A Regional Network Topology Construction Algorithm Based On Sampling Measurement

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Abstract. Network topology construction is one of the basic means to study the target network. Whether it is the discovery of vital nodes, IP location or network characteristics mining, a complete and accurate network topology is needed. In this paper, a regional network topology construction algorithm based on sampling measurement is proposed to solve the problem of high time cost and resource waste of existing algorithms. Firstly, multiple vantage points located inside and outside the target area are selected to form a probing set. Then the IPes of the target area is extracted based on sampling to form the target IP set. Finally, the probing set is used to probe the target IP set periodically. The network topology of the target region was constructed based on the results of a 40-day internet measurement and compared with the existing database. The experimental results show that the coverage rate of routing nodes in the target area is improved by more than 90% compared with the measured data provided by CAIDA (Center for Applied Internet Data Analysis) and by more than 10% compared with the measured data provided by IPIP.

1. Introduction
The complete network topology is the basis of network structure analysis, vital nodes discovery, boundary identification and IP location. Internet measurement methods include based on SNMP (Simple Network Management Protocol), based on IGMP (Internet Group Management Protocol), based on ICMP (Internet Control Message Protocol), etc. The SNMP-based method[1] and IGMP-based method[2] require the network equipment passing through during the probing process to support the corresponding protocol, so the scope of adaptation is limited. The current mainstream measurement method is to use tools such as traceroute developed based on the ICMP. Traceroute[3] is a network management tool developed by Van Janbson in 1989, which can get the route from a source to a destination. Traceroute has been widely used in a variety of fields. Many researchers have applied the function of Traceroute to internet measurement and developed some internet measurement systems based on Traceroute.

The improvement of traceroute can be divided into two aspects: the improvement of probe mode and the improvement of probe message. Benoit Donnet[4] proposed a collaborative internet measurement algorithm called DoubleTree, which considered that routes on the Internet had a tree-like structure, and improved Traceroute by adopting two probe modes of forward probe and backward probe, and applying two stop sets to reduce redundant probe. M Engin[5] developed the system by collecting all IP addresses in the subnet of the router corresponding to this hop after probing each hop, and then carries out the probe of the next hop. Therefore, Tracenet can obtain the sequence of subnets passing from the vantage points to the destination. Augustin[6] proposed Paris- Traceroute[7] probe
method based on ICMP-Paris, TCP-Paris and UDP-Paris through the transformation of ICMP, TCP and UDP packets. Compared with Traceroute, Paris-Traceroute can reduce the influence of the load balancing strategy on the probe and make the probe more accurate.

The traditional internet measurement methods are mostly based on the probe of all IP addresses of the target area to get the topology. However, the time cost of probing all IP addresses is high, and the network is dynamic, so the probe with a large time span often cannot truly reflect the overall situation of a regional network.

In view of this fact, this paper proposes a network topology construction algorithm based on sampling measurement. The main contributions of this paper are as follows:

1. The target area topology built with fewer resources has higher coverage-rate than existing public and commercial databases.
2. Obtain network topology information with different time-delays and time-spans.

The structure of the remaining chapters is as follows: The second chapter introduces the algorithm of this paper and the analysis of related primitives; The third chapter introduces the experimental results; The fourth chapter summarizes and looks forward to the paper.

2. Regional Network Topology Construction Algorithm Based on Sampling Measurement

The topology of the Internet is difficult to obtain directly, but the network connection of the area can be obtained by constructing the appropriate packet to send to the IPes of the corresponding area, to construct the network topology. However, the number of IPes on a city scale is too large to probe. Therefore, this paper proposes a regional network topology construction algorithm based on sampling measurement. The basic steps of the algorithm are shown in the figure below:

![Figure 1. Overall architecture of our proposed method](image)

As can be seen from the figure, the main steps of the proposed algorithm are as follows:

2.1. Vantage points selection strategy with internal and external distribution

Selecting \(n_I\) vantage points located inside the target city A and \(n_O\) vantage points located outside the target city to form the vantage points set \(P_V\). Because the probe results have spatial deviation and are accidental when only a single vantage point is used to probe the target IP, \(n_I\) and \(n_O\) vantage points are respectively arranged inside and outside the target city in this paper to obtain a more completed network topology.
2.2. Target IP extraction strategy based on subnet partitioning

Get the IP blocks assigned to the target city A from the IP address database $D=\{D_1, D_2, ..., D_n\}$. In each IP block, the representative IP of the block is selected to form the target IP set $P_T$. Existing studies show that in the same IP block, IP addresses assigned to the same organization often have the same or similar characteristics, for example, the export routers they use for external communication tend to be the same[8][9]. Based on this network characteristics, IP addresses of the target cities are screened in this paper. On the basis of ensuring that at least one IP address is reserved for each C-class network, one or more IP addresses are selected for each IP block according to the IP address database. Then, only the IP addresses selected will be probed, which can shorten the probe period and ensure the integrity of the acquired topology as much as possible.

2.3. High-frequency network probing strategy

The vantage points set $P_V$ is used to probe the target IP set $P_T$ with a period $t_D$. Due to the long period of probing all IPes, the target IP is likely to be in a different network environment (for example, the network may be congested). Each target IP can only be measured once in the probing cycle, which will lead to the results with contingency. By using the internet measurement method proposed in this paper, multiple rounds of probing can be carried out in the same time, and the internet measurement results under different time-delay conditions can be included, so a more completed topology can be obtained.

2.4. Network topology construction method

According to the measurement results, the node-set $P_A$ in the target city is extracted, and the path is encoded. Then, the anonymous routing is processed according to the path analysis. Finally, an inference-based alias resolution method APAR (Analytical and Probe-based Alias Resolver) is used for Alias resolution[10] to obtain the basic routing node information and connections of the target city. Construct network topology $G$ of target city $A$.

3. Experiments

In order to verify the effectiveness of the proposed algorithm, experiments of internet measurement are carried out in this section. It includes four parts: data acquisition, probing speed analysis, probing environment analysis and probing coverage-rate analysis.

3.1. Data acquisition

Experimental Setup in the data acquisition stage are shown in Table 1:

| Parameter | Setup |
|-----------|-------|
| $A$       | Chengdu, Sichuan; Hangzhou, Zhejiang; Zhengzhou, Henan |
| $D$       | Maxmind\(^1\), IP2location\(^2\), Whois\(^3\), IPIP\(^4\), IPPlus\(^5\), IPcn\(^6\) |
| $P_V$     | 211.149.219.168, 47.110.233.88, 122.114.14.202 |
| $t_D$     | 2 hours |

In the table, $A$ represents the target region, $D$ represents the IP database adopted, $P_V$ represents vantage points, and $t_D$ represents the probe cycle.

\(^1\) http://www.maxmind.com/
\(^2\) http://www.ip2location.com/
\(^3\) http://www.whois.com/
\(^4\) http://www.ipip.net/
\(^5\) https://www.ipplus360.com/
\(^6\) http://www.ip.cn/
This paper uses Scamper[11] developed by CAIDA for IP probe, which is widely used in Internet measurement. The IP address blocks of the three target cities (Zhengzhou, Hangzhou and Chengdu) were selected from 6 IP address databases released in November 2019: IPIP, Whois, IPPlus, IP2location, Maximd and IPcn. There were 6,174 IP blocks, including 12,748,117 IPes. Combined with the IP selection method adopted in this paper, the target IP set constructed for Zhengzhou, Hangzhou, and Chengdu contains 60,337 target IPes in total. The number of IP blocks, full IP and target IP of the three cities are shown in Table 2.

Table 2. Statistics of the Number of IP Addresses in the Target City

| Target City | # IP blocks | # Full IP  | # Target IP |
|-------------|-------------|------------|-------------|
| Zheng Zhou  | 1,702       | 2,725,327  | 11,598      |
| Hang Zhou   | 2,221       | 7,501,838  | 30,694      |
| Cheng Du    | 2,251       | 4,2747,36  | 18,045      |

In 2019-2020, this paper probe all IPes and Target IPes in Zhengzhou, Hangzhou and Chengdu, respectively. Obtaining 43,475,703 results from Full IP probe, among which 9,301,149 responded and 3,274,157 IPes responded. The sampling probing set the period $t_D$ as 2 hours, and conducted 12 rounds every day. A total of 480 rounds of probing were conducted, and 86,885,280 probe results were obtained, among which 28,987,966 were responded, and 26,985 IPes responded. Detailed data are shown in Table 3.

Table 3. Statistics of Internet Measurement Results

| City      | # Target IP | # Probe result | # Completed IP | # Completed result |
|-----------|-------------|----------------|----------------|-------------------|
| Zheng Zhou| 11,598      | 16,701,120     | 4,837          | 5,484,648         |
| Hang Zhou | 30,694      | 44,199,360     | 15,212         | 14,977,107        |
| Cheng Du  | 18,045      | 25,984,800     | 6,936          | 8,526,211         |

3.2. Analysis of Probing Speed

The internet measurement method proposed in this paper only probes the representative IP of each IP block, as shown in Table 4, which can greatly reduce the number of target IP, reduce the time cost and improve the probe efficiency.

Table 4. Number of Target IPes and Time Cost of Different Probing Method

| City      | Method of Probing all IPes | Proposed Probing Method |
|-----------|----------------------------|-------------------------|
|           | # Target IPes $T_R$        | # Target IPes $T_R$     |
| Zheng Zhou| 2,725,327                 | 11,598                  |
| Hang Zhou | 7,501,838                 | 30,694                  |
| Cheng Du  | 4,2747,36                 | 18,045                  |
| Total     | 12,748,117                | 60,337                  |

3.3. Analysis of Probing Environment

Count the time-delay information of each round of probing on the results of the three cities, and the results are shown in the following figure:
In Fig. 2, the horizontal axis is the target city, V(C) represents the vantage point located in C. The vertical axis is the statistical result of the round-trip time of each round, including the maximum and minimum value of the average time delay, the median, and the mean value, etc. It can be seen from the figure that the time-delay with different rounds from different vantage points varies greatly, which is resulted from the different network conditions in different periods and different regions. Therefore, the multi-source, continuous and high-frequency probing method adopted in this paper is helpful to obtain measurement results under different conditions, so as to ensure the integrity of internet measurement.

3.4. Analysis of Coverage-rate of the Probing Result

The results of sampling probing and probe all IPes are compared, and the measurement results provided by CAIDA and IPIP are compared. The results are shown in Table 5:

| City      | Probing All IPes | Probing Target IPes | CAIDA | IPIP |
|-----------|------------------|---------------------|-------|------|
|           | NC               | NR                  | NC    | NR   |
| Zheng Zhou| 5,519            | 9,264               | 5,466 | 8,809 |
| Hang Zhou | 16,641           | 23,354              | 16,443 | 22,220|
| Cheng Du  | 7,526            | 13,383              | 7,462 | 10,956|
| Total     | 29,686           | 46,001              | 29,371| 41,985|

In Table 5, NC is the number of /24 prefix IP blocks covered by measurement results, and NR is the number of routing nodes probed.

It can be seen from the table, the coverage of /24 prefixed IP blocks and nodes in the network using the method proposed in this paper reaches 98% and 91% of probing all IPes, respectively; while the data CAIDA provided can only cover less than 3% of the /24 prefix IP blocks and 8% of nodes; the coverage rate of IPIP’s data reached 82%, 59% respectively. This result proves the rationality of probing method and IP sampling method of the algorithm proposed in this paper; it can significantly improve the speed of internet measurement on the basis of obtaining the basic topology of the target region.

4. Conclusions

In this paper, a local network topology construction algorithm based on sampling measurement is proposed, which not only improves probing efficiency but also ensures the integrity of topology construction. Experimental results show that the proposed algorithm can obtain more complete measurement results than CAIDA, IPIP and other public or commercial databases with fewer resources.
Acknowledgements
This work was supported by the Zhongyuan Science and Technology Innovation Leading Talent Project (No. 214200510019).

References
[1] Li, J., Zhang, X.F., Shen, W.H., et al. (2013) Network topology discovery based on SNMP. In: International Conference on Computational Intelligence and Security. Sichuan. pp. 194-199.
[2] Yin, J.B, Li, Y.M., Wang, Q., et al. (2012) SNMP-based network topology discovery algorithm and implementation. In: International Conference on Fuzzy Systems and Knowledge Discovery. Chongqing. pp. 2241-2244.
[3] Van Jacobson et al. (1989) Traceroute. ftp://ftp.ee.lbl.gov/traceroute.tar.gz.
[4] Marchetta, P., Mé rindol, P., Donnet, B., et al. (2011) Topology discovery at the router level: a new hybrid tool targeting ISP networks. IEEE Journal on Selected Areas in Communications, 29: 1776-1787.
[5] Marchetta, P., Mé rindol, P., Donnet, B., et al. (2012) Quantifying and mitigating IGMP filtering in topology discovery. In: Global Communications Conference. Anaheim. pp. 1871-1876.
[6] Marchetta, P., Pescape, A. (2013) Drago: Detecting, quantifying and locating hidden routers in traceroute IP paths. In: INFOCOM Workshops. Turin. pp. 3237-3242.
[7] Govindan, R., Tangmunarunkit, H. (2000) Heuristics for Internet map discovery. In: INFOCOM. Tel Aviv. pp. 1371-1380.
[8] Donnet, B., Raoult, P., Friedman, T., et al. Deployment of an algorithm for large-scale topology discovery. (2006) IEEE journal on selected areas in communications, 24: 2210-2220.
[9] Tian, Y., Dey, R., Liu, Y., et al. Topology mapping and geolocating for China's Internet. (2012) IEEE Transactions on Parallel and Distributed Systems, 24: 1908-1917.
[10] Gunes, M.H., Sarac, K. (2009) Resolving IP aliases in building traceroute-based Internet maps. IEEE/ACM Transactions on Networking, 17: 1738-1751.
[11] Luckie, M. (2010) Scamper: a scalable and extensible packet prober for active measurement of the internet. In: ACM SIGCOMM conference on Internet measurement. Melbourne. pp. 239-245.