Poster: AIDE: An Accurate Internet Distance Estimation System

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***Abstract*—Network Coordinate (NC) is a scalable and efficient mechanism for Internet distance estimation. IDES is the first matrix factorization based NC system. However it suffers from a significant drawback: high distance estimation error in short links, which degrades practical performance in many Internet applications. To overcome this problem, we propose AIDE, a new accurate Internet distance estimation system based on matrix factorization, which is decentralized with robustness. Our experiments demonstrate that AIDE performs far more accurate estimation in short Internet latency, which is significantly important in many applications, for example, network overlay multicast and server selection.**

I. Introduction

Network coordinate (NC) is an efficient and scalable mechanism to predict network latency between any two hosts in the Internet without much measurement. Internet Distance Estimation Service (IDES) [1] is the first matrix factorization based NC system, which has two inherent advantages over coordinate based NC systems that IDES is not constrained by: triangle inequality violation (TIV) and asymmetry of distances.

However, IDES has a significant shortcoming. IDES suffers from high inaccuracy in short Internet latency estimation [5], which limits its benefit on many practical Internet applications. Because many network applications, such as server selection in Content Delivery Network (CDN) and overlay network multicast, use the closest nodes for their service, it is significant for a NC system to improve the accuracy in short distance estimation.

Therefore, we propose AIDE NC system to address this problem. AIDE is also a matrix factorization based NC system using singular value decomposition (SVD) algorithm. AIDE is decentralized with robustness, because it does not fully rely on infrastructure nodes: any node that has joined the system can be assigned as a landmark. Moreover, AIDE reduces relative errors (REs) about short links obviously. As we mentioned above, the accuracy of short link estimation is significantly important in many applications, we believe AIDE should have better performance than IDES in practical applications.

The rest of this abstract is organized as follows. In section II, we demonstrate the system design of our AIDE NC system in detail. Then in section III, we evaluate our system with several experiments. In the end, we make the conclusion in section IV.

II. AIDE Design

A. Principle of AIDE system

Suppose there are N hosts $H_1, H_2, \ldots, H_N$ in the network. The network distance matrix is an $N \times N$ matrix D, and D_{ij} or $D(H_i, H_j)$ is the distance from H_i to H_j.

AIDE aims to seek an approximate factorization of the distance matrix, given by

$$D \simeq SE^T$$

Where D is an $N \times N$ distance matrix, S and E are $N \times d$ matrices with $d \ll N$. From such a model, we can estimate the network distance from H_i to H_j by $\hat{D_{ij}} = \overrightarrow{S_i} \cdot \overrightarrow{E_j}$, where $\overrightarrow{S_i}$ is the ith row vector of the matrix S and $\overrightarrow{E_j}$ is the jth row vector of the matrix E. Therefore, for each host, for example host H_i, it stores its starting vector $\overrightarrow{S_i}$ and ending vector $\overrightarrow{E_i}$.

Suppose we select L initial landmarks in the network, AIDE first uses SVD algorithm to factorize the initial landmark distance matrix to get the singular value, which is approximately suitable for the whole network distance matrix D.

In AIDE, the $L \times L$ landmark distance matrix $D_{Landmark}$ is factorized into three matrices by SVD with the form

$$D_{Landmark} = UWV^T$$

where U and V are $L \times L$ orthogonal matrices and W is an $L \times L$ diagonal matrix with nonnegative singular values (ranged in decreasing order). Let $P = UW^{\frac{1}{2}}$ and $Q = W^{\frac{1}{2}}V$, so $PQ^T = (UW^{\frac{1}{2}})(VW^{\frac{1}{2}})^T = UWV^T = D_{Landmark}$.

Then we obtain an approximate factorization by using only the largest d singular values. So P and Q become $N \times d$ matrices, that means each landmark gets its starting vector from P and ending vector from Q. Define the $N \times d$ matrices:

$$P_{ij} = U_{ij}\sqrt{W_{jj}}$$
$$Q_{ij} = V_{ij}\sqrt{W_{jj}}$$

where $i = 1 \ldots N$ and $j = 1 \ldots d$.

B. Work Flow of AIDE

Figure 1 shows the system architecture of AIDE. First, we set L landmarks and get an $L \times L$ distance matrix. Then we use SVD to get two $L \times d$ matrix: starting matrix S and ending matrix E. Each landmark gets its starting vector and ending vector.

When host H_i is computing its vectors in AIDE system, it can select the initial landmarks or any hosts that have joined the system as reference nodes. For example, it selects k initial landmarks and $L - k$ closest neighbor nodes in the system as its L reference nodes $R_{i1}, \ldots, R_{iL}$. H_i gets the new starting vector $\overrightarrow{S_i}$ and new ending vector $\overrightarrow{E_i}$ by minimizing the following squared error functions

$$Error(\overrightarrow{S_i}) = \sum_j [D(H_i, R_{ij}) - \overrightarrow{S_i} \cdot \overrightarrow{E_j}]^2$$
$$Error(\overrightarrow{E_i}) = \sum_j [D(R_{ij}, H_i) - \overrightarrow{S_j} \cdot \overrightarrow{E_i}]^2$$

where $j = 1 \ldots L$.

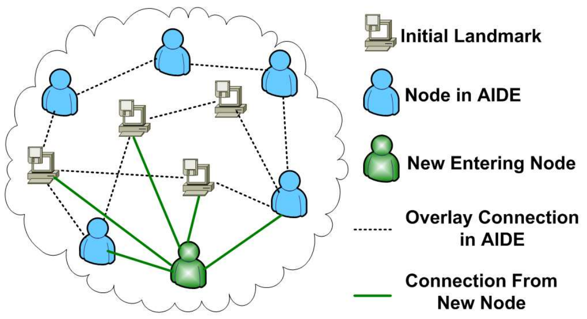

Fig. 1. AIDE system design

Selecting the closest hosts as landmarks can reduce the short link estimation errors. However, choosing too many new joined hosts as landmarks may cause the decreasing of the relativity between vectors of the initial landmarks and the singular values. Therefore, there is a tradeoff between reducing short distance estimation errors and keeping the relativity between vectors of the initial landmarks and singular values. In our experiments, we assign 20 reference nodes for each joining host, with 15 initial landmarks and 5 closest neighbors.

III. Performance Evaluation

In this section, we evaluate AIDE in following respects comparing with IDES. In our experiments, we use King data set from [3], which contains 1740 host nodes.

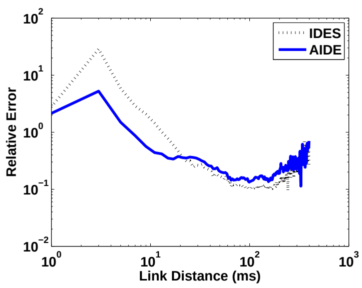

Fig. 2. Relation Between RE and Link Distance

A. Relation between relative error and range of distance

The accuracy of NC system is often evaluated with the metric named relative error (RE) [2], which is defined as

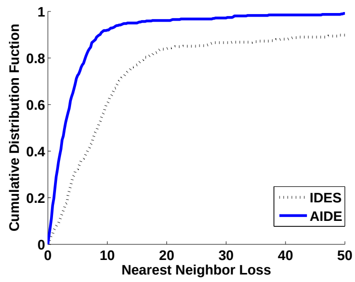

Fig. 3. Cumulative Distribution Function of NNL

$$RE = \frac{|MeasuredDistance - PredictedDistance|}{min(MeasuredDistance, PredictedDistance)}$$

Figure 2 shows that IDES system suffers from high relative error of short link distance, while AIDE has better performance in short link estimation with more accuracy.

B. Nearest Neighbor Loss

Nearest neighbor loss (NNL) [4] is defined as the difference between the delay to the node predicted to be the nearest neighbor and the delay to the true one. This metric reflects the accuracy for one host node in a network coordinate system to find the closest neighbor host.

Figure 3 shows the NNL of AIDE and IDES. It is clearly obvious that AIDE has much better performance than IDES in this metric which means AIDE predicts the distance between the closest hosts with far more accuracy. We believe this advantage will benefit Internet applications.

IV. Conclusions

In this abstract, we propose AIDE, a novel accurate and decentralized NC system based on matrix factorization. By comparative experiments, we find that AIDE significantly outperforms IDES in estimation of short link distance, which will bring great benefits in many applications. Since AIDE does not rely much on infrastructure nodes, AIDE is a scalable and robust NC system with accurate estimation in large-scale network distance.

Acknowledgments

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