Static Analysis of Inter-AS Routing

João Luís Sobrinho

I. Introduction

The Internet is an interconnected collection of about $60,000$ networks, called Autonomous Systems (ASes). Every pair of neighbor ASes is associated with a commercial relationship. Ultimately, these relationships shape how traffic flows throughout the Internet. With some oversimplification, the commercial relationship between two neighbor ASes belongs to one of two types. In a *provider-customer* relationship the customer pays the provider to transit its traffic to and from the rest of the Internet, whereas in a *peer-peer* relationship the two peers exchange traffic between themselves and their customers without monetary compensations. The customer-provider relationships create an hierarchy in the Internet. At the bottom of the hierarchy are ASes without customers, called stubs. All other ASes are Internet Service Providers (ISP). At the top of the hierarchy are ASes without providers, called Tier-1s. The majority of ASes are stubs, which include content provider and content distribution networks, such as those of Google, Facebook, Amazon, and Akamai, access networks, and many enterprise networks. There only a dozen or so Tier-1s, including Level3, TeliaSonera, AT&T, Verizon, Deutsche Telekom, Telefonica, and NTT.

Figure 1 shows a small internet, where a provider is joined to a customer by a solid line, with the provider placed higher than the customer, and two peers are joined by a dashed line. For example, u_6 is a provider of both u_2 and u_3; u_6 and u_7 are peers. Nodes u_{10} and u_{11} are Tier-1 and nodes u_1, u_2, u_3, and u_4 are stubs.

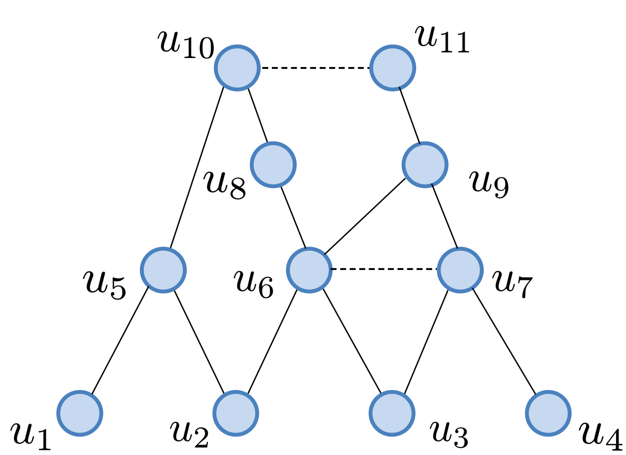

Fig. 1. An internet. Solid lines join providers to customers, with providers placed higher than customers. Dashed lines join peers.

II. Routing according to commercial relationships

The Border Gateway Protocol (BGP) is the routing protocol running among the ASes of the Internet. It is configured at each AS as a function of the commercial relationships the AS has with its neighbor ASes. We assume that BGP is configured according to the following routing policies [1].

- An AS prefers a customer route (learned from a customer) to a peer route (learned from a peer), and prefers a peer route to a provider route (learned from a provider). The AS elects the most preferred of the routes learned from its neighbors.
- An AS exports all elected routes to its customers and exports customers routes to all its neighbors, these being the only exportations allowed.

A customer cycle is a cycle where every node is a customer of the next around the cycle. If there are no customer cycles in a network, then BGP reaches a unique stable state. In that unique stable state, given a destination, every node elects one of the following types of route to reach the destination: (i) a customer route; (ii) a peer route; (iii) a provider route; (iv) no route at all. The network is commercially connected if, for every destination, every node elects a customer, a peer, or a provider route to reach that destination.

The network of Figure 1 does not have customer cycles and is commercially connected. As examples of elected routes, we have that u_{11}, u_9, and u_7 elect customer routes to reach u_4; u_{10} and u_6 elect peer routes to reach u_4; and u_1, $u2$, u_3, u_5, and u_8 elect provider routes to reach u_4. Node u_{10} elects a peer route to reach u_{11}; all nodes other than u_{10} elect a provider route to reach u_{11}.

III. Static analysis of inter-AS routing

In a static analysis of inter-AS routing, we are given a network where each link is labeled with the information of whether it goes from a provider to a customer, a customer to a provider, or a peer to a peer. We want to determine the stable state of BGP in that network, that is, for every two nodes, we want to determine the type of elected route with which the first node reaches the second. We could simulate BGP on the network and wait for a stable state to be attained. However, that is time a consuming proposition. On the other hand, there are very efficient sequential algorithms to perform a static analysis of inter-AS routing.

Specifically, given a network, the static analysis of inter-AS routing comprises the following elements. (i) an algorithm to check whether the network has customer cycles; (ii) an algorithm that receives as input a destination in the network and returns the type of route each node elects to reach the destination; (iv) statistics of the types of routes taken over all destinations; (v) an algorithm to check whether the network is commercially connected. Clearly, the algorithm in (v) could be based on the algorithm in (ii) run over all destinations. However, there is a much more efficient algorithm for (v). Moreover, if we know that the network is commercially connected, then there is an algorithm for (ii) that runs really fast.

The Center for Applied Internet Data Analysis (CAIDA) provides inferred topologies of the Internet annotated with the type of commercial relationships between neighbor ASes [2].

IV. YOUR ASSIGNMENT

What you have to do.

- Design and implement an algorithm to check whether a network has customer cycles. The network is given in the format below. Each line represents a link. The first value is the identifier of the node at the tail of the link. The second value is the identifier of the node at the head of the link. The third value is 1 if the tail of the link is a provider of the head of the link; it is 2 if the tail of the link is a peer of the head of the link; and it is 3 is the tail of the link is customer of the head of the link. For example, in the table above, 4323 is a provider of 12122.

4323	12122	1
12122	4323	3
7018	17228	1
17228	7018	3
29017	34309	2
34309	29017	2

- Design and implement an algorithm to determine whether a network is commercially connected.
- Design and implement an algorithm that receives as input a network and a destination in that network and computes the type of route elected at each node to reach the destination. Build a program from that algorithm.
- Build your algorithms into a program that receives as input a network, states whether the network has a customer cycle, whether it is commercially connected, and produces statistics for the types of elected routes. A concrete network will be given later on.

What do you have to deliver, how, and when.

- You have to deliver your code and a report with a cover page and no more than three other pages containing a clear explanation of your algorithms, the statistics for the concrete network that will be given, and a short discussion.
- The code and the report should be sent in a .zip file to my email address with subject p2.<group number>.zip where <group number> is your group number.
- The deadline is November 10, 2017, 23:59.

How I will evaluate your assignment.

- Write your report clearly. Present your algorithms in a precise and concise manner.
- Be sure to test your code for correctness. I will take into consideration the efficiency of your algorithms.
- I will have a discussion with you about your report and will test your code at the end of the semestre, jointly with the other assignments.

REFERENCES

[1] L. Gao and J. Rexford, "Stable Internet routing without global coordination," *IEEE/ACM Transactions on Networking*, vol. 9, no. 6, pp. 681–692, December 2001.

[2] "The CAIDA AS relationships dataset," http://www.caida.org/data/active/as-relationships/.