Network Distance Estimation with Virtual Topology

[Extended Abstract]

Sanghwan Lee, UMN
Zhi-Li Zhang, UMN
Sambit Sahu, IBM
Mukund Srinivasan, UMN
Debanjan Saha, IBM

{sanghwan, zhzhang, mukund}@cs.umn.edu, {sambits, dsaha}@us.ibm.com

1. INTRODUCTION AND MOTIVATION

During the past several years, the network distance estimation problem gains increasing popularity because of the obvious benefit to many applications. Especially, many Euclidean space based schemes have been proposed. Even though their overall accuracy is high, the relative errors are larger than 0.25 for more than 20 % of the estimations ([3]). It is also well known that the accuracy does not improve much as the number of dimensions increases beyond 7 or 8. We think that the intrinsic discrepancy between the Internet topology and the Euclidean space model may prohibit further improvement in the accuracy.

To reduce the discrepancy between the model and the Internet topology, we propose to use a topology based model instead of the Euclidean space based model. In short, we construct a simplified topology and map the Internet hosts to the nodes of the simplified topology such that the distances between hosts are preserved as much as possible. The main benefits of the topology based model are three folds. First, the topology can be extended as the required accuracy increases. With a more detailed topology, we may be able to achieve a better accuracy. In the Euclidean space case, even though the number of dimensions increases, the accuracy may not improve as much. Second, the topology is easy to be augmented with other properties such as bandwidth and loss. Third, distance changes can be adapted easily because many distance changes might be caused by the distance changes of a few links in the Internet. By changing the distances in the corresponding links on the model, we can adapt the changes among a large number of hosts.

One extreme topology based model is the Internet topology itself. Network distance estimation is trivial with the Internet topology because the estimated distance between two nodes is just the sum of the delays of the links on the path. However, even though there are many topology discovery schemes, it is still hard, if not impossible, to get an accurate topology. Thus, our motivation is whether we can use a simplified topology to model the Internet without loosing much accuracy.

SIGCOMM'05, August 21-26, 2005, Philadelphia, Pennsylvania, USA.

In this paper, we propose a new topology based model called Virtual Topology. Virtual Topology is basically a mesh star topology. Virtual Topology consists of special nodes, called virtual tracers, with the distances among themselves. Each Internet host has one virtual tracer that it belongs to. It should be noted that the virtual tracer does not represent any physical router or host in the Internet. The distance between two hosts is estimated by the sum of the distances from the two hosts to the corresponding virtual tracers and the distance between the two virtual tracers. In short, the Internet is simplified to be a mesh star topology.

Virtual Topology is similar to IDMaps ([2]). However, it differs in that Virtual Topology does not use the physical tracers. By using virtual tracers, the errors introduced by the access links of the physical tracers can be easily eliminated. Virtual Topology model is also similar to the height vector model in Vivaldi ([1]) in that the distance from a host to the virtual tracer can be considered as a height. However, in Virtual Topology, the hosts are forced to have the heights (distances) to the virtual tracers while, in Vivaldi, the height depends on the optimization process. In the following sections, we provide the algorithms to compute the distances among the virtual tracers and the distances from the hosts to the corresponding virtual tracers.

2. VIRTUAL TOPOLOGY MODEL

To construct the Virtual Topology, we use a distance matrix $D = (d_{ij})$, where d_{ij} is the distance between host i and j. In the next section, we provide a sampling based scalable algorithm that does not use D so that the model can be used in practice. We assume that the hosts are grouped into clusters. Each cluster has *one* virtual tracer. We show how to cluster the hosts in the next section. Let $c(i)$ be host i's cluster. Let $v(c)$ be the virtual tracer of the cluster c. Let x_i be the distance from host i to $v(c(i))$, i.e., the virtual tracer of host i's cluster. Let $l_{v(c)v(c')}$ be the distance from $v(c)$ to $v(c')$. It should be noted that $x_i + l_{v(c(i))v(c(j))} + x_j$ is the estimated distance between host i and host j. The main question is how to compute x_i's and $l_{v(c(i))v(c(j))}$'s based on D such that the estimation errors are minimized.

We divide the procedure into two steps. First, we compute x_i's and then compute $l_{v(c(i))v(c(j))}$'s. We have the following linear equation for each pair of hosts in each cluster.

$$x_i + x_j = d_{ij}, \text{for } i < j \quad (1)$$

In a matrix formulation, (1) becomes

$$Ax = d, \quad (2)$$

where each row of A represents a pair of hosts i and j such that only the ith column and jth column have 1 and others have 0. Each row of d contains the distance between the corresponding host pair. Since we have $\frac{n(n-1)}{2}$ such host pairs for n hosts, A is a $\frac{n(n-1)}{2} \times n$ matrix, x is a $n \times 1$ vector, and d is a $\frac{n(n-1)}{2} \times 1$ vector. Since A is not a square matrix, we use linear least square method to solve $\hat{x}$, the least square solution of x, as follows.

$$A^T A \hat{x} = A^T d \quad (3)$$

$$\hat{x} = (A^T A)^{-1} A^T d \quad (4)$$

The solution $\hat{x}$ minimizes $||d - Ax||^2$. To be complete, for $n = 1$ case, $\hat{x} = (0)$. For $n = 2$ case, $\hat{x} = (\frac{d_{ij}}{2}, \frac{d_{ij}}{2})^T$.

After we compute all x_i's, we can compute $l_{v(c)v(c')}$ for a cluster pair c and c' in a similar way. Fortunately, the solution is as simple as (5).

$$l_{v(c)v(c')} = \frac{\sum_{i \in c} \sum_{j \in c'} (d_{ij} - x_i - x_j)}{|c||c'|}, \quad (5)$$

where $|c|$ is the number of hosts in cluster c.

Now, we compare the performance of the (Centralized) Virtual Topology (CVT) with GNP, Virtual Landmark ([4]), and IDMaps. Fig. 1 shows the 50th, 70th, and 90th percentiles of relative errors with different methods over different data sets. PL, King, NLANR are real distance measurement data sets and 18CL is a synthetic data set from a 2 level topology that has 18 ASes. "VL All" represents the VL method of using all the hosts as landmarks. As can be expected, CVT shows much higher performance than IDMaps. CVT shows comparable performance as GNP and better performance than Virtual Landmarks. It should be noted that CVT is good especially in a clustered data set such as 18CL.

3. DISTANCE ESTIMATION SYSTEM

The virtual topology model described in section 2 requires the distances among all the hosts. To come up with a scalable algorithm, we use a sampling based approach. As can be seen in (5), the distance between the virtual tracers is computed by the average of $(d_{ij} - x_i - x_j)$ for all pairs. The average of sampled pairs can be used as the real average. In a similar way, in (2), instead of using all the rows of A, we can use only a subset of rows to compute $\hat{x}$. Based on this basic intuition of the sampling based method, we propose a scalable distance estimation system.

For clustering the hosts, multiple landmarks are placed around the Internet. When a new host joins the system, the host measures the distances to the landmarks and considers the closest landmark as the cluster id. The tuple, <cluster id, host>, is maintained in the servers called Distance Information Server (DIS). Each host measures the distances to a small number of hosts in the same cluster and a small number of hosts in other clusters. DISes provide the list of such hosts. Then, the host informs the measured distances to a DIS. DISes share the information among themselves. DIS computes the distances among the virtual tracers based on the given sampled distances. The hosts can query the distances to DIS. Even with fixed number of measurements from each host, since the number of sample distances increases as the number of joining hosts increases, the sampling based approach would be comparable to CVT in a steady state. We plan to evaluate the performance of this approach in the future.

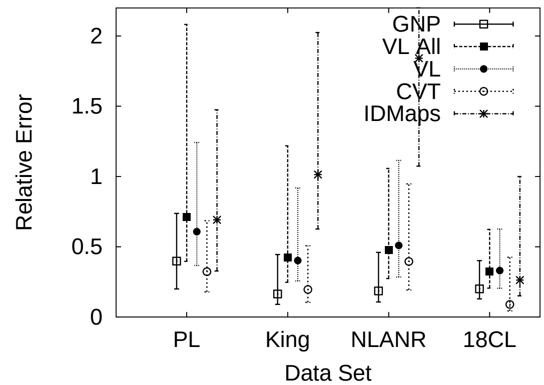

Figure 1: 50th, 70th, and 90th percentiles of relative errors with different methods over different data sets. Dimension=7 and 18-20 landmarks are used for GNP and VLs.

4. CONCLUSION

In this paper, we provide a virtual topology based system for network distance estimation. The new system improves the performance of IDMaps. The topology construction is done by the linear least square method. The topology in this system is a simple mesh star topology, where virtual tracers form a full mesh and hosts form the star topology with the virtual tracer in the center. This basic scheme can be extended by using any arbitrary shaped topology. We plan to evaluate this scheme further and investigate the feasibility for using arbitrary topologies. More information can be found at "http://www.cs.umn.edu/research/networking/vit".

5. ACKNOWLEDGMENTS

This work was supported in part by the National Science Foundation under the grants ITR-0085824 and CNS 0435444. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the funding agencies.

6. REFERENCES

[1] F. Dabek, R. Cox, F. Kaashoek, and R. Morris. Vivaldi: A decentralized network coordinate system. In *Proceedings of ACM SIGCOMM 2004*, Portland, OR, Aug. 2004.

[2] P. Francis, S. Jamin, C. Jin, Y. Jin, D. Raz, Y. Shavitt, and L. Zhang. Idmaps: A global internet host distance estimation service. *IEEE/ACM Transactions on Networking*, 2001.

[3] T. E. Ng and H. Zhang. Predicting internet network distance with coordinates-based approaches. In *Proc. IEEE INFOCOM*, New York, NY, June 2002.

[4] L. Tang and M. Crovella. Virtual landmarks for the internet. In *Proceedings of the Internet Measurement Conference(IMC)*, Miami, Florida, Oct. 2003.