

An IP Geolocation Method Based on Rich-connected Sub-networks

Shichang Ding, Xiangyang Luo, Meijuan Yin, Yan Liu and Fenlin Liu
State Key Laboratory of Mathematical Engineering and Advanced Computing,
Zhengzhou Science and Technology Institute, China

dscgongzuo@yeah.net, luoxy_ieu@sina.com, raindot_ymj@163.com, ms_liuyan@aliyun.com, liufenlin@vip.sina.com

Corresponding Email: luoxy_ieu@sina.com

Abstract—Recent years have seen a rapid growth of location-aware applications such as targeted marketing, restricted content delivery and location-based security check. Although existing delay-based IP geolocation techniques work well in some developed countries, the assumption of a strong delay-distance correlation that they often rely on may fail in many developing countries for poor network connectivity. To obtain more accurate delay-based IP geolocation results in poor-connected networks, an IP geolocation method based on rich-connected sub-networks is presented in this paper. At first, the network connectivity of one particular network is measured. Next, if the network is poor-connected, the method will divide it and search rich-connected sub-networks based on properties such as ISP and location information of probing hosts and landmarks. Then, based on the discovered rich-connected sub-networks, landmarks and probing hosts are deployed and selected to measure data such as delay, distance and topology, etc. At last, the location of the target host is estimated by modifying the processes of existing delay-based IP geolocation techniques based on selected landmarks and probing hosts. The experiments which cover 30 provinces and 3 major ISPs of China show that the proposed method can find corresponding rich-connected sub-networks and significantly improve the performance of existing typical delay-based IP geolocation techniques in an actual poor-connected network.

Index Terms—IP Geolocation, Delay-distance Correlation, Rich-connected Sub-network, Poor-connected Network, Network Measurement

I. INTRODUCTION

IP geolocation is of great value to many location-aware applications such as targeted marketing, restricted content delivery and location-based security (e.g. credit card fraud prevention). Especially, IP geolocation has become more important in finding and preventing rapidly-grow cyber attacks because it can help law enforcement organizations and government agencies to identify location information of criminals or the resources of cyber attacks.

IP geolocation techniques can be categorized into three kinds: IP geolocation databases, data-mining-based IP geolocation and delay-based IP geolocation. IP geolocation databases can hardly satisfy the demand of many developing countries because the vast majority of entries in IP geolocation databases refer only to a few popular countries (e.g., U.S.)

[1]. Data-mining-based IP geolocation techniques often have to increase IP coverage by mapping an IP segment to one location, which may lead to significant localization errors [2–4]. For delay-based IP geolocation techniques, they can geolocate most target hosts as long as they can be probed and provide a city-level estimation in certain network environments [5–10]. Delay-based IP geolocation techniques can play an important role if one wants to provide city-level location information for most hosts in a developing country.

However, many existing delay-based IP geolocation techniques are based on the assumption of a strong correlation between network delay and geographical distance [9]. This assumption has been validated in several developed countries in North America and Western Europe [11, 12]. But the network connectivity in many developing countries is poor, which will seriously affect the accuracy of existing delay-based IP geolocation techniques [9].

To obtain more accurate delay-based IP geolocation results in poor-connected networks, an IP geolocation method based on rich-connected sub-networks is presented in this paper. First, the network connectivity of a specific network is measured by calculating the delay-distance correlation between the probing hosts and landmarks which can cover whole network. If the network connectivity is too poor, rich-connected sub-networks inside the whole network are searched based on properties such as ISP and location information of probing hosts and landmarks. After searching rich-connected sub-networks, landmarks and probing hosts are deployed and selected so that the network connectivity between them and target hosts are rich enough for delay-based IP geolocation techniques. Finally, to geolocate a particular target host, the processes of existing delay-based IP geolocation techniques are modified based on selected landmarks and probing hosts.

II. RELATED WORK

A. IP Geolocation Databases

IP Geolocation databases are widely used in commercial environments for easy deployment and short response time.

They manually maintain large numbers of IP/Location mapping records which come from sources like Whois databases, DNS-Loc records, users contribution and so on. However, the wrong or outdated records are hard to distinguish and update. IP geolocation databases are not suitable to provide city-level IP geolocation services to many developing countries because the vast majority of entries in IP geolocation databases refer only to a few popular countries and they can only claim country-level accuracy, but not city-level [1].

B. Data-mining-based IP Geolocation Techniques

Data-mining-based IP geolocation techniques try to discover the relationship between location and IP addresses from websites, location-share applications and so on. One of the latest data-mining IP geolocation technique – Checkin-Geo [3] can reduce the median error distance to 799 meters, which is very impressive. However, the information resources that this technique relies on are usually only abundant in several metropolises, possessed by a minority of Internet giants and inaccessible to public for privacy concern. Besides, data-mining geolocation techniques such as [2] and [3] can hardly cover most IP addresses so they have to increase IP coverage by mapping a block of IP addresses to one location, which may lead significant localization errors according to [4].

C. Delay-based IP Geolocation Techniques

Delay-based IP geolocation techniques deploy a set of probing hosts with well-known location first (sometimes also include landmarks which only can answer to probes). Then a relationship between delay and distance or other kinds of location constraints is built. The location of a target host can be estimated by the relationship and delay between target hosts and probing hosts. Theoretically speaking, one advantage of delay-based IP geolocation techniques is that they can geolocate any host in developing countries as long as it can be probed. However, the relationships between delay and distance are based on the assumption there is an strong correlation between network delay and direct geographical distance [9], which often fails in the poor-connected networks of developing countries. In this paper, the processes of two existing typical delay-based IP geolocation techniques – CBG and GeoGet are modified to get better accuracy in poor-connected networks. The two techniques are briefly introduced in the following paragraphs.

CBG measures delay and distance between each probing host and calculates each probing host's relationship of delay-distance conversion by drawing a tightest lower linear bound of all the (delay, distance) pairs, which is called bestline [6]. Then probing hosts measure delay to the target host and convert delay to distance using their bestlines. Every probing host draws a circle with center at their respective location and of radius equal to their own estimated distances. CBG thinks in most cases these estimated distances are larger than the actual distances so if all circles can intersect to a region, the location of the target host lies in the centroid of the region.

GeoGet actually maps a target host to the location of

the landmark which has the shortest delay to the target host. GeoGet deploys landmarks in every city and divides cities into different areas. There is one center city in each area. GeoGet sends the IP addresses of landmarks in all center cities to the target host. The target host probes these landmarks and selects the areas whose landmarks have the shortest delay as the candidate areas. Then the delay to the landmarks in all cities of the candidate areas are measured by the target host. The city whose landmarks have the shortest delay is selected as the city-level location of the target host.

III. PROPOSED METHOD

This section shows how to get more accurate IP geolocation results in poor-connected networks based on rich-connected sub-networks. The general procedure of the method includes:

- ① Deploy the initial group of probing hosts and landmarks and measure the network connectivity.
- ② Search the rich-connected sub-networks based on properties.
- ③ Deploy landmarks and probing hosts based on discovered rich-connected sub-networks.
- ④ Modify IP geolocation techniques based on deployed landmarks and probing hosts.

A. Measure the Network Connectivity Based on Delay-distance Correlation

First we need to know whether a network is poor-connected or rich-connected. Though “rich-connected network” and “poor-connected network” have been appeared in several papers [9, 12], there have no been authoritative definitions for them until now. This paper defines them based on the delay-distance correlation. Delay-distance correlation is the first-order linear correlation coefficient between network delay and direct geographical distance. Assume the variance of delay is V_{delay} , the variance of distance is $V_{distance}$, and the covariance of *delay* and *distance* is $cov(delay, distance)$, then the delay-distance correlation *Corr* can be calculated by the following formula [9]:

$$Corr = \frac{cov(delay, distance)}{\sqrt{V_{delay} \times V_{distance}}} \quad (1)$$

The range of *Corr* is $[-1, 1]$. Usually, a first-order linear correlation coefficient is thought to be strong if its absolute value is beyond 0.7 and moderate if between 0.3 and 0.7. If the absolute value is less than 0.3, there is no or very weak relationship between delay and distance. As a relationship between delay and distance, *Corr* is positive in most circumstances because delay generally becomes larger as distance increases and smaller as distance decreases. In IP geolocation, researchers think that a negative *Corr* can be seen the same as a weak *Corr* because existing delay-based IP geolocation techniques can not work well in this kind of network. Previous works such as [9] and [12]

often distinguish networks into rich-connected, moderately-connected and weak-connected according to the above division method. This paper refers moderately-connected and weak-connected networks as one kind – poor-connected networks, because the accuracy of existing delay-based IP geolocation techniques is usually low in both moderately-connected and weak-connected networks.

To calculate the *Corr* of each network, we need to deploy an initial group of probing hosts and landmarks which can cover the whole network. If the *Corr* is below 0.7, the method will try to search the rich-connected sub-networks inside it. If the *Corr* is beyond 0.7, the network connectivity is usually rich enough to get accurate results. Of course, researchers can still search richer-connected sub-networks to make the location estimation errors even smaller.

B. Search Rich-connected Sub-networks Based on Properties

If the *Corr* between all probing hosts and landmarks in the network is below 0.7, we should search sub-networks whose *Corr* is beyond 0.7. Actually, the question is how to divide the initial group of probing hosts and landmarks and check which sub-group has a strong *Corr*. A property-based rich-connected sub-networks searching method is presented in this subsection.

First, to divide all hosts into sub-groups, researchers need to find properties which can influence network-connectivity. There are two problems. One is that the reliable properties are quite limited. The other one is not all properties of hosts can influence network-connectivity. This paper provides two properties which are suitable to many poor-connected networks and delay-based IP geolocation techniques. The first reliable properties is the city-level location information of probing hosts and landmarks because they are often deployed or at least controlled by researchers themselves. The second one is the ISP information of probing hosts, landmarks and target hosts. ISP information is an important influencing factor on network connectivity in many countries. And for most countries, IP geolocation databases can offer correct ISP information of IP addresses because they are stabler and simpler to update and maintain than location information.

Previous works such as [5], [9] and [12] point out that the less network congestion and straighter data transmission path will lead to stronger delay-distance correlation. Generally, the intra-ISP network congestion is weaker than inter-ISP network congestion because the number of Internet Exchange Points (IXP) between different ISPs is often less than those inside one ISP. So for most networks, we can first divide them by ISP information and check whether the *Corr* between all probing hosts and landmarks in the same ISP is strong. This kind of *Corr* includes data from all probing hosts so it reflects the average network connectivity of one particular ISP.

If the average intra-ISP *Corr* is not up to requirement, we need to check the *Corr* between one particular probing host and all landmarks in the same ISP. The network infrastructure

is uneven in different cities. Some cities act like the hubs of certain regions and are in charge of transmitting the main intra-region network traffic and most inter-region network traffic [13]. These cities, which can be referred as Regional Network Centres, are usually important economic and political centres of one region or the whole country. Probing hosts which are in these Regional Network Centres tend to have straighter data transmission path to landmarks than those which are in other cities. Because the data transmission paths from probing hosts in other cities sometimes have to take a long detour to the Regional Network Centres. Based on this characteristic, we should divide the probing hosts that are in single ISP by city-level location information and check whether the intra-ISP *Corr* of probing hosts in certain cities is beyond 0.7.

It is possible that we are not be able to find any rich-connected sub-networks in some poor-connected networks only based on ISP and location information. It is advised that researchers find more reliable properties when facing a particular network. Take Indonesia for an example. It is apparent that the geographical features of this country (it consists of many huge islands) also strongly affect network connectivity of this country. In this case, researchers may need to find more properties to divide the network by island.

C. Deploy Landmarks and Probing Hosts Based on Rich-connected Sub-Networks

The estimation results are calculated based on the relationship between location and the measured data like delay and topology, which are directly influenced by the deployment of landmarks and probing hosts. We need to make sure that the delay-distance relationship between target hosts, landmarks and probing hosts are strong enough for IP geolocation techniques to get accurate geolocation results. The principle is that for any target host, researchers should try their best to deploy landmarks and probing hosts in the same rich-connected sub-network with it. Because this paper searches rich-connected sub-networks based on ISP and city-level information, the deployment is also designed based on ISP and city coverage of sub-networks. For example, if the *Corr* of a probing host in a particular city is too weak, then there is no need to deploy probing hosts in this city; if the rich-connected sub-network only cover one ISP, landmarks and probing hosts have to be deployed in each ISP.

D. Modify Existing Typical delay-based IP Geolocation Techniques

After deploying landmarks and probing hosts, the processes of existing delay-based IP Geolocation techniques need to be modified to get more accurate results. This paper takes two existing typical delay-based IP Geolocation techniques – CBG and GeoGet for examples.

The accuracy of CBG is actually based on the distance estimated by bestlines [6]. When the *Corr* is strong, the

TABLE I: The Intra-ISP *Corr* and Inter-ISP *Corr* of Three Major ISPs

ISP	CERNET	Telecom	Unicom
CERNET	0.6895	0.1398	0.0298
Telecom	0.1614	0.6701	0.3142
Unicom	0.0296	0.2601	0.6114

TABLE II: The *Corr* of Probing Hosts in Different Cities

City	Intra-ISP	Inter-ISP(T)	Inter-ISP(U)
Beijing	0.9064	0.4745	0.7834
Shanghai	0.9503	0.4906	0.1549
Chongqing	0.4524	-0.2964	-0.2910
Hangzhou	0.9267	0.5996	0.7140
Wuhan	0.7671	0.3670	0.1760
Chengdu	0.7821	-0.4375	-0.1313
Jinan	0.8611	0.0182	0.5143
Guangzhou	0.7375	0.6147	-0.1974

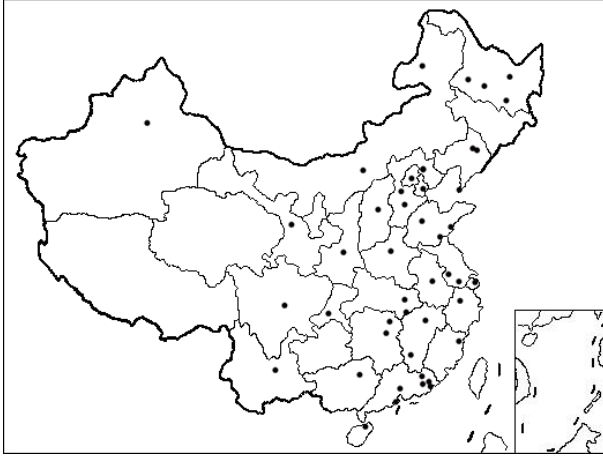


Fig. 1: The Distribution of Probing Hosts in China

error distance (the difference between estimated distance and actual distance) is little and thus the location error can be small. If the *Corr* is too weak, the error distance tends to be larger. To get more accurate results, Modified CBG should select the probing hosts and target hosts which are in the same rich-connected sub-network. Before geolocating a target host, Modified CBG checks ISP information of the target host and chooses probing hosts which are in the same ISP with target hosts and have an intra-ISP *Corr* more than 0.7. If there is no eligible probing hosts in certain cities, probing hosts which are in the other ISPs and have an inter-ISP *Corr* more than 0.7 can also be chosen.

The accuracy of GeoGet is actually based on the shortest-closest rule – the shortest delay comes from the closest distance [9]. The shortest-closest rule is closely related to *Corr*. The probability that the shortest-closest applies is higher in a rich-connected network than poor-connected network. To get more accurate results, Modified GeoGet should select the landmarks which are in the same rich-connected sub-network as target hosts. For example, if the average intra-ISP *Corr* is strong enough, we can simply

select landmarks in the same ISP as target hosts.

IV. EXPERIMENTS

This section tests the effectiveness and performance of the proposed method in an actual poor-connected network. China Mainland Internet is chosen because the whole network is poor-connected [9] while its need for IP geolocation services grows very fast in recent years.

A. Dataset

The dataset is consisted of round-trip time (RTT) and direct geographic distance between 90 probing hosts and 450 landmarks. RTT of each (probing host, landmark) pair is measured every minute for a week and only the minimum one is selected. *distance* of each (probing host, landmark) pair is calculated by Vincenty's formula based on [14].

China Mainland is consisted of 31 provinces (or provincial administrative regions). The major ISPs which can cover the whole country are China Telecom, China Unicom, China Mobile and China Education and Research Network (CERNET) [15–17]. This paper manually deploys 90 probing hosts: 24 probing hosts belong to CERNET, 36 probing hosts belong to China Telecom and 30 probing hosts belong to China Unicom. The distributions of probing hosts are shown in Fig. 1. There are more than one probing hosts in certain cities. 450 landmarks are distributed evenly in three major ISPs and 30 province capitals, which means there are 5 landmarks in each province capital and each ISP.

B. Finding Rich-connected Sub-networks in China

The overall *Corr* of whole China Mainland Internet (between 90 probing hosts and 450 landmarks) is 0.1674, which is very weak. The intra-ISP *Corr* and inter-ISP *Corr* of three major ISPs in China are shown in Table I. The first column of Table I represents the ISP information of the probing hosts and the first row represents the ISP information of the landmarks. From Table I, all three intra-ISP *Corr* are between 0.6 and 0.7, which is close to rich-connected networks and much stronger than the overall *Corr*.

Then Table II show the intra-ISP *Corr* and inter-ISP *Corr* of CERNET probing hosts in different cities (the *Corr* of a particular probing host is calculated based on the data measured between this probing host and the landmarks). The CERNET-intra-ISP *Corr* of probing hosts in 7 out of 8 cities are larger than 0.7. For inter-ISP *Corr*, the CERNET-Telecom-inter-ISP *Corr* of probing hosts in 2 cities are larger than 0.7 while the CERNET-Telecom-inter-ISP *Corr* of all probing hosts are less than 0.7. It can be concluded that the intra-ISP *Corr* of most CERNET probing hosts are strong while the inter-ISP *Corr* of most CERNET probing hosts are weak.

We calculate the intra-ISP *Corr* and inter-ISP *Corr* of all probing hosts in three major ISPs. Among them, the

intra-ISP *Corr* of 51% of probing hosts are beyond 0.7 and the intra-ISP *Corr* of all probing hosts are beyond 0.3. The inter-ISP *Corr* of 12% of probing hosts are beyond 0.7 and the inter-ISP *Corr* of 50% of probing hosts are beyond 0.3. Overall, 25% of the sub-networks in this poor-connected network are beyond 0.7.

C. The Performance of Modified CBG

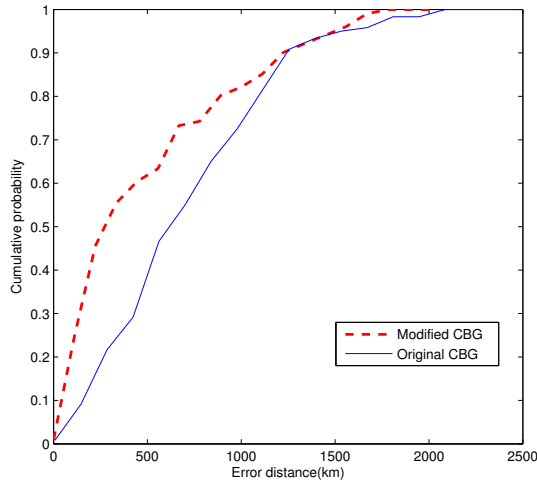


Fig. 2: CDF of Error Distances of Modified CBG and Original CBG.

This paper geolocates 989 target hosts in China using 116 probing hosts by Modified CBG and Original CBG (Original CBG randomly selects probing host in each city without considering *Corr*). There are 62 target hosts that Modified CBG and Original CBG can not form intersection regions. Fig. 2 shows the CDF of error distances of Modified CBG and Original CBG. The median error distance of Modified CBG is 315.4km while Original CBG is 629.8km. The comparison results show that the median error distance of CBG can be reduced by about 50%.

D. The Performance of Modified GeoGet

This paper geolocates 116 target hosts in China using 1350 landmarks by Modified GeoGet and Original GeoGet. There are 5 landmarks in each province capital cities and 3 landmarks in each non-capital cities. In each city, the landmarks can cover three major ISPs of China. 116 target hosts are actually the probing hosts we used in Modified CBG so the exact location information of 116 target hosts are already known in advance. The target hosts involve 28 out of 31 provinces in China and 3 major ISPs.

The ratio of target hosts which are mapped to correct cities is calculated. Modified GeoGet can successfully map 112, about 97% of target hosts to correct cities. Original GeoGet which randomly selects landmarks without considering ISP information can map 44, about 38% of target hosts to correct

cities. So the city-level mapping accuracy of GeoGet in this poor-connected network can be increased by nearly 2 times.

V. CONCLUSIONS

To increase the accuracy of delay-based IP geolocation techniques in poor-connected networks, this paper proposes a IP geolocation method based on rich-connected sub-networks. The experiments show that after dividing an actual poor-connected network of which the overall *Corr* is only 0.1674, about 25% of sub-networks are rich-connected. Based on the discovered rich-connected sub-networks, the accuracy of existing delay-based IP geolocation techniques such as GeoGet and CBG can be increased by more than 50%. In further research, we will try to find more reliable properties and study how the network characteristics in different networks may influence the delay-distance correlation.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China(No.61379151,61274189,61302159 and 61401512), the Excellent Youth Foundation of Henan Province of China (No.144100510001) and the Foundation of Science and Technology on Information Assurance Laboratory (No. KJ-14-108).

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Shichang Ding was born in Shandong Province, China, in 1990. Ding received the B.S. degree from Zhengzhou Science and Technology Institute, Zhengzhou, China, in 2013. He is currently a M.S. candidate in the State Key Laboratory of Mathematical Engineering and Advanced Computing at Zhengzhou Science and Technology Institute. His research interests include IP geolocation and network measurement.



networking and information security.

Xiangyang Luo was born in Hubei Province, China, 1978. Luo received the B.S. degree, the M.S. degree and the Ph.D. degree from Zhengzhou Science and Technology Institute, Zhengzhou, China, in 2001, 2004 and 2010, respectively. Luo is currently an associate professor of Zhengzhou Science and Technology Institute. He is the author or co-author of more than 70 refereed international journal and conference papers. He is also a guest editor for "International Journal of Internet" and "Multimedia Tools and Applications". His research interest is



Meijuan Yin was born in Anhui Province, China at November, 1977. She received the M.S. degree and the Ph.D. degree in Zhengzhou Science and Technology Institute, Zhengzhou, China, in 2003 and 2007. She is currently a lecturer of Zhengzhou Science and Technology Institute. Her current research interests include data mining, social network analysis, and information security.



Yan Liu was born in Shandong Province, China, 1979. She received Ph.D. in Zhengzhou Science and Technology Institute, Zhengzhou, China. She is currently an associate professor of Zhengzhou Science and Technology Institute. Her research interests include network information security and data mining.



FenLin Liu was born in Jiangsu Province, China, 1964. He received the B.S. degree from Zhengzhou Science and Technology Institute, Zhengzhou, China, in 1986, the M.S. degree from Harbin Institute of Technology in 1992, and the Ph.D. degree from the Eastnorth University in 1998. Now, he is a professor of Zhengzhou Science and Technology Institute. His research interest is networking and information security.